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Assessment of radon radiation index hazards in soil samples from Al-Tuwaitha and surrounding areas using alpha guard detector and nanotechnology-based approaches

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Alpha GUARD 2000 PRQ radon analyzer is used to measure the Soil's radon concentration (^{222}Rn) at 45 locations at the Tuwaitha nuclear and surrounding areas. The results obtained from the survey that the highest radon concentration is 21011 ± 3408 Bq/m³ at a depth of 55 cm in front of the medical building (sample S20). The temperature mean is 27.2°C, the pressure mean is 1011 mbar, and the relative humidity is 28.7%. The lowest concentration is 56 ± 33 Bq/m³ at a depth of 55 cm (sample S11) at the site opposite the Policy Department. The temperature mean is 29°C, the pressure mean is 1008.7 mbar, and the relative humidity is 27.7%. Based on the research results, can conclude that all radon concentrations in this study are within the permissible limits of 0.4 to 40 kBq/m³ . Due to its gaseous state, radon can easily leak into homes and accumulate. Exposure to radon causes a health concern for humans and animals because radon is closely linked with lung cancer. Therefore, careful monitoring of radon levels is crucial. In addition, recent advances in nanotechnology offer promising improvements in radon detection. Nanomaterial-based sensors such as graphene and metal oxide nanoparticles provide higher sensitivity, faster response, and real-time monitoring capabilities. Integrating nanosensors with conventional devices can enhance measurement accuracy and support more effective environmental radiation assessment.

Keywords: Radioactive material; Radon; Soil; Alpha guard; Nanotechnology.

1. INTRODUCTION

Radioactivity is a natural component of our everyday environment. It is omnipresent and beyond the reach of our sensory faculties (Abdul et al., 2024). Naturally occurring radioactive material (NORM) has its origin, first of all, in materials of which the Earth is made and in cosmic radiation, and, in second place, in human activities [1-5]. There are several important sources of radiation in the environment, meanwhile, including natural radioactivity [6]. All minerals and raw materials contain natural radioactive nuclides. NORM is the exposure of human beings due to ionizing radiation arising from natural sources and/or anthropogenic activities [7]. Radon is an important source of natural radiation [8-10]. The presence of uranium in all rocks and soils leads to radioactive decay, forming radium and radon. The alpha particles produced during the decay of radium release it from the soil. Radon gas can enter homes through soil compaction and concentration gradients [11-15]. The relationship between soil concentrations and indoor radon levels is well established, but the accuracy of predictions is limited. The first few meters of the ground account for 80% of atmospheric radon [16-20]. Natural radioactivity content can vary greatly depending on the type of soil used [21-25].

In addition to natural sources, soil radioactivity can also result from human activities: 1) Accidental or intentional releases from nuclear facilities, mines, and industries that handle radioactively enriched materials, such as fertilizer production. 2) Radioactive fallout from nuclear accidents or explosions and using phosphates in agricultural fertilizers [26-30]. Miner's workers in Schneeberg, Germany, and Jachymov, Czechoslovakia, are susceptible to respiratory diseases, particularly lung cancer. Initially, radon is associated with health problems. The primary cause of the disease is initially thought to be my dust. However, it is only around the beginning of the 20th century that the disease is identified as primary lung cancer. It has been established that individuals working with high radon levels have a higher incidence of lung cancer [31-35]. Consequently, the first studies evaluated miners' exposure to high radon levels in the workplace [36]. International health organizations have recognized the risks of radon gas to human health [37]. Figure 1 shows annual deaths by category compared to radon cases. Radon is second only to smoking as a leading cause of lung cancer, and radon is classified as a human carcinogen [38-40]. Radon gas results from the decay of the naturally occurring radioactive uranium series, which begins with uranium (^{238}U) and has a half-life of 3.824 days. Its density is approximately 7.5 times that of air and it emits alpha particles [39]. Radon gas or its decay products can enter the human body. Radon is absorbed by the body when it consumes contaminated water or ingests animal products containing contaminants from plants exposed to radon in the soil [40]. The gas accumulates in the respiratory tract, and its decay products (alpha and beta particles) settle in the airways. These high-energy particles (ionizing radiation) are capable of penetrating tissues and internal cellular components, causing DNA damage and increasing the risk of cancer, especially lung cancer [41]. In Europe, in 1979, the World Health Organization (WHO) published data on the impact of indoor air quality and radon gas in residential buildings on people's health. Since then, several countries have conducted national or subnational measurements of radon levels in homes. Efforts have been made to conduct similar research in Iraq. Tables (1) and (2) show previous and current studies on radon in Iraq and other countries. A direct relationship is observed between radon concentrations and lung cancer cases per million inhabitants per year in all indoor building samples taken at all locations [42].

Table 1 Previous and current studies in Iraq.

Region	Instrument/Tool Used	Reference
Baghdad	Alpha Guard	[31]
Karbala	CR-39	[14]
Basra	CR-39	[8]
Baghdad	CR-39	[9]
Samawa	Rad 7	[10]
Erbil	Rad 7	[22]
Baghdad	Alpha Guard	Present study

Table 2 Previous and current studies in others country.

Others Country	Instrument/Tool Used	Reference
Tanzania	Alpha Guard	[23]
India	Alpha Guard	[19]
Turkey	Alpha Guard	[12]
Morocco	Alpha Guard	[1]
Iran	Alpha Guard	[13]
Yalova	Alpha Guard	[16]

The study aimed to understand the potential radiation risks to humans and the environment by assessing radon gas levels in the soil of Tuwaitha and surrounding areas in Baghdad. The Tuwaitha site is an important area because it contains former reactor waste and has received local and international attention since 2003. The study also aimed to determine whether radon concentrations are within or above normal limits [43].

