

ARTICLE

Measurement of some natural radioactive isotopes concentrations in soil samples in the northern part of West Bank – Palestine

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Abstract – In this specific study, the concentration of radon, radium content, and annual effective dose were meticulously measured and calculated utilizing solid-state nuclear track detectors (CR-39). The research was centered on soil samples extracted from diverse locations in the northern regions of the West Bank, Palestine. A comprehensive set of 40 soil samples was systematically collected from Tulkarm, Jenin, and Tubas Governorates. The average concentrations of ^{222}Rn and ^{226}Ra in Tulkarm, Jenin, and Tubas governorates were found to be 505.2 Bq/m^3 and 22.0 Bq/kg ; 528.4 Bq/m^3 and 23.1 Bq/kg ; and 515.3 Bq/m^3 and 22.5 Bq/kg , respectively. Calculating the overall total average effective dose for these governorates yielded values of 17.5, 18.3, and 17.8 mSv/year, respectively. These values slightly exceed the action levels (3–10 mSv/year) recommended by ICRP-1993. It's noteworthy that the measurements established in this study provide a foundational database of activity levels, serving as a reference for future studies assessing the potential impacts of events to come.

Keywords: radioactive isotopes / radon / CR-39 detector / soil samples. Palestine

1 Introduction

Radon-222, an isotope of radon, an inert, colorless and tasteless noble gas, is naturally generated as a byproduct of the decay sequence of uranium-238. This radioactive gas undergoes decay through the emission of alpha particles, each carrying a specific amount of energy. This decay process gives rise to a series of short-lived radionuclides, including polonium-218 and polonium-214. Radon-222, with a half-life of 3.82 days, provides a relatively extended window for detection and measurement, especially when compared to its progenies. The soil surface is the primary contributor to radon-222 gas in the atmosphere. Nevertheless, additional sources contribute to its presence, including ground and surface water, as well as natural and volcanic gases. The characteristics of radon-222, both in terms of its radioactivity and its various sources, make it a subject of interest and concern in environmental and health-related studies (Hatif and Muttaleb, 2016; Ahmed and Abdulameer, 2019).

Once inhaled, this gas enters the lungs, leaving behind radioactive residues that constitute a significant portion of the overall radiation exposure experienced by individuals. This underscores the importance of monitoring and managing radon-222 levels, especially in enclosed spaces where

prolonged exposure could have health implications (Alrowaili, 2023; Deveci and Oncel, 2023). The heightened health risk associated with radon-222 gas is exacerbated by the prevalent practice of spending a substantial amount of time indoors, thereby increasing the probability of monitoring and mitigating radon-222 levels, especially in areas where prolonged indoor exposure occurs within enclosed spaces. Radon-222 gas is a byproduct of the decay of radium in the soil, permeating the air from soil particles. The release of this gas into the atmosphere involves diffusion through pores, with some radon-222 atoms potentially becoming trapped in confined spaces. This indoor accumulation that underscores the importance of exposure is common (Wanga *et al.*, 2022; Yonca *et al.*, 2023). Given the alarming global health crisis associated with inhaling elevated concentrations of radon-222, it becomes imperative to address this issue. Vigilant monitoring and control of radon-222 levels are crucial in mitigating the potential health risks associated with prolonged indoor exposure, underlining the significance of proactive measures in safeguarding human well-being (Yonca *et al.*, 2023).

Radon-222 gas easily escapes from surface soils and rocks through a process known as exhalation. Numerous factors impact the exhalation of radon-222 from soil into the air, including concentrations of uranium, thorium, and radium in the bedrock and soil, the emanation capacity of the ground, soil or rock porosity, barometric pressure gradients, soil moisture

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levels, water saturation of the medium, and other variables like micro-cracks in bedrocks, rainfall, air temperature, and surface winds. Due to its low mobility and short half-life, radon-222 primarily diffuses from a shallow distance below the measuring device. In areas with slow diffusive flow, this distance is typically around 2 meters beneath the soil surface. Understanding these complex interactions is crucial for assessing radon-222 exposure risks and implementing effective mitigation strategies (Alharbi and Abbady, 2013; Hatif and Muttaleb, 2016; Ahmed and Abdulameer, 2019).

The health risks associated with radon-222 primarily arise from the inhalation and ingestion of its short-lived decay products. While the majority of inhaled radon-222 is expelled and does not accumulate in the respiratory system, a small fraction can reach the inner regions of the lungs. In these areas, radon-222 can damage the DNA in sensitive lung tissue, potentially leading to cancer. Furthermore, suspended radon-222 decay products in the air can be inhaled during breathing, entering the respiratory system. Due to their short half-life, these decay products rapidly undergo decay within the lungs. During this process, alpha particles are emitted, depositing a significant amount of energy into vulnerable lung cells and posing various health risks. Understanding these mechanisms is crucial for assessing the potential health impact of radon-222 exposure and implementing measures to mitigate associated risks (Jibiri and Esen, 2011; Nada and Jaafar, 2015; Sudhir *et al.*, 2016).

The primary goal of this paper is to quantify radon-222 concentrations, radium contents, and exhalation rates in soil samples collected from the northern region of the West Bank. Through these measurements, the study aims to provide insights into potential risks associated with radon-222 and to evaluate whether further investigations or mitigation measures are warranted in the region. This research contributes to a better understanding of the local radon-222 scenario and forms the basis for informed decisions regarding public health and safety.

2 Materials and methods

2.1 Study area

A total of 40 soil samples from the surface were collected from various locations within the regions of Jenin, Tulkarm, and Tubas governorates, situated in the northern part of the West Bank in Palestine (Fig. 1). In Jenin governorate, the samples were obtained from areas such as Ya'bad, Qabatiya, Zababida, Meithalun, Hadad, and Salem. In Tulkarm governorate, the collection zones included Qaffin, Baqa ashariya, An Nazla al-Gharbiya, Zeita, Attil, Deir al-Ghusun, Jarushiya, Irtah, Anabta, Kafr al-Labad, Shwaika, and Iktaba. Lastly, in Tubas governorate, the samples were collected from Al'Aqaba, Tubas-Gore Zone.

