



Assessment of terrestrial gamma radiation and the implications for radiological risks in Shaqlawa, Erbil, Iraq

Sardar Qader Othman^{a,b}

^a Department of Medical Technical Radiology, Erbil Technical Health and Medical College, Erbil Polytechnic University, Kurdistan Region, Iraq

^b College of Medical Technology, Al-Kitab University, Kirkuk, Iraq

Keywords : gamma dose rate; indoor; outdoor; AED; annual effective dose; ELCR; excess lifetime cancer risk

*Corresponding author: sardarqader@epu.edu.iq

Abstract

An initial assessment of absorbed gamma dose rates was conducted at around 30 monitoring locations situated within specific residential structures in Shaqlawa, Iraq. This represents the first instance of conducting such measures within this particular environment. A Geiger-Müller digital survey meter was used to quantify the gamma exposure at each monitoring station, 1 meter above ground. Additionally, a GPS device was employed to correctly capture the coordinates. The average absorbed gamma dose rates observed were $0.123 \mu\text{Sv} \cdot \text{h}^{-1}$ and $0.117 \mu\text{Sv} \cdot \text{h}^{-1}$ for indoor and outdoor environments, respectively, while the average annual effective doses for these areas were found to be $0.864 \text{ mSv} \cdot \text{y}^{-1}$ and $0.205 \text{ mSv} \cdot \text{y}^{-1}$, respectively. The findings indicate that both the indoor and outdoor gamma dose rates in Shaqlawa are approximately twice the global average values reported by UNSCEAR, suggesting elevated natural background radiation exposure in the area. Additionally, the excess lifetime cancer risk was estimated at 3.74×10^{-3} , which is considerably higher than the global average of 0.29×10^{-3} . These results highlight a potential radiological health concern for residents and emphasize the need for continuous environmental radiation monitoring and further investigation of radionuclide sources in building materials and soils.

1. Introduction

The global concern over gamma irradiation is a substantial issue that encompasses both indoor and outdoor environments. Approximately 80% of the global population's cumulative radiation exposure originates from natural sources [1, 2]. The evaluation of natural background radiation for radiation protection is a highly important topic within the field of health physics [3]. Consequently, natural sources consistently expose individuals to ionizing radiation [4, 5]. In addition to naturally occurring radiation sources, anthropogenic radioactivity also directly elevates environmental radiation levels [6].

Anthropogenic radionuclides are a consequence of human activities involving the utilization of specific radioactive elements for various purposes. These anthropogenic radionuclides are currently extending beyond the boundaries of monitored regions [7, 8]. Due to their inherent radioactivity, terrestrial substances like water, soil, construction materials, and coal have the potential to rapidly elevate ambient radiation levels within a given vicinity [9]. The manner in which natural radiation spreads through the atmosphere is affected by the topographic features [4].

According to scientific measurements [10], the natural radiation at sea level is recorded to be approximately $32 \text{ (nGy} \cdot \text{h}^{-1})$. In contrast, the absorbed dosage rate in the external environment might range from 18 to $93 \text{ nSv} \cdot \text{h}^{-1}$, with an average value of $59 \text{ nSv} \cdot \text{h}^{-1}$. Malaysia recorded the highest outdoor dosage rate in Asia, while Hong Kong and Iran recorded the highest interior dose rate. The typical values for radiation levels in both countries are 200 and $115 \text{ nSv} \cdot \text{h}^{-1}$, respectively. This indicates the extensive utilization of stone or masonry materials in the construction of buildings within these regions [10]. Numerous investigations pertaining to background radiation in the gamma field were carried out across various towns in Iraq [3, 11-16]. All previously stated studies demonstrated that the average outdoor dose rates in Nineveh, Al-Twath, and Najaf exceed the reported mean value [10].

The measurement of background radiation levels holds significant importance in establishing baseline data. Radionuclides like ^{238}U , ^{232}Th , ^{40}K , and various other isotopes emit gamma rays [17-19]. Of all forms of ionizing radiation, gamma radiation possesses the highest degree of penetration, enabling it to effectively traverse the human body [19, 20].

The geological structure of Shaqlawa City in Erbil Province in the Kurdistan Region of Iraq comprises sedimentary rock formations such as limestone, black shale, and sandstone [21]. These formations may possess varying concentrations of radioactive elements, including uranium, thorium, and potassium-40. The city's nearness to tectonic activity in the Zagros Fold-Thrust Belt may promote the migration of radionuclides into soil and groundwater. This has resulted in elevated radiation exposure thresholds for public health and safety [22]. People can be exposed to natural radiation from NORMs in soil, quarried rocks, stone crushing sites, and building materials, either by touching them or breathing in the ^{222}Rn rays emitted from uranium in structures [23].