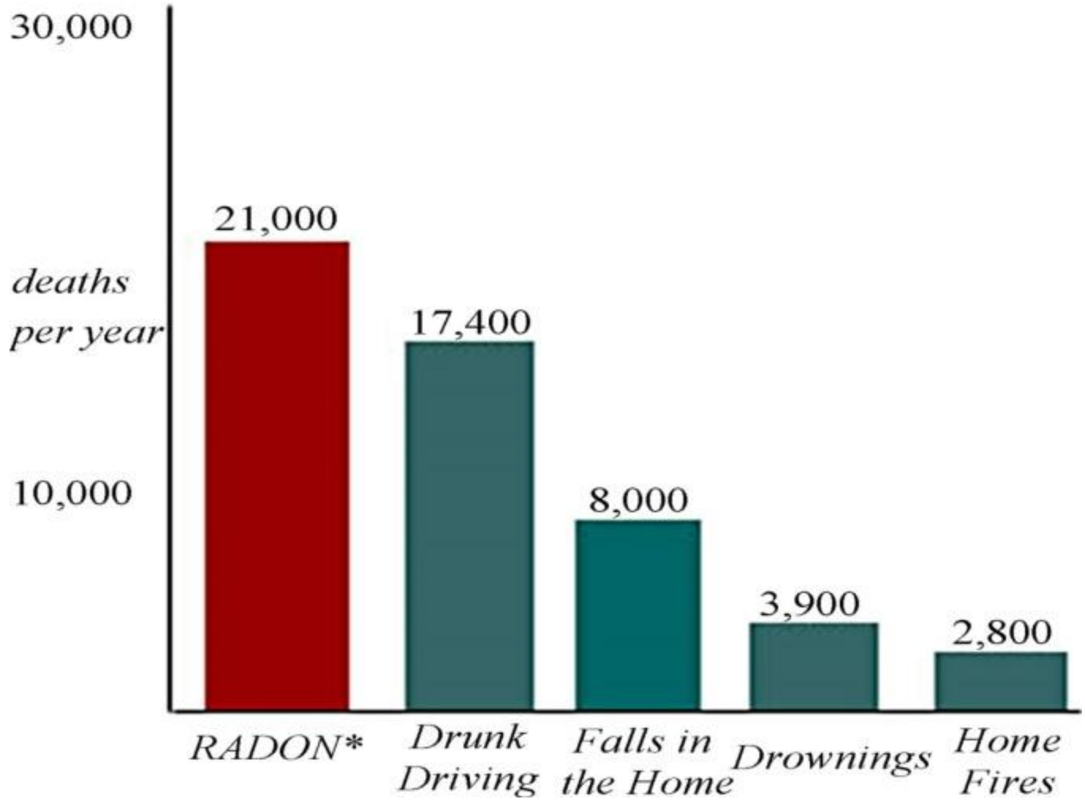

Figure 1 Each category's yearly deaths (EPA 2003) (Al-Harbi and Abbadi, 2013).

Nanotechnology has recently emerged as a promising tool in environmental radiation monitoring and detection. Nanomaterials such as metal oxide nanoparticles, carbon nanotubes, and graphene-based sensors exhibit high surface area, enhanced sensitivity, and rapid response times, making them suitable for detecting low concentrations of radioactive gases such as radon. Nanosensors can improve the accuracy and efficiency of traditional detection systems like Alpha Guard by enabling real-time, in situ monitoring with higher precision. Integrating nanotechnology into radiation assessment studies provides advanced solutions for environmental protection, early warning systems, and risk mitigation, particularly in areas affected by nuclear activities such as Al-Tuwaitha [44].

2. MATERIALS AND METHODS

2.1. Device used for measurement

Several radon ^{222}Rn detectors have been developed to measure radon concentrations in Soil during the past decades. Radon measurements in soil are important for human health and useful for monitoring environmental radioactivity in uranium mines. The Alpha Guard has been used to monitor radon. The Alpha Guard can measure ^{222}Rn in soil using a soil probe. It also has an ionization chamber to measure alpha particles emitted by ^{222}Rn and its daughters [41]. The gamma (γ) dose rates and radiation intensities of radon, thoron (^{220}Rn), and radon products are measured with the portable radiation detector Alpha Guard. It is a steel gadget that operates at 750 V and has an ionization chamber. It has an effective volume of 560 cm³ and a total volume of 620 cm³. The measurements with the Alpha Guard device are between 6Bq/m³ and 2.106 Bq/m³. The margin of error is 3%. Therefore, by counting the alpha spectrometer pulses, the Alpha Guard is an effective tool for real-time measurement of radon concentrations in the ambient air entering the ionization chamber. The device also enables real-time measurement of active radiation in Soil, air, and water [45-50].

2.2. Measurement of radon concentration in soil

The ionization chamber contains a glass filter that enables the gas to enter and spread into the 0.56-liter volume chamber. A solid center electrode receives a 0 V potential from the signal input of its highly sensitive preamplifier. The instrument's metal interior reaches +750 V when users rotate it along its longitudinal axis [51-55]. The preamplifier unit sends its processed measuring signals through an electronic network for digital processing. The ionization chamber allows only radon-222 gas to pass through but blocks all radon decay products from entering. The filter acts as a barrier to stop airborne particles from entering the chamber space. The computer software enables users to display graphs and compute average concentration values from the measured period. A 55 cm long metal rod with distinct edges is an insertion tool into the ground. Then, it extends 5 cm to allow radon gas access for the Alpha PM device to measure airborne radon progeny concentration. The Alpha Guard measuring device contains an ionization chamber that accepts the diffused sample. Each analysis sample required a 30-minute measurement period to determine the average radon gas concentration in Bq/m³ [56].

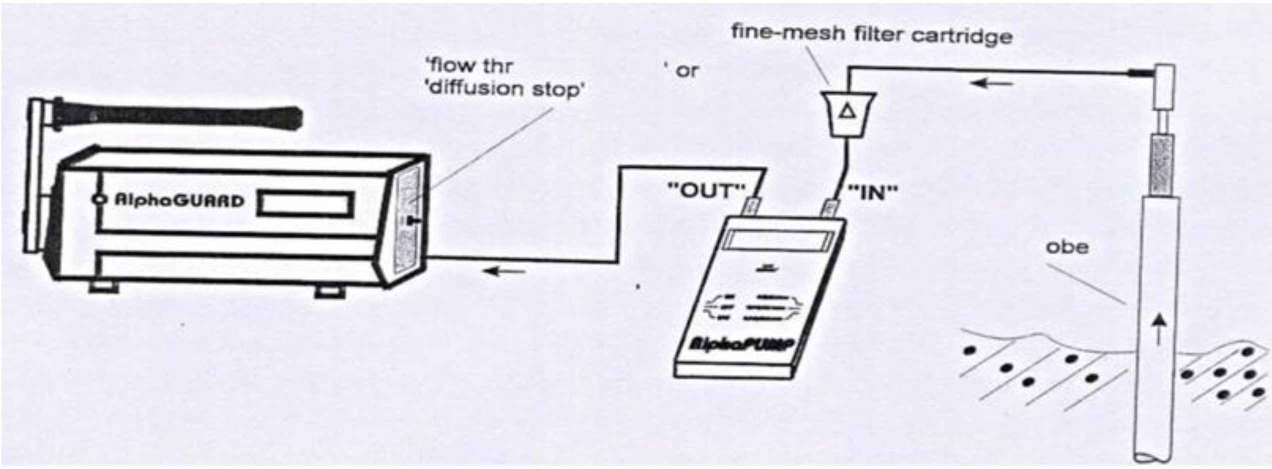

Figure 2 Alpha GUARD measuring equipment for determining radon soil gas concentration.