Indeed, the northern region of the West Bank holds strategic importance as it serves as a central nexus connecting three distinct areas. Geographically, the West Bank is primarily characterized by mountain ranges oriented from north to south, with average elevations ranging from 200 to 1020 meters. These mountainous terrains gradually descend eastward, leading to the low-lying rift valley where the Jordan River and the Dead Sea are located. It's important to note that the

elevated areas in the western section of West bank give rise to streams that flow westward, ultimately reaching the Mediterranean Sea (Hejaz *et al.*, 2020).

The West Bank encompasses a land area of 5655 km², and as of the end of 2023, it had an estimated population of around 3,464,858 people (PCBS, 2021). In the specific analysis area within the northern part of the West Bank, it includes districts such as Jenin with a population of 359,934 individuals, Tulkarm with 216,586 individuals, and Tubas and the northern valleys with 68,779 individuals. These figures reflect the approximate population distribution in the respective districts as of the specified time (Hejaz *et al.*, 2020; PCBS, 2021).

The West Bank is predominantly characterized by a Mediterranean climate. This climate type is typically associated with mild temperatures and ample rainfall. The northern regions of the West Bank largely experience the Mediterranean climate, while Tubas, located on the eastern slopes, is influenced by a semi-arid climate due to its distance from the marine effects. The annual average temperatures in the West Bank vary between 17 °C and 32 °C. These temperature ranges are typical for the Mediterranean climate and contribute to the overall moderate and comfortable weather conditions in the region (Ghodieh, 2019).

2.2 Samples collection and preparation

Every sample was collected using a template measuring 25 cm by 30 cm with a depth of 5 cm, specifically from the surface layer within an area (Dabayneh *et al.*, 2008). Before collection, meticulous care was taken to eliminate the outer layer of the soil, which could potentially harbor diverse wastes and impurities. Roughly 1 kg of soil from each sampling point was gathered and stored in a plastic bag. The selected method for soil analysis and testing was designed to ensure uniformity and streamline the collection of a sufficient quantity of soil samples (Ferreira and Pecequillo, 2011).

After the removal of any foreign materials, such as stones or gravel, the soil samples underwent a thorough mixing process to achieve homogeneity. Following the mixing step, all the samples were sieved using a mesh sieve with a 1 mm aperture size. This sieving process ensured uniformity and eliminated any larger particles from the samples. Once sieved, the soil samples were placed in a hot air oven and dried at a temperature of 110 °C for a period of 12 h. This drying process effectively removed all moisture content from the samples, ensuring material homogeneity and stability. After the drying process, the samples were weighed to determine their mass accurately. This step allowed for precise measurements and analysis. Finally, the weighed and prepared samples were securely stored for further examination and testing (Dabayneh and Mashal *et al.*, 2008; Thabayneh, 2018).

2.3 Dosimeters preparation

To measure the concentration of radon-222 and the exhalation rates in the soil samples, we utilized the can technique. This technique involved sealing the samples in cylindrical containers constructed from a suitable type of plastic, specifically high-density polyethylene (HDPE). The containers had dimensions of 6.5 cm in diameter and 12 cm in



Fig. 1. West Bank map including the north districts (Tulkarm, Jenin and Tubas).

depth. Each container was carefully sealed and left undisturbed for a period of 75 days (Thabayneh, 2015). Within each securely sealed container, a CR-39 detector was affixed beneath the cork head. Positioned approximately 1.5 cm from the soil sample's surface, the sensitive part of the detector was oriented towards the emanating radon-222. This configuration allowed the detector to register alpha particles resulting from the decay of radon-222 across the entire volume of the container. To seal the container tightly, an inverted cylindrical plastic cover was used, as illustrated in Figure 2. This arrangement upheld the sample's integrity and enabled precise measurements of radon-222 concentration and radon-222 exhalation rates (Thabayneh, 2015).

After the exposure period, during which alpha particles from radon-222 and its daughters bombarded the CR-39 detector, the detectors were gathered for subsequent analysis. These detectors underwent an etching process in a 6.25 M NaOH solution at a temperature of 70 °C for 4 h. The purpose of this etching process was to unveil the tracks generated by the alpha particles on the detector surface. Post-etching, the detectors were rinsed with distilled water and allowed to air

dry. The tracks on the detectors were manually enumerated utilizing an optical microscope with a 160× magnification. For each detector, 10 random fields of view were chosen, and the average number of tracks per field of view was calculated. The area of each field of view was determined to be approximately 0.0133 cm². The resultant average track density per field of view was then employed to compute the track density per square meter (Jazzar and Thabayneh, 2014; Thabayneh, 2016, 2018).

This information, along with other data, was subsequently employed to calculate the concentration of radon-222 in the soil samples. By analyzing the track densities, it was possible to estimate the levels of radon-222 present in the tested soil items or other relevant samples.

3 Theoretical calculations

3.1 Calculations of radon-222 concentrations

To estimate the concentration of radon-222 in secular equilibrium (C_{Rn}), the following equation can be used

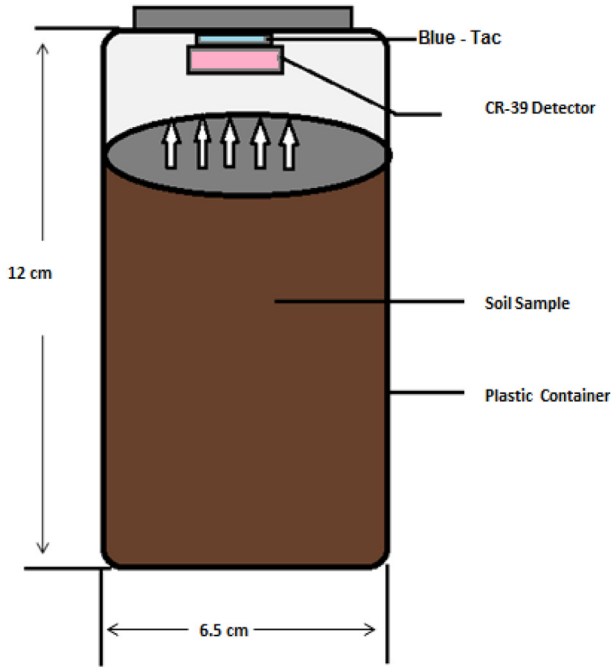


Fig. 2. Experimental setup for the measurement of radon-222 concentration.