Despite its geological significance and growing urban development, there is a scarcity of investigations assessing indoor and outdoor gamma radiation exposure in Shaqlawa. Therefore, the present study aims to measure the absorbed gamma dose rates in selected residential locations, estimate the annual effective dose (AED) received by the population, and evaluate the associated excess lifetime cancer risk (ELCR). The findings provide baseline radiological data for the region and support future environmental radiation monitoring programs.

2. Materials and Method

2.1. Study Area

Shaqlawa is a historic city and a hill station in the Erbil Governorate in the Kurdistan Region of Iraq. Shaqlawa, a city of approximately 25,500 people, lies 51 km to the northeast of Erbil and sits 1066 m above sea level. The city is situated at the bottom of Safeen Mountain, between that and Sork Mountain, and in the foothills of the Zagros Mountains [21].

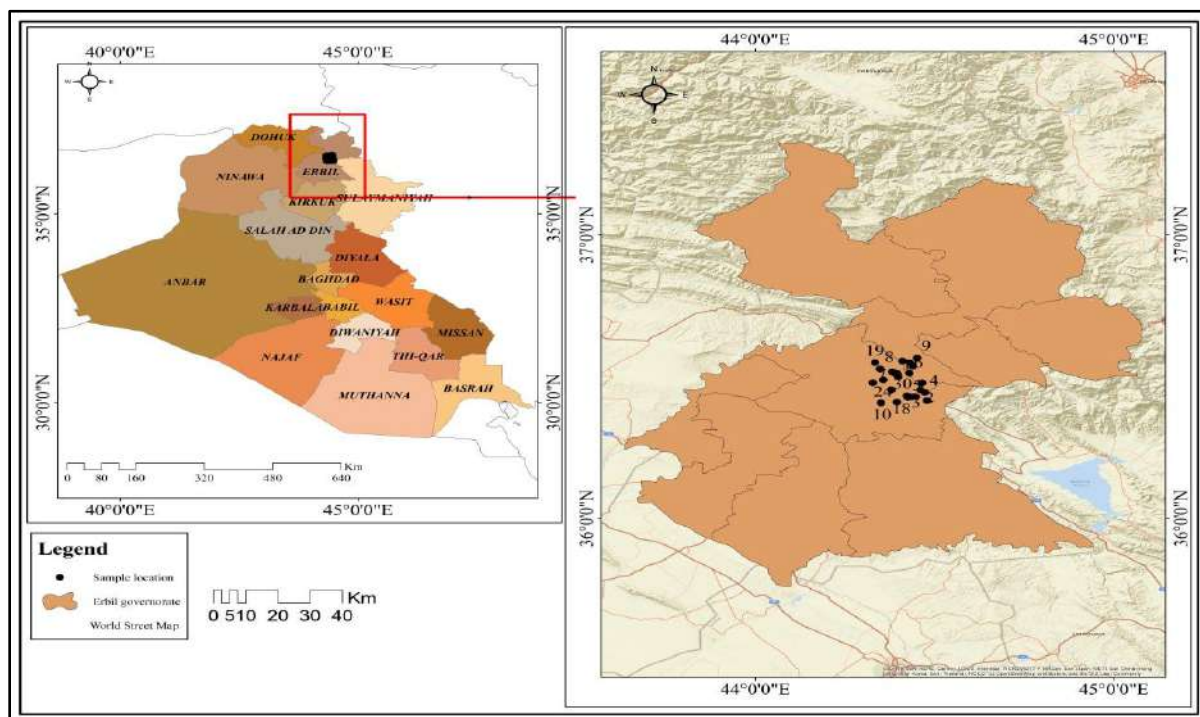


Fig. 1. The cartographic representation of Shaqlawa.

Table 1. Geographical position of the selected locations in Shaqlawa City.