2.3. Nanotechnology-based enhancement

In addition to conventional radon detection methods, nanotechnology-based sensing techniques are increasingly being explored to enhance measurement accuracy and sensitivity. Nanomaterials such as zinc oxide (ZnO) nanoparticles, graphene oxide, and carbon nanotubes can be utilized as sensing layers for detecting radon and its decay products. These nanomaterials possess high adsorption capacity and electrical conductivity, enabling improved detection of alpha-emitting particles. In this study, although measurements are conducted using the Alpha Guard detector, the integration of nanosensors is proposed as a complementary approach for future investigations. These nanosensors can be deployed in soil probes to allow continuous monitoring, reduced detection limits, and faster response times compared to conventional systems [57-60].

3. STUDY AREA AND SAMPLE COLLECTION

The Tuwaitha nuclear facility is located a few kilometers from the outskirts of Baghdad, on the banks of the Tigris and Euphrates rivers. The site is surrounded by 160-foot-high sand barriers that stretch for four miles. It is located approximately one kilometer east of the Tigris River and 18 kilometers south of Baghdad and covers an area of roughly 1.3 square kilometers (Al-Bakhat et al., 2020). Sampling Sites As part of the study, shown in Figure 3, 24 samples are collected from the nuclear facility site. By comparison, 21 other samples are taken from surrounding areas, including Jisr Diyala, Ishtar, Tamim, Al Jaara , and Al-Wardiya. The goal of collecting all these samples is to determine the safety level of workers and residents in the area from exposure to radon radiation. These samples are taken from schoolyards, administrative buildings, farms, residential areas, and storage sites for radioactive materials. Table 3 below shows the areas from which samples are taken.

Table 3 Sample locations.

Samples	East	North	Samples	East	North
S1	33.20913889	44.51597222	S24	33.21041667	44.52919444
S2	33.20544444	44.51658333	S25	33.22363889	44.51213889
S3	33.205	44.51758333	S26	33.23380556	44.52361111
S4	33.20736111	44.51319444	S27	33.22655556	44.53319444
S5	33.20925	44.51138889	S28	33.19602778	44.53702778
S6	33.20344444	44.50872222	S29	33.19344444	44.53452778
S7	33.20475	44.51138889	S30	33.19127778	44.52863889
S8	33.20538889	44.51211111	S31	33.19313889	44.53194444
S9	33.20727778	44.51744444	S32	33.18519444	44.53227778
S10	33.20552778	44.51794444	S33	33.18438889	44.48763889
S11	33.20475	44.51744444	S34	33.19169444	44.54208333
S12	33.20580556	44.51347222	S35	33.18305556	44.48791667
S13	33.20502778	44.51436111	S36	33.20877778	44.49844444
S14	33.20033333	44.5125	S37	33.21997222	44.50797222
S15	33.20694444	44.51366667	S38	33.20375	44.55186111
S16	33.20644444	44.51269444	S39	33.17666667	44.55252778
S17	33.20763889	44.51297222	S40	33.16933333	44.55780556
S18	33.20733333	44.51202778	S41	33.20011111	44.56675
S19	33.20866667	44.51141667	S42	33.19530556	44.56502778
S20	33.20880556	44.51236111	S43	33.21372222	44.5525
S21	33.20902778	44.52061111	S44	33.20302778	44.5695
S22	33.20855556	44.52469444	S45	33.21025	44.55133333
S23	33.21058333	44.52705556			

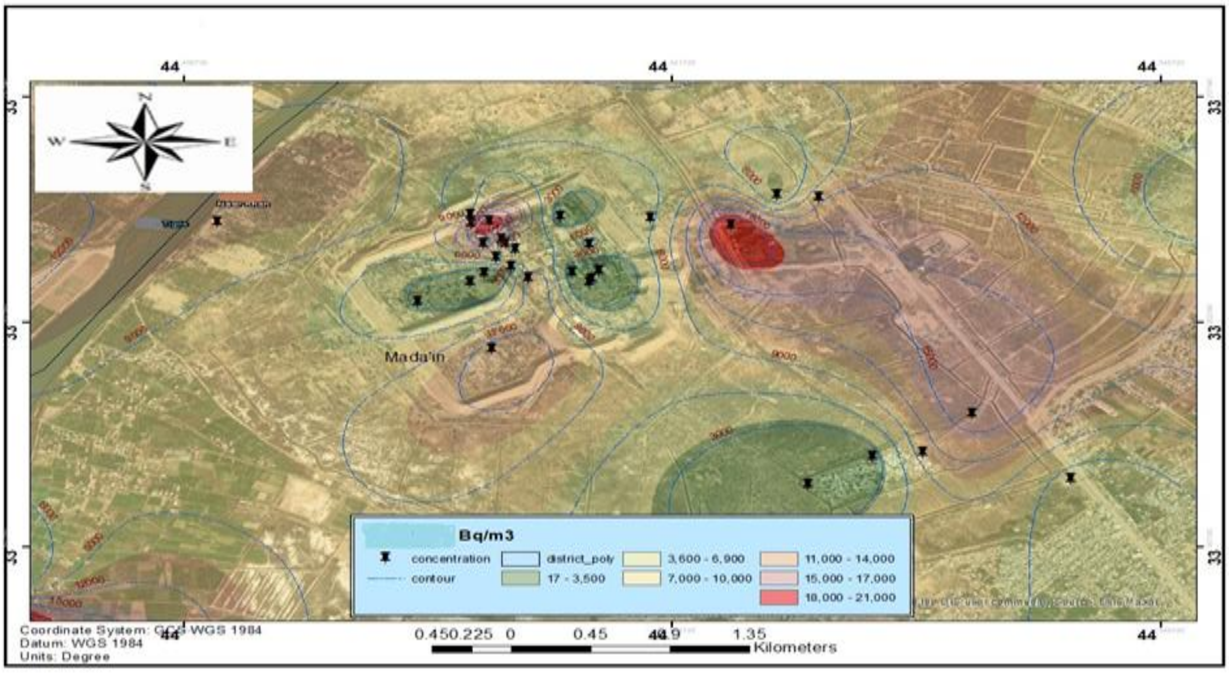

Figure 3 Map showing the locations of the soil samples measured using the Alpha Guard in Al-Tuwaitha and the Surrounding Area.