(El-Ghossain and Shammala, 2012; Thabayneh, 2015; Thabayneh and Gharaybeh, 2023):

$$C_{Rn}(\text{Bqm}^{-3}) = \frac{c_0 t_0}{\rho_0} \left(\frac{\rho}{t} \right) = k \left(\frac{\rho}{t} \right), \quad (1)$$

where c_0 is the activity concentration of ^{226}Ra (solid radium source) equal 800 Bqm^{-3} ; ρ_0 is the track density (number of tracks per cm^2) in detectors exposed to ^{226}Ra ; t_0 is the exposure time (in days) of detectors exposed to ^{226}Ra , equal 70 days; k is the calibration factor, equal $24.2 \text{ Bqm}^{-3} \text{ day tracks}^{-1} \text{ cm}^2$; ρ is track density (number of tracks/ cm^2) in detectors exposed to soil samples and t is the exposure time (in days) of detectors exposed to soil samples, equal 75 day (El-Ghossain and Shammala, 2012; Thabayneh, 2015).

3.2 Determination of radium contents

To calculate the radium concentration (C_{Ra}) in soil samples, the following relation can be used (Yousef *et al.*, 2016; Thabayneh, 2018):

$$C_{\text{Ra}} = \frac{\rho h A}{k T_{\text{eff}} M}, \quad (2)$$

where ρ is the track density (tracks per cm^2); h is the distance between the detector and the top of the sample; A is the surface area from which radon-222 is exhaled (m^2); M is the mass of the sample (kg); and T_{eff} is the effective exposure time (hr), which is related to the actual exposure time t , by the relation:

$$T_e = t - \frac{1}{\lambda(1 - e^{-\lambda t})} \quad (3)$$

where λ is the decay constant of radon-222 ($\lambda = 7.56 \times 10^{-3} \text{ h}^{-1}$).

3.3 The radon-222 exhalation rate

The radon-222 exhalation study is important for understanding the relative contribution of the material to the total radon-222 concentration found in the dwellings. The equation used for surface exhalation rate is written as (Shoeib and Thabayneh, 2014; Thabayneh, 2018):

$$E_A = \frac{C v \lambda}{A T_{\text{eff}}}, \quad (4)$$

and for mass exhalation rate is written as

$$E_M = \frac{c v \lambda}{M T_{\text{eff}}}, \quad (5)$$

where; E_A ($\text{Bqm}^{-2} \text{ h}^{-1}$): is the surface radon-222 exhalation rate, E_M ($\text{Bq Kg}^{-1} \text{ h}^{-1}$): is the mass radon-222 exhalation rate, C : is the integrated radon-222 exposure in ($\text{Bqm}^{-3} \text{ h}$), v : is the void volume of the container (m^3), A : is the area of the sample (m^2), M : is the mass of the sample (kg) (Shoeib and Thabayneh, 2014).

3.4 The annual effective dose

To calculate the annual effective dose resulting from radon-222 concentrations, it is essential to consider the conversion coefficient from absorbed dose and the indoor occupancy factor. Following the UNSCEAR 2000 recommendation (UNSCEAR, 2000), the annual effective dose for a one-year radon-222 exposure can be estimated using the formula as outlined by Kumar *et al.* (2014) and Mashal *et al.* (2021):

$$AED(m\text{Svy}^{-1}) = C_{Rn} * F * T * Q, \quad (6)$$

where F (is the conversion factor) $= 9 \text{ nSv (Bq} \cdot \text{hm}^{-3})^{-1}$; T is 8760 h of a year (Assuming an indoor occupancy factor is about 80% of 8760 h, which equals 7008 h and 20% for outdoors, which equals 1752 hours); and Q is the equilibrium fraction (0.6) for outdoors and (0.4) for indoors (UNSCEAR, 2000).

From equation (6), we can calculate the annual effective dose for indoors and outdoors according to the following relations (Challan and Atteyat, 2018):

$$AED_{\text{in}}(m\text{Svy}^{-1}) = 0.02523 C_{Rn}, \quad (7)$$

$$AED_{\text{out}}(m\text{Svy}^{-1}) = 0.00946 C_{Rn}, \quad (8)$$

Table 1. Radon- 222 concentration (C_{Rn}), Radium contents (C_{Ra}), Exhalation rates (E_A and E_M) and the total annual effective dose (AED_{tot}) in Tulkarm Governorate- Palestine.

Site	Sample code	C_{Rn} (Bq/m ³)	C_{Ra} (Bq/kg)	E_A (mBq m ⁻² h ⁻¹)	E_M (mBq kg ⁻¹ h ⁻¹)	AED_{tot} (mSvy ⁻¹)
Qaffin	Tuss 1	465.6	20.0	437.0	10.0	16.1
Baqa asharqiya	Tuss 2	476.6	20.8	447.0	10.6	16.5
An Nazla	Tuss 3	498.4	21.7	467.8	11.0	17.3
al-Gharbiya						
Zeita	Tuss 4	701.7	30.6	658.7	15.6	24.3
Illar	Tuss 5	826.0	36.0	775.6	18.0	28.6
Attil	Tuss 6	681.0	29.7	639.0	15.0	23.6
Deir	Tuss 7	542.0	23.6	508.9	12.0	18.7
al-Ghusun(1)						
Deir	Tuss 8	453.6	19.8	425.8	10.0	15.7
al-Ghusun(2)						
Jarushiya	Tuss 9	362.9	15.8	340.6	8.0	12.6
Shwaika	Tuss 10	281.0	12.0	263.7	6.0	9.7
Bal"a	Tuss 11	377.0	16.0	354.0	8.0	13.1
Iktaba	Tuss 12	365.0	16.0	342.7	8.0	12.7
Tulkarm western region	Tuss 13	524.6	22.9	492.5	11.7	18.2
Anabta	Tuss 14	618.7	27.0	580.7	13.7	21.4
Kafr al-Labad	Tuss 15	436.1	19.0	409.0	9.7	15.1
Irtah (1)	Tuss 16	474.0	20.7	445.0	10.5	16.5
Irtah(2)	Tuss 17	503.9	22.0	473.0	11.0	17.5
Min		281.0	12.0	263.7	6.0	9.7
Max		826.0	36.0	775.6	18.0	28.6
Average		505.2	22.0	474.2	11.2	17.5

And the total annual effective dose calculated as:

$$AED_{tot}(\text{mSvy}^{-1}) = AED_{in} + AED_{out}. \quad (9)$$

4 Results

Tables 1- 3 display recorded and computed data concerning radon concentrations, radium contents, exhalation rates, and annual effective doses in various soil samples collected from the northern part of the West Bank in Palestine. These tables provide valuable insights into the radiological characteristics of the examined soil samples.

Table 1 presents the radon-222 concentrations and radium contents in soil samples collected from various sites in the Tulkarm Governorate in Palestine, along with additional information. The radon-222 concentrations exhibited a range from 281.0 Bq/m³ (in Shwaika site) to 826.0 Bq/m³ (in Illar site), with an average value of 505.2 Bq/m³. Similarly, the average radium concentrations varied from 12.0 Bq/kg to 36.0 Bq/kg, resulting in an overall average value of 22.0 Bq/kg. Additionally, Table 1 provides data on the surface and mass exhalation rates of radon-222 for the soil samples. The surface exhalation rate showed a range from 263.7 mBq m⁻² h⁻¹ to 775.6 mBq m⁻² h⁻¹, with an average value of 474.2 mBq m⁻² h⁻¹. The mass exhalation rate was found to fluctuate from 6.0 mBq kg⁻¹ h⁻¹ to 18 mBq kg⁻¹ h⁻¹, with an average value of 11.2 mBq kg⁻¹ h⁻¹.

Moreover, the total annual effective dose (AED_{tot}) derived from these soil samples ranged from 9.7 mSvy⁻¹ to 28.6 mSvy⁻¹, with an average value of 17.5 mSvy⁻¹. These findings offer valuable insights into the levels of radon-222 and radium observed in the soil samples collected from various locations within the Tulkarm Governorate.

In Table 2, the data presents measurements of radon-222 concentrations, radium contents, exhalation rates, and total annual effective doses in soil samples collected from various locations in the Jenin Governorate, Palestine. The radon-222 concentrations in the collected samples exhibit a range from 116.0 Bq/m³ at the Jenin city roundabout site to 746.0 Bq/m³ at the Salem village site (middle 2), with an average value of 528.4 Bq/m³. These measurements provide insight into the levels of radon-222 gases, a radioactive gas that can be present in soil, potentially posing health risks. Furthermore, the radium concentrations observed in the soil samples range from 5.1 Bq/kg to 32.5 Bq/kg, with an overall average value of 23.1 Bq/kg. Radium, a naturally occurring radioactive element found in soil and rocks, indicates the potential for increased radiation exposure.

The surface exhalation rates in the collected samples exhibit variability, ranging between 108.8 mBq m⁻² h⁻¹ and 699.7 mBq m⁻² h⁻¹, with an average value of 496.0 mBq m⁻² h⁻¹. This measurement indicates the rate at which radon-222 gas is released from the soil surface into the atmosphere. Additionally, the mass exhalation rates range from 2.6 mBq kg⁻¹ h⁻¹ to 16.5 mBq kg⁻¹ h⁻¹, with an average value of 11.73 mBq kg⁻¹ h⁻¹. These findings provide insights into the dynamics of radon-222

Table 2. Radon- 222 concentration (C_{Rn}), Radium contents (C_{Ra}), Exhalation rates (E_A and E_M) and the total annual effective dose (AED_{tot}) in Jenin Governorate- Palestine.

Site	Sample code	C_{Rn} (Bq/m ³)	C_{Ra} (Bq/kg)	E_A (mBq m ⁻² h ⁻¹)	E_M (mBq kg ⁻¹ h ⁻¹)	AED_{tot} (mSvy ⁻¹)
Jenin city- north	Jss1	442.7	19.3	415.5	9.8	15.4
Jenin city roundabout	Jss2	116.0	5.1	108.8	2.6	4.1
Salem village- Entrance	Jss3	565.0	24.6	530.4	12.5	19.6
Salem village –middle 1	Jss4	678.0	29.6	637	15	23.5
Salem village –middle 2	Jss5	746.0	32.5	699.7	16.5	25.8
Entrance Ya'bad	Jss6	439.4	19.2	412.5	9.7	15.3
Ya'bad-Middle of village	Jss7	571.7	24.9	536.6	12.7	19.8
Ya'bad- south of the village	Jss8	416.4	18.2	391	9.3	14.5
Qabatiya_north	Jss9	593.5	25.9	557	13.2	20.6
Qabatiya_middle of village	Jss10	547.6	24.0	514	12.2	19.0
Zababida-Arab American University	Jss11	280.9	12.3	263.68	6.2	9.75
Zababida-Arab as suweitat 1	Jss12	489.7	21.4	459.6	10.9	17.0
Zababida-Arab as Suweitat 2	Jss13	472.2	20.6	443	10.5	16.4
Entrance Meithalun	Jss14	509.4	22.2	478	11.3	17.7
Meithalun_North1	Jss15	475.5	20.7	446	10.6	16.5
Meithalun_North2	Jss16	625.0	27.3	586.9	13.9	21.7
Meithalun_middle of village	Jss17	722.5	31.5	678.2	16.1	25
Jenin Hadad 1	Jss18	638.3	27.8	599	14.2	22.1
Jenin Hadad 2	Jss19	710.5	31.5	667	15.8	24.7
Min		116.0	5.1	108.8	2.6	4.1
Max		746.0	32.5	699.7	16.5	25.8
Average		528.4	23.1	496.0	11.7	18.3

Table 3. Radon-222 concentration (C_{Rn}), Radium contents (C_{Ra}), Exhalation rates (E_A and E_M) and the total annual effective dose (AED_{tot}) in Tubas Governorate- Palestine.

Site	Sample Code	C_{Rn} (Bq/m ³)	C_{Ra} (Bq/kg)	E_A (mBq m ⁻² h ⁻¹)	E_M (mBq kg ⁻¹ h ⁻¹)	AED_{tot} (mSvy ⁻¹)
Tubas- Al'Aqaba 1	Uss 1	346.5	15.1	325.2	7.7	12.0
Tubas- Al'Aqaba 2	Uss 2	426.3	18.6	400.0	9.5	14.5
Tubas- Gore Zone 1	Uss 3	650.4	28.4	610.5	14.4	22.6
Tubas- Gore Zone 2	Uss 4	638.0	27.8	599.0	14.2	22.1
Min		346.5	15.1	610.5	14.4	12.0
Max		650.4	28.4	325.2	7.7	22.6
Average		515.3	22.5	483.7	11.5	17.8

release from the soil samples, contributing to a better understanding of potential radiation exposure.