4. RESULTS AND DISCUSSION

Soil radon concentrations are measured over half an hour for 45 samples at the Tuwaitha nuclear site and some surrounding locations identified using GPS technology during the fall and winter seasons using an Alpha GUARD 2000 PRQ. Table 4 and Figure 5 show the average radon concentrations for 24 samples from the Tuwaitha nuclear site and 21 samples from the surrounding areas. The highest radon concentration is measured at the point in front of the medical building (sample S20), with an average value of 21011 ± 3408 Bq/m³. The average temperature is 27.2°C, the average pressure is 1011 mbar, and the average humidity is 28.7%. The lowest radon concentration is measured at the site opposite the Policy Department (sample S11), with an average value of 56 ± 33 Bq/m³. The average temperature is 29°C, the average pressure is 1008.7 millibars, and the humidity is 27.7%. These concentration measurements are well below the permissible range, indicating no imminent danger that would require the closure of these areas. As shown in Table (5), radon levels vary from country to country depending on soil type, humidity, and geological conditions. There is no fixed global level, but previous studies have estimated soil radon levels to be between 0.4 and 40 KBq/m³ (Al -Hamidawi et al., 2012). Based on this ratio, the current study classified samples into three highest concentration categories, with samples ranging from 0.4 to 40 kBq/ m³ : Samples S13, S14, S18, S19, S20, S22, S24, S25, S27, S28, S29, S35, S36, S38, S41, and S42. While the average radon concentrations ranged between 1-10 kBq/m³ in samples S1, S2, S3, S4, S5, S6, S9, S12, S15, S16, S17, S21, S23, S26, S31, S32, S33, S34, S37, S39, S40, S43, S44, and S45 (±1942). The lowest values are found in samples S7, S8, S10, S11, and S30, all of which are less than 1 kBq/m³. Figure 4 shows the relationship between radon concentration and atmospheric parameters (temperature, humidity, and atmospheric pressure) and the impact of these variables, especially in the spring and winter seasons [61]. The correlation coefficient (R) ranges between 1 and -1. A value of +1 indicates a strong positive relationship between any two parameters, while a value of -1 indicates a strong negative relationship. Typically, R indicates a weak negative relationship if the value is close to zero on the negative side. Conversely, it indicates a weak positive relationship if it is close to zero on the positive side. When R = 0 there is no relationship between the two variables (Saleh et al., 2018). In areas with balanced natural conditions or limited human activity, an analysis of environmental factors revealed a weak inverse relationship between radon concentration and temperature (correlation coefficient: -0.45), suggesting that higher temperatures may reduce soil radon levels. Humidity (0.18) and barometric pressure (0.12) showed little effect, suggesting little influence on radon accumulation (EPA, 2003). Human activity, particularly proximity to nuclear sites, has emerged as a major factor in elevated radon levels, underscoring the need for targeted monitoring. International agencies have highlighted the health risks associated with prolonged radon exposure, such as lung cancer. Shown in Table 6.

Table 4 Average humidity, temperature, pressure and radon concentration for Al-Tuwaitha nuclear site and surrounding area.

Sample Code	Sample location name	Date	Concentration of ^{222}Rn Bq/m^3	Humidity %	Temperature C°	Air pressure millibar
S1	Near library	07/11/2024	1877 ±144	36.4	24.5	1019
S2	In front of the presidency of the Atomic Energy Authority	11/11/2024	1394 ±288	41	33.1	1012.9
S3	Behind the radioactive waste treatment plant	13/11/2024	3133 ±870	42.2	25.8	1012.9
S4	Near building 61	13/11/2024	3119 ±811	42	25.8	1012.9
S5	Projects and Technical Support Directorate	13/11/2024	3133 ±170	40	26	1013.3
S6	End of the Alealawiaat site	14/11/2024	2663 ±774	36.5	27	1012.6
S7	Alealawiaat site/ Near the basins	14/11/2024	158 ±132	34.5	26.5	1012.9
S8	/Next to the crematorium Alealawiaat site	14/11/2024	655 ±418	33.3	26.4	1009.7
S9	In front of the financial and legal department	18/11/2024	6407 ±680	29.5	29.2	1009.5
S10	In front of the restaurant	18/11/2024	416 ±211	27.7	29.8	1008.7
S11	Opposite the Department of Science Policy	18/11/2024	56 ±33	38.5	27.6	1012.1
S12	Behind the Holocaust (near Russian Reactor)	19/11/2024	2087 ±680	37.4	26.1	1012.1
S13	near Italian fuel	19/11/2024	10764 ±2157	32.2	28.4	1011.6
S14	Behind Russian Reactor	19/11/2024	13139 ±2347	31	25	1012.7
S15	In front of the Nuclear and Radiation Safety and Security Directorate building	26/11/2024	9916 ±1891	29.1	25,7	1013.2
S16	Behind the Directorate of Nuclear and Radiation Safety and Security	26/11/2024	9033 ±1795	52.4	22.9	1012.2
S17	In front of the central laboratories	26/11/2024	8518 ±2001	35.2	24.3	1012.1
S18	Behind the Central Laboratories Directorate	26/11/2024	14642 ±2959	32.4	25.4	1010.7
S19	Near the Directorate of	26/11/202	17039 ±2985	28.7	27.2	1011

	Radioactive Waste Purification	4				
S20	In front of the medical building	26/11/2024	21011 ±3408	38.1	22	1017.5
S21	In front of bunker B Gate	09/12/2024	5476 ±1395	34.3	25	1017
S22	Near the bunker door (enter the BRC)	09/12/2024	20388 ±3299	33.2	26	1016.7
S23	Behind the Bunker B gate on the left side between the inner and outer doors	09/12/2024	3730 ±1752	33	25.2	1016.7
S24	Next to the external gate of the Al-Tuwaitha site	09/12/2024	11450 ±2766	44	18.1	1016.4
S25	In front of Ibn Zohr Hospital	12/12/2024	10885 ±2399	23.5	32	1015.9
S26	Opposite Sahroon area/ Diyala Bridge	12/12/2024	2975 ±1317	28,2	25.3	1015.1
S27	Qais Al-Ansari Intermediate School	12/12/2024	11336 ±2727	33.1	17.3	1019.4
S28	Entrance to Ishtar village, towards the Tuwaitha nuclear site	19/12/2024	16738 ±3060	23.5	24	1018.6
S29	Near the Ishtar entrance checkpoint	19/12/2024	10182 ±2614	24	23.3	1017.3
S30	The end of Ishtar village from the side of the Tuwaitha site	19/12/2024	170 ±81	27.9	19.5	1018
S31	Behind Al Takhi Elementary School	19/12/2024	2045 ±921	38.1	24.2	1016.9
S32	Next to Omar Al Mukhtar School / Al Wardiya	24/12/2024	8292 ±1787	39.6	21.9	1015.7
S33	Western Tuwaitha	24/12/2024	3395 ±1155	34.4	26.6	1015.6
S34	lord ship / flower garden	24/12/2024	4859 ±1142	35.7	24.2	1018.8
S35	Al Wardiya / Al Tafawul Mixed Secondary School	24/12/2024	18293 ±3197	34.4	24.2	1018.9
S36	Behind the Tuwaitha nuclear site near the river	31/12/2024	11052 ±2720	35.7	24.2	1018.8
S37	Near the confluence of the Diyala River with the Tigris	31/12/2024	5579 ±1942	34.4	24.2	1018.9
S38	Al-Jaara / Jaber neighborhood	31/12/2024	12989 ±2801	32.7	22.3	1018.8
S39	Near Al-Jaara Health Center	31/12/2024	3110 ±1313	33.7	19.8	1018
S40	front of Bilal Al-Habashi School	21/01/2025	3966 ±1004	39.4	19	1022.4

S41	Near the International Gas Production and Bottling Company	21/01/2025	14146 ±3021	29.8	23.9	1022.1
S42	Near Al-Tuwaitha National Gas Plant	21/01/2025	11464 ±2858	36.9	18.2	1022.4
S43	Diyala Bridge / Opposite Sayed Jawad Al-Baaj Services	28/01/2025	8660 ±2026	8.8	20	1058
S44	Diyala Bridge / near Baghdad Agricultural Development and Development Company	28/01/2025	1830 ±1000	17.7	22.4	1049.3
S45	Diyala Bridge/Near Ambassador Services	30/01/2025	2200 ±1124	11.7	20.2	1058

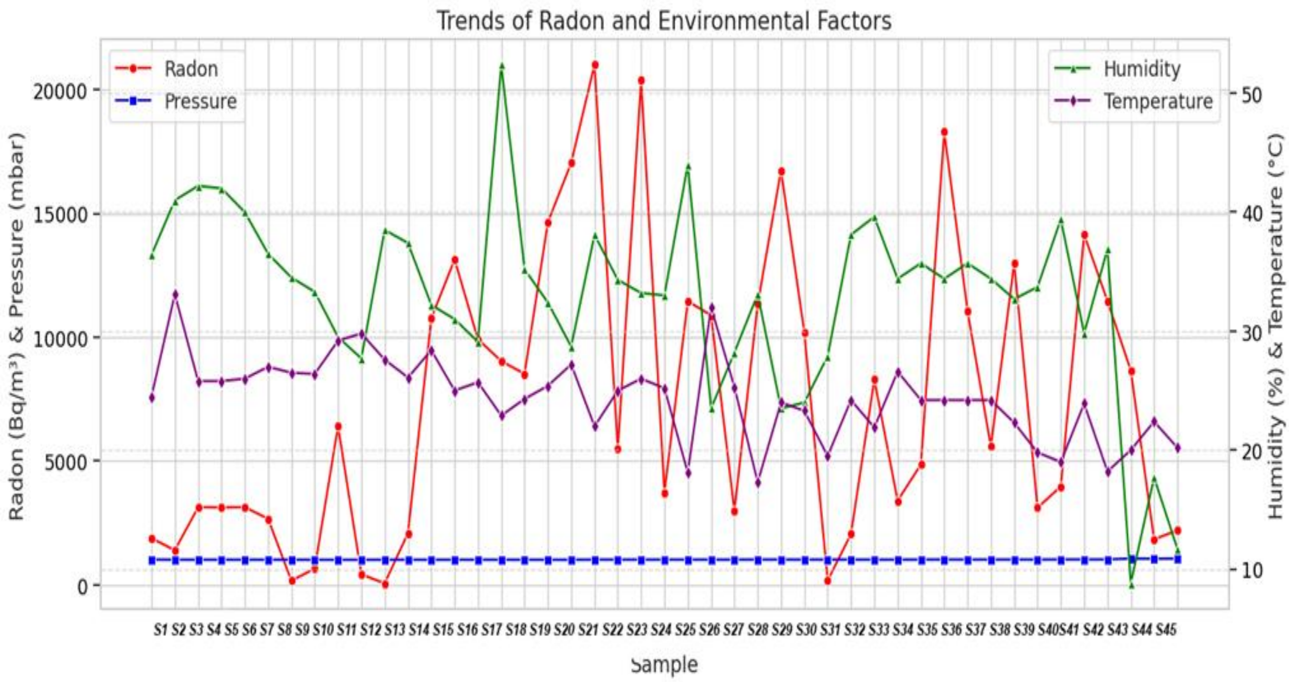

Figure 4 The effect of pressure, humidity, and temperature on radon concentration in soil.

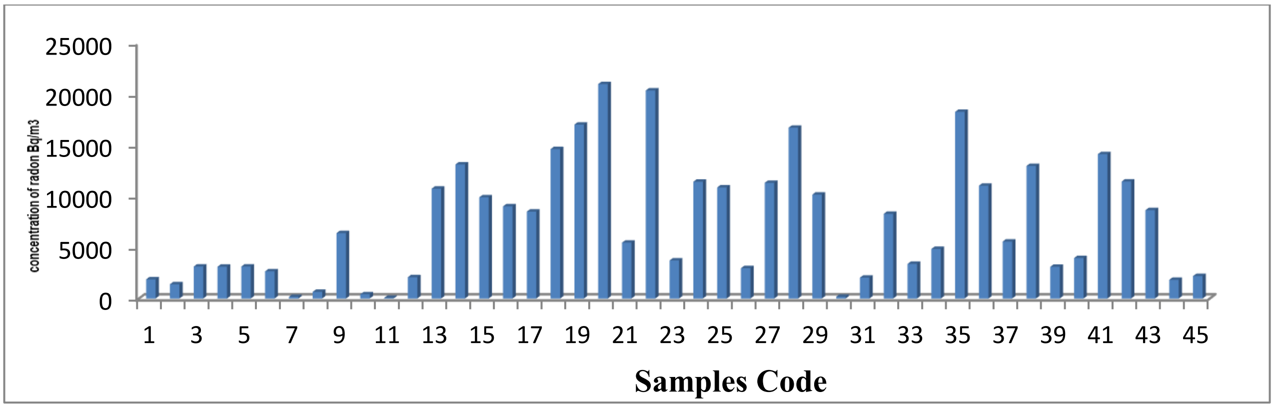

Figure 5 Average radon concentration for selected samples in Tuwaitha nuclear site and surrounding area.

Table 5 Classification of radon concentrations in soil samples.

Category	Concentration Range	Number of Samples	Sample Codes	Interpretation
High	0.4–40 kBq/m³	16	S13, S14, S18, S19, S20, S22, S24, S25, S27, S28, S29, S35, S36, S38, S41, S42	Proximity to nuclear facilities, uranium-rich soil, or radioactive waste disposal sites.
Medium	1–10 kBq/m³	24	S1, S2, S3, S4, S5, S6, S9, S12, S15, S16, S17, S21, S23, S26, S31, S32, S33, S34, S37, S39, S40, S43, S44, S45	Areas with limited human activity or balanced environmental factors.
Low	<1 kBq/m³	5	S7, S8, S10, S11, S30	Distance from radiation sources or well-ventilated terrain.

Table 6 Correlation coefficients.