In conclusion, the AED_{tot} in these soil samples exhibit variability, ranging from 4.1 mSv/year to 25.8 mSv/year, with an average value of 18.3 mSv/year. The total annual effective dose provides an estimate of the radiation dose that individuals may receive over the course of a year due to exposure to radon-222 and its decay products present in the soil.

In Table 3, the measurements of radon-222 concentrations, radium contents, exhalation rates, and total annual effective doses in soil samples collected from diverse sites in the Tubas Governorate, Palestine, are presented. Radon-222 concentrations in the collected samples range from 346.5 Bq/m³ at the Al'Aqaba site to 650.4 Bq/m³ at the Gore Zone 1 site, with an average value of 515.3 Bq/m³. These measurements offer valuable insights into the levels of radon-222 gas, a radioactive

substance found in soil that may pose potential health risks. Additionally, the observed radium concentrations in the soil samples range from 15.1 Bq/kg to 28.4 Bq/kg, with an overall average value of 22.5 Bq/kg. Radium, as a naturally occurring radioactive element, can be present in soil and rocks, suggesting the potential for increased radiation exposure.

The surface exhalation rates in the collected samples exhibit a range from 325.2 mBq/m² h to 610.5 mBq/m² h, with a total average value of 483.67 mBq/m² h. This measurement signifies the rate at which radon-222 gas is released from the soil surface into the surrounding atmosphere. Additionally, the mass exhalation rates in the soil samples vary from 7.7 mBq/kg h to 14.4 mBq/kg h, with an average value of 11.45 mBq/kg h. The mass exhalation rate quantifies the rate at which radon-222 gas is released per unit mass of soil, providing valuable information about the potential radon-222 exposure in the environment.

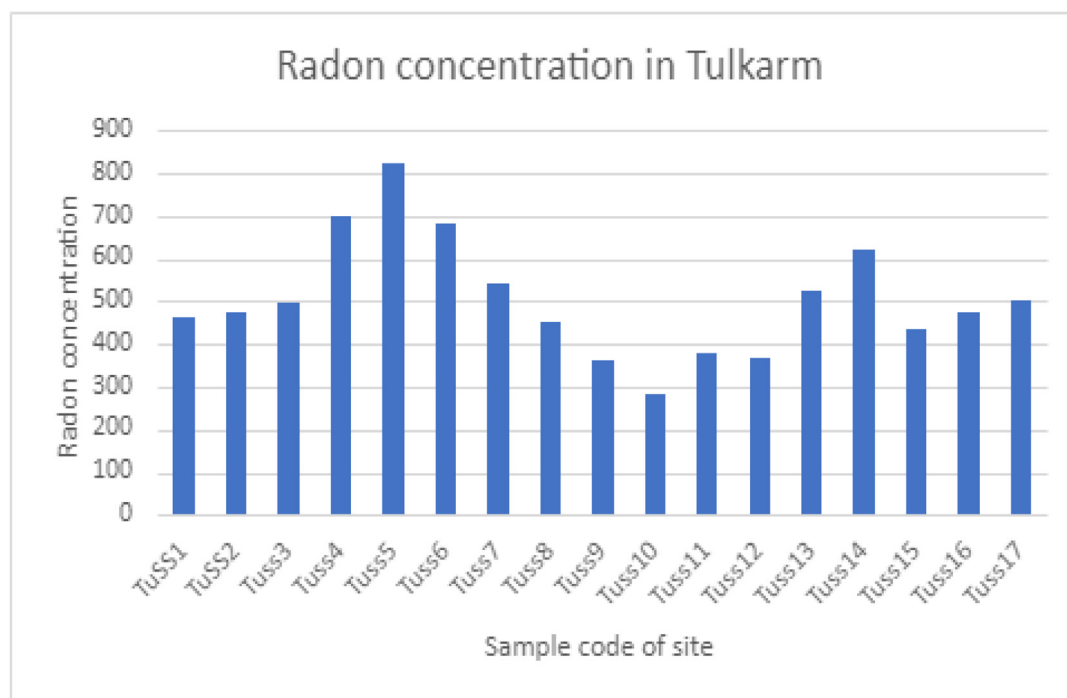


Fig. 3. The correlation between radon-222 concentrations with the site for Tulkarm governorate.

Finally, the AED_{tot} in these soil samples span from 12.0 mSv/year to 22.6 mSv/year, with an average value of 17.8 mSv/year. The total annual effective dose represents the estimated radiation dose received by individuals over the course of a year due to exposure to radon-222 and its decay products in the soil. This metric is crucial in assessing the potential health risks associated with prolonged exposure to radiation in the studied area.

Figures 3–5 depict separate graphs comparing radon concentrations in the Tulkarm, Jenin, and Tubas governorates. These visual representations serve to illustrate the variations in radon-222 levels among the three regions. According to the earlier statement, the average radon-222 concentration in the Jenin region was the highest among the three, followed by Tubas and then Tulkarm. These figures likely offer a graphical insight into this comparison, enabling a visual observation of the differences in radon-222 concentrations between the governorates.

Figure 6 displays the correlation between radium content (C_{Ra}) and radon-222 concentration (C_{Rn}) specifically in the Tulkarm Governorate. The purpose of this figure is to analyze the relationship between radium content and radon-222 concentrations in this region. By examining the scatter plot, one can deduce whether there is a correlation or association between these two variables. A positive correlation would suggest that higher radium content is associated with higher radon-222 concentrations, while a negative correlation indicates the opposite. This figure helps provide insights into the interdependence of radium content and radon-222 concentrations in the Tulkarm region.

Table 4 provides a comprehensive comparison of radon-222 concentration levels in soil samples from the present study with data reported in other studies conducted in Palestine. This comparison suggests that the measured radon-222 levels in the

Nablus, Jenin, and Tubas regions are elevated in comparison to other areas in Palestine. The presence of elevated radon-222 levels in the soil implies a higher potential for radon-222 infiltrations into buildings and homes in these regions. Given that radon-222 is a radioactive gas that can seep from the ground and accumulate indoors, these findings underscore the importance of monitoring and addressing potential health risks associated with elevated radon-222 concentrations.