Parameter	Related Variable	Relationship Type	Correlation Coefficient (R)
	Temperature (°C)	Weak negative	-0.45
The average concentration of radon	Humidity (%)	Weak positive	0.18
	Air Pressure (millibar)	Weak positive	0.12

The incorporation of nanotechnology into radon monitoring systems offers significant advantages over conventional techniques. Nanosensors can enhance detection sensitivity, particularly in low-concentration regions, and allow continuous monitoring of environmental radiation [62-65]. Compared to the Alpha Guard device, nanotechnology-based systems may reduce measurement time and improve spatial resolution. This is particularly important in high-risk areas such as near nuclear facilities, where early detection of elevated radon levels is essential [66-70].

Table 7 Comparison of conventional radon detection methods and nanotechnology-based sensors in terms of sensitivity, response time, portability, and application.

Method	Sensitivity	Response Time	Portability	Application
Alpha Guard	High	Moderate	Medium	Standard radon measurement
Nanotechnology Sensors	Very High	Fast	High	Real-time monitoring
CR-39 Detector	Moderate	Slow	High	Passive long-term detection

Figure 6 presents a comparative analysis of radon detection methods, illustrating that nanotechnology-based sensors exhibit higher sensitivity and faster response times compared to conventional techniques such as Alpha Guard and CR-39 detectors [71-75].

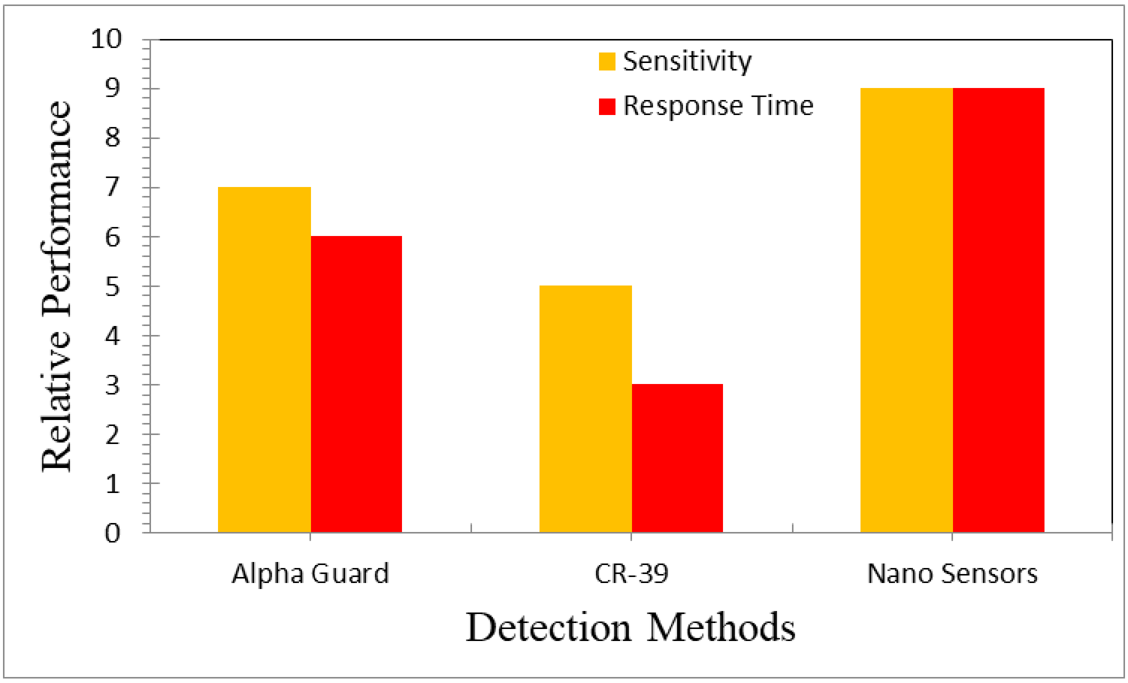

Figure 6 Comparison of radon detection methods showing the relative performance of conventional techniques (Alpha Guard and CR-39) and nanotechnology-based sensors in terms of sensitivity and response time.

5. CONCLUSIONS

This study determined radon-222 concentration levels in the soil at the Tuwaitha site and surrounding areas. The obtained values indicate that the targeted area experiences varying radiation levels, as our current research confirms. Concentrations of 20-21 KBq/m³ indicate that the sites of these samples require special attention from the relevant authorities. Radon levels at the Tuwaitha site are due to soil characteristics and its location near nuclear equipment. In 2023, lung cancer was the third most common cancer in Iraq, with 3,020 new cancer cases reported among the population, particularly among men. The incidence rate per 100.000 population was approximately 14.4, including 891 cases among females (29.5%) and 2,129 cases among males (70.5%). Several governorates experienced high rates of lung cancer. For example, the incidence rate in Karbala was 22.7 per 100.000 population, Al-Qadisiyah (19.2 per 100.000 population), Muthanna (22.2 per 100.000 population), Erbil (20.8 per 100.000 population), and Najaf (21.9 per 100.000 population), according to the Iraqi Cancer Registry's annual report (2023). Based on the research results, all radon gas concentrations fall within the permissible limits, ranging from 0.4 to 40 KBq/m³ .However, it is important to reduce health risks in areas with high concentrations and implement preventive measures and continuous environmental monitoring. The integration of nanotechnology presents a promising advancement in radiation monitoring. Nanomaterial-based sensors can significantly improve detection sensitivity, enable real-time monitoring, and enhance environmental safety strategies. Therefore, future studies should focus on combining conventional instruments such as Alpha Guard with nanosensor technologies to achieve more accurate and efficient radon assessment systems.

References

[1] M. Sellam, M. Rasheed, S. Azizi, T. Saidani. Ceram. Int. 50 (2024) 20917. https://doi.org/10.1016/j.ceramint.2024.03.094
[2] A. Abojassim, S. Kadhim, A. Alasadi, A. Ali, Asian J. Earth Sci. (2017) 44. 10.17311/ajes.2017.44.49
[3] A. Boumezoued, K. Guergouri, Régis Barillé, Rechem Djamil, Mourad Zaabat, M. Rasheed, J. Alloys Compd. 791 (2019) 550. https://doi.org/10.1016/j.jallcom.2019.03.251
[4] Y.M.Z. Al-Bakhat, Iraqi J. Phys. 15 (2017) 14–23. 10.30723/ijp.v15i35.49
[5] I. Alshalal, H. M. I. Al-Zuhairi, A. A. Abtan, M. Rasheed, M. K. Asmail. J. Mech. Behav. Mater. 32 (2023) 1. https://doi.org/10.1515/jmbm-2022-0280
[6] W.R. Al-Harbi, A.G. Abbadi, Nat. Sci. 5 (2013) 1. 10.4236/ns.2013.51015
[7] A. R. J. Katae, H. H. Hussein, A. S. Jaber, M. A. Sarhan, M. RASHEED, Experimental and Theoretical NANOTECHNOLOGY, 10 (2026) 357. https://doi.org/10.56053/10.s.357
[8] A. Alwan, A. Al-Obiady, S. Amin, Eng. Technol. J. 35 (2017) 1. 10.30684/etj.35.1B.1
[9] A.H. Al-Mashhadani et al., IOP Conf. Ser. Mater. Sci. Eng. 757 (2020) 012015. 10.1088/1757-899X/757/1/012015
[10] N. Arshad et al., AIP Conf. Proc. 2111 (2019) 020021. 10.1063/1.5089320
[11] A. A. Hateef, E. Dhahri, M. Rasheed, H. Kadhim, Z. Abbas, N. Hassan, Physics and Chemistry of Solid State, 25 (2024) 801. https://doi.org/10.15330/pcss.25.4.801-810
[12] Y.Y. Celen et al., J. Radiat. Res. Appl. Sci. 16 (2023). 100718. 10.1016/j.jrras.2023.100718
[13] G.D. Belete, Y.A. Anteneh, J. Oncol. (2021) 6659795. 10.1155/2021/6659795
[14] A.K. Hashim et al., IOP Conf. Ser. Mater. Sci. Eng. 928 (2020) 072152. 10.1088/1757-899X/928/7/072152
[15] A. Hashim, E. Mohammed, J. Radiat. Nucl. Appl. 1 (2016) 17. 10.18576/jrna/010103
[16] M. Ichedef et al., J. Radioanal. Nucl. Chem. (2025) 1. 10.1007/s10967-025-10169-0
[17] A. I. A. Ali, M. RASHEED, Experimental and Theoretical NANOTECHNOLOGY, 10 (2026) 277. https://doi.org/10.56053/10.s.277
[18] A. Keziz, M. Heraiz, F. Sahnoune, M. Rasheed, Ceram. Int. 49 (2023) 32989. https://doi.org/10.1016/j.ceramint.2023.07.275

[19] S. Mitra et al., J. Radioanal. Nucl. Chem. 330 (2021) 1331. 10.1007/s10967-02108024-z
[20] A. I. A. Ali, M. RASHEED, Experimental and Theoretical NANOTECHNOLOGY, 10 (2026) 239. https://doi.org/10.56053/10.s.239
[21] Y. Morishita et al., Radiat. Meas. 137 (2020) 106428. 10.1016/j.radmeas.2020.106428
[22] Y.M.Y. Muhammad et al., Zanco J. Pure Appl. Sci. 35 (2023) 58. 10.21271/zjpas
[23] A. Jaber, M. Ismael, T. Rashid, M. A. Sarhan, M. Rasheed, I. M. Sala. Eureka: Phys. Eng. 4 (2023) 29. https://doi.org/10.21303/2461-4262.2023.002770
[24] P.T.H. Nguyen et al., J. Environ. Radioact. 193 (2018) 27. 10.1016/j.jenvrad.2018.08.017
[25] N.A.M. Salih et al., Baghdad Sci. J. 15 (2018) 278. 10.21123/bsj.2018.15.3.0278
[26] A. Keziz, M. Heraiz, M. RASHEED, A. Oueslati. Mater Chem. Phys. 325 (2024) 129757. https://doi.org/10.1016/j.matchemphys.2024.129757
[27] A. Khaleefah, M. RASHEED, Experimental and Theoretical NANOTECHNOLOGY, 10 (2026) 289. https://doi.org/10.56053/10.s.289.
[28] A. R. J. Katae, H. H. Hussein, A. S. Jaber, M. A. Sarhan, M. RASHEED, Experimental and Theoretical NANOTECHNOLOGY, 10 (2026) 795. https://doi.org/10.56053/10.2.795
[29] A. Raghdi, M. Heraiz, M. Rasheed, A. Keziz, Journal of the Indian Chemical Society, 101 (2024) 101413. https://doi.org/10.1016/j.jics.2024.101413.
[30] A. Zubaidi, L.M. Asaad, I. Alshalal, M. Rasheed, J. Mech. Behav. Mater. 32 (2023) 1. https://doi.org/10.1515/jmbm-2022-0302
[31] A.H. Ali, A.S. Jaber, M.T. Yaseen, M. Rasheed, O. Bazighifan, T.A. Nofal, Complexity 2022 (2022) 1. https://doi.org/10.1155/2022/9367638
[32] A.J. Hussein, M.N. Al-Darraji, M. Rasheed, M.A. Sarhan, IOP Conf. Ser.: Earth Environ. Sci. 1262 (2023) 022007. https://doi.org/ 10.1088/1755-1315/1262/2/022007
[33] A.J. Hussein, M.N. Al-Darraji, M. Rasheed, M.A. Sarhan, IOP Conf. Ser.: Earth Environ. Sci. 1262 (2023) 022005. https://doi.org/10.1088/1755-1315/1262/2/022005
[34] D. Bouras, M. Rasheed, Opt. Quantum Electron. 54 (2022) 12. https://doi.org/10.1007/s11082-022-04161-1
[35] D. Kherifi, A. Keziz, M. Rasheed, A. Oueslati. Ceram. Int. 50 part A (2024) 30175. https://doi.org/10.1016/j.ceramint.2024.05.317
[36] E. Arif, R. Jamal, M. RASHEED, Experimental and Theoretical NANOTECHNOLOGY, 10 (2026) 453. https://doi.org/10.56053/10.2.453
[37] E. Kadri, K. Dhahri, R. Barillé, M. Rasheed. Phase Transi. 94 (2021) 65. https://doi.org/10.1080/01411594.2020.1832224
[38] F. Boudou, A. Belakredar, A. Berkane, M. Rasheed. Not. Sci. Biol. 17 (2025) 12183. https://doi.org/10.55779/nsb17212183
[39] F. Boudou, A. Guendouzi, A. Belkredar. M. Rasheed, Not. Sci. Biol. 16 (2024) 13837. https://doi.org/10.55779/nsb16211837
[40] F. Boudou, et al., Not. Sci. Biol. 17 (2025) 12593. https://doi.org/10.55779/nsb17312593
[41] F. Dkhilalli, S. M. Borchani, M. Rasheed, R. Barille, K. Guidara, M. Megdiche, J. Mater. Sci. Mater. Electron, 29 (2018) 6297. https://doi.org/10.1007/s10854-018-8609-z.
[42] H. K. Aity, E. Dhahri, M. Rasheed. Ceram. Int. 50 (2024) part B 54666. https://doi.org/10.1016/j.ceramint.2024.10.324
[43] H. K. Aity, M. Rasheed, E. Dhahri, A. A. Hateef, T. Saidani, Journal of Materials Science, 61 (2026) 6226. https://doi.org/10.1007/s10853-026-12241-w.
[44] I.M. Mohammed, M. Rasheed, AIP Conf. Proc. 3321 (2025) 020026. https://doi.org/10.1063/5.0289719