Monitoring radon-222 concentrations in indoor environments and adopting suitable ventilation or radon-222 mitigation strategies are crucial steps in minimizing potential health risks associated with prolonged exposure to radon-222. This emphasizes the importance of proactive measures to ensure a healthier and safer living environment for the residents in these regions.

5 Discussion

As we mentioned earlier, the measurements indicate that the area under investigation display higher levels of radon-222 concentration in soil samples compared to other regions. This heightened concentration could be attributed to increased radium and uranium contents in these specific samples. Elevated radium values in specific samples may be linked to their association with phosphate, granite, sandstone, and quartzite. Radium, as a radioactive element, naturally occurs in soil, and its concentration can vary based on the geological composition of an area. Moreover, it is important to acknowledge that soil radon-222 concentrations can vary significantly based on factors such as weather conditions, climate, and soil type. Similar measurements conducted by different researchers have also highlighted this variability. This underscores the complex nature of radon-222 levels in soil and

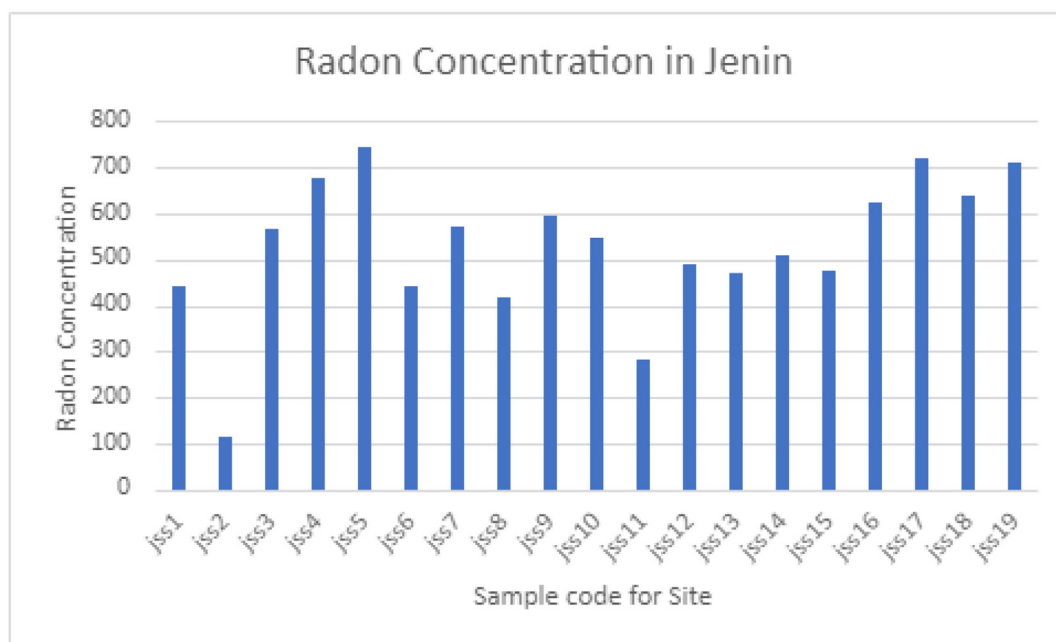


Fig. 4. The correlation between radon-222 concentrations with the site for Jenin governorate.

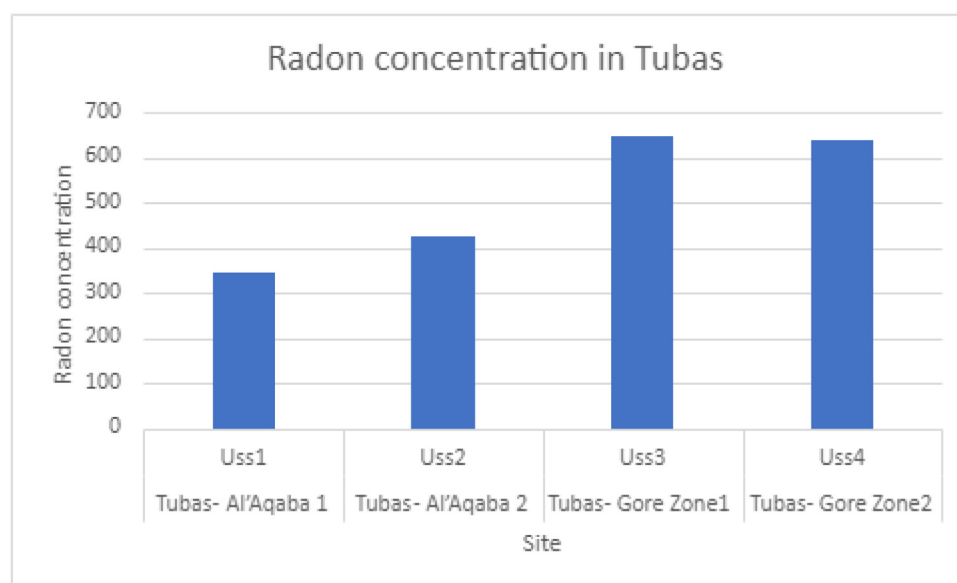


Fig. 5. The correlation between radon-222 concentrations with the site for Tubas governorate.

the need for comprehensive assessments that consider various influencing factors (Abdalsattar *et al.*, 2014; Dong *et al.*, 2015).

The results obtained reveal that the radon-222 concentration values in most samples are below the permissible limit set by the International Commission on Radiological Protection (ICRP, 1993), which recommends a radon-222 concentration range of 200 to 600 Bq/m³ for dwellings. However, it's noteworthy that the radon-222 levels mentioned surpass the new reference level of 100 Bq/m³ set by the World Health Organization in 2015 (WHO, 2015).

Addressing and mitigating radon-222 exposure in the affected regions is crucial to ensuring the well-being and safety

of the population. Implementing measures such as radon-222 testing, ensuring proper ventilation, and employing radon-222 mitigation strategies are essential steps in reducing the health risks associated with elevated radon-222 levels. These proactive measures contribute to creating a safer living environment and safeguarding public health in areas with heightened radon-222 concentrations (Selim *et al.*, 2019).