[45] M. A. Sarhan, S. Shihab, B. E. Kashem, M. Rasheed, J. Phy.: Conf. Ser., 1879 (2021) 022122. https://doi.org/10.1088/1742-6596/1879/2/022122.
[46] M. Enneffatia, M. Rasheed, B. Louati, K. Guidara, S. Shihab, R. Barillé, J. Phys.: Conf. Ser. 1795 (2021) 012050. https://doi.org/10.1088/1742-6596/1795/1/012050
[47] M. M. Najim, B. A. Yousif, M. RASHEED, Experimental and Theoretical NANOTECHNOLOGY, 10 (2026) 551. https://doi.org/10.56053/10.2.551.
[48] M. M. Najim, B. A. Yousif, M. RASHEED, Experimental and Theoretical NANOTECHNOLOGY, 10 (2026) 627. https://doi.org/10.56053/10.2.627
[49] M. Rasheed et al., J. Phys.: Conf. Ser. 1999 (2021) 012080. https://doi.org/10.1088/1742-6596/1999/1/012080
[50] M. RASHEED, A. Khaleefah, Materials Chemistry and Physics, 353 (2026) 132112. https://doi.org/10.1016/j.matchemphys.2026.132112.
[51] M. Rasheed, et al., J. Adv. Biotechnol. Exp. Ther. 6 (2023) 495. https://doi.org/10.5455/jabet.2023.d144
[52] M. Rasheed, I. Alshalal, A.A. Ashed, M.A. Sarhan, A.S. Jaber, Indones. J. Electr. Eng. Comput. Sci. 33 (2024) 653. https://doi.org/10.11591/ijeecs.v33.i1.pp653-660
[53] M. Rasheed, M. N. Mohammedali, F. A. Sadiq, M. A. Sarhan, T. Saidani. J. Optics (New Delhi. Print) 54 (2024) 3490. https://doi.org/10.1007/s12596-024-01928-5
[54] M. Rasheed, M. Nuhad Al-Darraji, S. Shihab, A. Rashid, T. Rashid. J. Phys.: Conf. Ser. 1963 (2021) 012058. https://doi.org/10.1088/1742-6596/1963/1/012058
[55] M. Rasheed, M.N. Al-Darraji, S. Shihab, A. Rashid, T. Rashid, J. Phys.: Conf. Ser. 1963 (2021) 012059. https://doi.org/10.1088/1742-6596/1963/1/012059
[56] M. Rasheed, O. Alabdali, S. Shihab, A. Rashid, T. Rashid, J. Phys.: Conf. Ser. 1999 (2021) 012078. https://doi.org/10.1088/1742-6596/1999/1/012078
[57] M. Rasheed, O. Alabdali, S. Shihab, J. Phy.: Conf. Ser. 1879 (2021) 032120. https://doi.org/10.1088/1742-6596/1879/3/032120.
[58] M. Rasheed, O.Y. Mohammed, S. Shihab, A. Al-Adili, J. Phys.: Conf. Ser. 1795 (2021) 012043. https://doi.org/10.1088/1742-6596/1795/1/012043
[59] M. Rasheed, SuhaShihab, O. Alabdali, H. H. Hassan, J. Phys. Conf. Ser., 1879 (2021) 032113. https://doi.org/10.1088/1742-6596/1879/3/032113
[60] N. Assoudi et al. Opt. Quant. Electron. 54 (2022) 9. https://doi.org/10.1007/s11082-022-03927-x
[61] N. Ben Azaza et al., Opt. Mater., 96 (2019) 109328. https://doi.org/10.1016/j.optmat.2019.109328.
[62] O. Alabdali, S. Shihab, M. Rasheed, T. Rashid. 3rd inter. Scient. conf. alkafeel univ. (ISCKU 2021) 2386 (2022) 050019. https://doi.org/10.1063/5.0066860
[63] R. Jalal, S. Shihab, M.A. Alhadi, M. Rasheed, J. Phys.: Conf. Ser. 1660 (2020) 012090. https://doi.org/10.1088/1742-6596/1660/1/012090
[64] R.S. Mahmood et al. J. Mech. Behav. Mater. 34 (2025) 1. https://doi.org/10.1515/jmbm-2025-0040
[65] S. S. Batros, M. Rasheed, H. K. Aity, A. A. Hatef, T. Saidani, Materials Chemistry and Physics, 355 (2026) 132243. https://doi.org/10.1016/j.matchemphys.2026.132243
[66] S. Shihab, M. Rasheed, O. Alabdali, A.A. Abdulrahman, J. Phys.: Conf. Ser. 1879 (2021) 022120. https://doi.org/10.1088/1742-6596/1879/2/022120
[67] T. Rashid, M. M. Mokji, M. Rasheed. J. Optics 54 (2024) 3490. https://doi.org/10.1007/s12596-024-02080-w
[68] T. Rashid, M.M. Mokji, M. Rasheed, J. Mech. Behav. Mater. 34 (2025) 77. https://doi.org/10.1515/jmbm-2025-0074

[69] T. Saidani, M. Rasheed, I. Alshalal, A.A. Rashed, M.A. Sarhan, R. Barillé, Res. Eng. Struct. Mater. 10 (2024) 743. http://dx.doi.org/10.17515/resm2023.21ma0922rs
[70] T. Saidani, S. Mokhtari, M. Rasheed, H. Lahmar, M. Trari, Journal of the Indian Chemical Society, 103 (2026) 102499. https://doi.org/10.1016/j.jics.2026.102499
[71] Z. S. Ahmed, M. RASHEED, H. S. Ahmed, Experimental and Theoretical NANOTECHNOLOGY, 10 (2026) 329. https://doi.org/10.56053/10.s.329
[72] Z. S. Ahmed, M. RASHEED, H. S. Ahmed, Experimental and Theoretical NANOTECHNOLOGY, 10 (2026) 343. https://doi.org/10.56053/10.s.343
[73] M. Rasheed, R. Barillé, J. Non-Cryst. Solids., 476 (2017) 1. https://doi.org/10.1016/j.jnoncrysol.2017.04.027
[74] M. Rasheed, R. Barillé, Opt. Quantum Electron. 49 (2017). https://doi.org/10.1007/s11082-017-1030-7
[75] M. Rasheed, S. Shihab, O. Alabdali, A. Rashid, T. Rashid, J. Phys.: Conf. Ser. 1999 (2021) 012077. https://doi.org/10.1088/1742-6596/1999/1/012077