The release or exhalation rate of radon-222 from the soil is influenced by the presence of radium and the soil porosity. Radon-222 exhalation rates from soil are typically higher compared to those from building materials due to the soil's greater porosity. However, the radon-222 exhalation rates observed in this study are notably lower than the world average

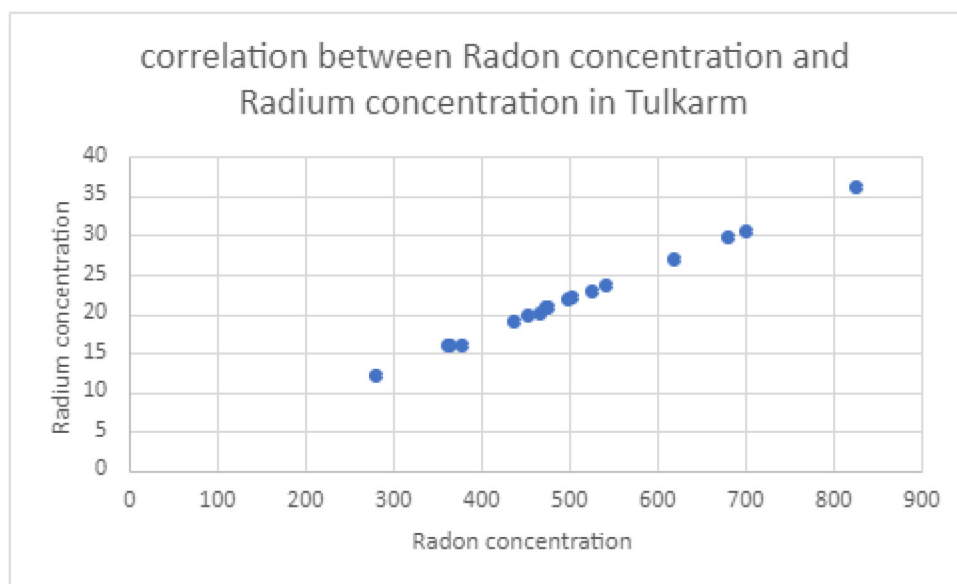


Fig. 6. The correlation between radium concentrations (C_{Ra}) with radon-222 concentration (C_{Rn}) in Tulkarm Governorate.

Table 4. Comparison of radon-222 concentration levels in soil samples at the present work with those in Palestine.

Site	Radon concentration (Bq m^{-3})			Ref.
	Min	Max	Av.	
North Gaza	23.5	584.1	303.8	(Hamed 2005)
Nablus	55.4	589.5	268.6	(Shoqwara <i>et al.</i> , 2013)
Hebron	294.0	512.0	403.0	(Thabayneh 2016)
Bethlehem	19.1	572.9	296.0	(Thabayneh 2018)
Present work				
Tulkarm	281.0	826.0	553.5	
-Jenin	115.8	745.5	430.7	Present work
-Tubas	346.5	650.4	498.5	

value of $57,600 \text{ mBq m}^2 \text{ h}^{-1}$ reported by UNSCEAR. Consequently, it is suggested that this soil can be safely used for construction purposes, as it exhibits a low radon-222 exhalation rate and does not pose significant health risks (UNSCEAR, 2000; Krishna *et al.*, 2023).

The annual effective dose, estimating the radiation dose received by individuals over a year, was found to be slightly higher than the action levels (3–10 mSv/year) recommended by the International Commission on Radiological Protection (ICRP) (ICRP, 1993). However, it's important to note that these values are still considered safe in terms of potential health hazards. While they exceed the lower end of the recommended action levels, they remain within a range that is generally considered acceptable and does not pose immediate health risks. Continued monitoring and assessment are advisable to ensure ongoing safety and to address any potential changes in radiation exposure.

In conclusion, based on the information provided, it can be inferred that the radon-222 exhalation rate from the soil is relatively low and does not pose significant health risks. Similarly, although the annual effective dose values slightly exceed the recommended action levels, they are still

considered within a safe range. It is worth noting that this work represents the first study conducted on the soil in the investigated area, and further research should be conducted to cover other locations and different seasons. Expanding the scope of research will contribute to a more thorough understanding of radon-222 levels, facilitating the implementation of targeted measures to ensure public safety across various regions and environmental conditions.

6 Conclusions

In this particular study, a cumulative passive dosimeter comprising a solid-state nuclear track detector (SSNTD) of type CR-39 was utilized to estimate radon-222 concentration, radium contents, radon-222 exhalation rate, and annual effective dose in 40 soil samples collected from various locations in the northern part of the West Bank, Palestine.

The average radon-222 concentration values for the sites in Tulkarm, Jenin, and Tubas were found to be 505.2 Bq/m^3 , 528.4 Bq/m^3 , and 515.3 Bq/m^3 , respectively. The corresponding average annual effective dose values for these sites were

17.5 mSv/year, 18.3 mSv/year, and 17.8 mSv/year. These values were slightly higher than the action levels (3-10 mSv/year) recommended by the International Commission on Radiological Protection (ICRP) in 1993.

Additionally, some of the samples exhibited radium concentrations exceeding the global value of 30 Bq/kg set by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). However, it is noteworthy that all the measured values were within the risk limits recommended by both the International Commission on Radiological Protection (ICRP) and the World Health Organization (WHO).

The measurements obtained emphasize the necessity for a more comprehensive survey of radon-222 risks throughout the entire country. The data collected in this study serves as a baseline database of activity levels, which can serve as a reference for future studies to assess potential impacts from future events.

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Conflicts of Interest

The authors declare no conflict of interest.

Data availability statement

This article has no associated data generated and/or analyzed.

Author contribution statement

Rounz J. Shawamreh distributed, collected, and read the dosimeters and contributed to the analysis of data; Khalil M. Thabayneh wrote the text of the manuscript, reviewed and approved the final manuscript.

References

- Abdalsattar K, Burhan R, Fadhil K. 2014. Study of radon and radium concentration in water samples in some regions of Lebanon. *J Kerbala Univ Sci* 12: 209–215.
- Ahmed A, Abdulameer K. 2019. Radon concentration measurements in soil gas of Sawa lake, *Samawa city - south of Iraq*. *Int J Adv Res* 7: 170–177.
- Alharbi W, Abbadly A. 2013. Measurement of radon concentrations in soil and the extent of their impact on the environment from Al-Qassim, *Saudi Arabia*. *Nat Sci* 5: 93–98.
- Alrowaili Z. 2023. Nature of radon, radium, exhalation and uranium concentration from construction materials used in Al Jouf city. *Saudi Arabia J Radiat Res Appl Sci* 16: Article 100579.
- Challan M, Atteyat A. 2018. Radiological assessment of exposure doses and radon exhalation rates of building materials in Saudi Arabia. *J Radiol Oncol* 2: 12–21.
- Dabayneh K, Sroor A, Abdel-Haleem S. 2008. Environmental nuclear studies of natural and manmade radioactivity at Hebron region in Palestine. *Al- Quds Univ J Res Stud* 12: 23–42.
- Dabayneh K, Mashal L, Hasan F. 2008. Radioactivity concentration in soil samples in the southern part of the West bank-Palestine. *Radiat Prot Dos* 131: 265–271.
- Deveci F, Oncel M. 2023. Investigation of Gebze-Darica metro line (Kocaeli province/Turkey) in terms of radon and gamma radiation levels. *J Radiat Res Appl Sci* 16: 100664.
- Dong X, Liao M, Kimberlee J. 2015. Influence of environmental factors on indoor radon concentration levels in the basement and ground floor of a building – a case study. *Radiat Measur* 82: 52–58.
- El-Ghossain M, Shammala A. 2012. Radioactivity measurements in tap water in Gaza Strip (Al-Naser Area). *J Assoc Arab Univ Basic Appl Sci* 11: 21–26.
- Ferreira AO, Pecequilo BR. 2011. Natural radioactivity assessment by gamma spectrometry in some commercially-used granites from Paraná State, Brazil: Preliminary results. *Radioprotection* 46: S43– S47.
- Ghodieh A. 2019. Crop area estimation for the northern West bank, Palestine using satellite remote sensing. *Human Sci* 1: 389–408.
- Hamed N. 2005. Measurement of radon concentration in soil at north Gaza, Unpublished master's thesis. *The Islamic University of Gaza, Palestine*.
- Hatif K, Muttaleb M. 2016. Determination of natural radioactivity and radon, thoron concentrations of soil in Hilla city - Iraq. *J Babylon Univ Pure Appl Sci* 24: 1295–1309.
- Hejaz B, Issam A, Mahmoud N. 2020. Domestic Groundwater Quality in the Northern Governorates of the West Bank, Palestine. *J Environ Public Health* 1: 1–6.
- ICRP Publication 65. 1993. Protection Against Rn-222 at Home and Work, *Annals of the ICRP* 65. Oxford: Pergamon.
- Jazzar M, Thabayneh KM. 2014. Exposure of dwelling populations to alpha particles and its health impact in Illar region, *Tulkarem – Palestine*. *Int J Environ Eng Nat Resour* 1: 171–178.
- Jibiri NN, Esen NU. 2011. Radionuclide contents and radiological risk to the population due to raw minerals and soil samples from the mining sites of quality ceramic and pottery industries in Akwa Ibom, Nigeria. *Radioprotection* 46: 75–87.
- Krishna P, Subhash Ch, Pooja P, et al., 2023. Measurement of radon concentration in soil gas and radon exhalation rate from soil samples along and across the Main Central Thrust of Garhwal Himalaya, India. *Res Square* 1–27.
- Kumar A, Chauhan R, Joshi M, Sahoo B. 2014. Modeling of indoor radon concentration from radon exhalation rates of building materials and validation through measurements. *J Environ Radioactiv* 127: 50–55.
- Mashal LA, Thabayneh KM., Abu-Samreh MM. 2021. The Alpha particles doses received by students and staff in twenty schools in the north of Hebron region – Palestine. *Jordan J Phys* 14: 309–316.
- Nada F, Jaafar J. 2015. Radon concentration in soil and radon exhalation rate at Al-Dora refinery and surrounding area in Baghdad. *Detection* 3: 37–44.
- PCBS. 2021. Palestinian Central Bureau of Statistics, Estimated population in the Palestine mid-year by governorate 1997-2026, *General statistics law No. (4)*.
- Selim M, James G, Daniel R. 2019. Radon interventions around the globe: A systematic review. *Heliyon* 5: e017137.

- Shoeib MY, Thabayneh K.M. 2014. Assessment of natural radiation exposure and radon exhalation rate in various samples of Egyptian building materials. *J Radiat Res Appl Sci* 7: 174–181.
- Shoqware F, Dwaikat N, Saffarini G. 2013. Measurement of radon exhalation rate from building materials. *Res Rev: J Phys* 2: 10–19.
- Sudhir M, Asha R, Rohit M. 2016. Estimation of radon concentration in soil and groundwater samples of northern Rajasthan, India. *J Radiat Res Appl Sci* 9: 125–130.
- Thabayneh KM. 2015. Measurement of ^{222}Rn concentration levels in drinking water and the associated health effects in the Southern part of West bank –Palestine. *Appl Radiat Isot* 103: 48–53.
- Thabayneh K.M. 2016. Determination of alpha particles concentration in some soil samples and the extent of their impact on the health. *Sains Malaysiana* 45: 699–707.
- Thabayneh KM. 2018. Determination of radon exhalation rates in soil samples using sealed can technique and CR-39 detectors. *J Environ Health Sci Eng* 16: 121–128.
- Thabayneh KM, Gharaybeh A. 2023. Determination of the radiation dose from radon ingestion and inhalation in different types of drinking water samples collected from Bethlehem province –Palestine. *Appl Radiat Isotopes* 200: 110972.
- UNSCEAR. 2000. Effects of Ionizing Radiation. United, Nations, Scientific, Committee, on the Effects, of Atomic Radiation. 453–487.
- Wanga H, Heb R, Hongb C *et al.*, 2022. Analysis for distribution estimation of soil radon concentration and its influencing factors: a case study in decommissioned uranium mill tailings pond. *J Radiat Res Appl Sci* 15: 100480.
- WHO. 2015. World Health Organization. *A new WHO Handbook on Indoor Radon: A Public health, environmental and social determinants of health.*
- Yonca Y, Osman G, Sule O, Baris N. 2023. Measurement of soil radon concentration in Balikesir and examination of its effects on health. *J Radiat Res Appl Sci* 16: 100718.
- Yousef H, Gehad M, El-Farrash A, Hamza A. 2016. Radon exhalation rate for phosphate rocks samples using alpha track detectors. *J Radiat Res Appl Sci* 9: 41–46.

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