Location site	Sample code	N (decimal)	E (decimal)
Khidr Girls' Dormitory	1	36°24'35.94096	44°18'35.24436
Roz Girls' Dormitory	2	36°24'19.37268	44°18'57.81672
Newly Built Building out of Blocks	3	36°24'11.78928	44°19'38.1126
Lehat Cafe (wooden wall)	4	36°24'15.88788	44°19'56.21232
Crowded Bazaar	5	36°24'9.53208	44°20'33.2358
Clay House	6	36°24'40.37041	44°20'34.51906
Shahidani Azadi Neighborhood	7	36°24'28.17576	44°19'3.95688
Boys' Modern Dormitory	8	36°24'45.8028	44°19'11.32932
Ayub Oil (sandwich panel wall)	9	36°24'59.6754	44°18'54.37044
Hafta Bazaar Market	10	36°25'2.85672	44°18'18.0522
Chicken Seller (PVC wall)	11	36°24'55.70604	44°17'45.63708
Yaran Mosque	12	36°24'53.42616	44°17'53.25828
Zaytuna Restaurant	13	36°24'3.67992	44°19'28.0596
Fire Station	14	36°24'39.70129	44°18'33.17588
Shaqlawa Church	15	36°23'34.10412	44°20'47.31612
Sabirawa Neighborhood	16	36°24'5.80896	44°20'52.34784
Shaqlawa View Residential Community	17	36°24'19.46304	44°20'16.43964
Lolan Residential Community	18	36°24'10.25964	44°19'43.17096
House in Tamtam Neighborhood	19	36°23'59.85132	44°20'0.07152
Dangara Neighborhood	20	36°23'55.2156	44°19'44.04864
Teahouse in Bazaar	21	36°24'10.43928	44°20'40.72992
Bale Market from Shahidani Azadi Neighborhood	22	36°24'40.70582	44°18'32.01395
Barbershop from Azadi Neighborhood	23	36°24'41.03634	44°18'31.30370
Gulan Neighborhood	24	36°24'31.9284	44°18'20.45556
College of Education	25	36°24'41.4515	44°18'30.90452
Shaqlawa Hospital	26	36°24'40.6308	44°18'31.4096
Shaqlawa Hospital next to the X-Ray Room	27	36°24'40.6308	44°18'31.4096
Hawcharkh Market	28	36°24'40.4771	44°18'31.8748
Nut Shops	29	36°24'40.2915	44°18'34.3222
Fantasy Castle	30	36°24'42.01855	44°18'29.29623

2.2. Instrumentation

Geographical coordinates were obtained using a GPS device in order to provide convenient referencing of each selected point for further research purposes. A random selection process was employed to choose residential buildings from each of the eighty local governments within the study area.

The absorbed dose radiation level in each area was determined by employing a portable Geiger-Müller counter equipped with a rate meter, namely, the G.M. survey meter (SOEKS 01M radiation detector – Geiger counter: New version). A large-area pancake-geometry Geiger-Müller tube with a 45-millimeter diameter and mica window make up the Inspector. The device detects alpha and beta particles, as well as electromagnetic radiation like γ -rays and X-rays. The huge display measures the count and dose rates in CPM and mR/hr, respectively.



Fig.2. SOEKS 01M radiation detector (Germany Secondary Standard Dosimetry Laboratory Calibrated G.M. detector).

2.3. Measurements and Calculations

To monitor the absorbed dose rate, measurements were conducted at several locations. A digital Geiger detector was used, positioned 1 meter above the ground surface and away from walls to minimize the influence of radiation emitted from soil or building materials. Each monitoring site was observed for a duration of 2 minutes. Similarly, the outdoor measurements were conducted using the same 30 location points. Each outdoor measurement was conducted at a minimum distance of 6 meters from the walls of adjacent buildings [24]. Two repetitions were conducted for each measurement, and the resulting average was used to represent the value for the specific location point. At each juncture, the associated geographic location was captured and documented using GPS technology [25].

The monitoring panel of the gamma detector displayed the absorbed gamma dose rate (DR) in units of ($\mu\text{Sv/h}$).

The calculation of the annual effective dosage (AED) is determined using the formula provided below [4]:

$$\text{AED}_{\text{Indoor}} = D_{\text{Rin}}(\mu\text{Sv. h}^{-1}) \times \text{OF}(0.8) \times \text{Total time}(8760 \text{ h}^{-1}) \quad (1)$$

$$\text{AED}_{\text{Outdoor}} = D_{\text{Rout}}(\mu\text{Sv. h}^{-1}) \times \text{OF}(0.2) \times \text{Total time}(8760 \text{ h}^{-1}) \quad (2)$$

The public setting has an outdoor occupancy factor (OF) of 0.2 and an indoor OF of 0.8 [26]. The OF refers to the proportion of time an individual allocates to a certain geographic area. The formula provided below is utilized to compute the ELCR factor [10]:

$$\text{ELCR} = \text{AED total} \times \text{DL} \times \text{RF} \quad (3)$$

The variable AED represents the total annual effective dose, whereas DL denotes the duration of life for the general population of Iraqi. In 2015, the World Health Organization published a survey indicating that the mean life expectancy (LE) for individuals in Iraq was 70 years [27]. The risk factor (RF) for deadly cancer associated with exposure to radiation is measured in units per sievert. According to the International Commission on Radiological Protection (ICRP), the RF assigned to low-dose radiation's stochastic effects is determined to be 0.057 for the general population [28].

3. Results and Discussion

Table 2 presents a summary of the average absorbed gamma dose rates, both indoors and outdoors, as well as the AED rates and the ELCR associated with gamma background radiation in 30 locations within Shaqlawa City. Radionuclides found in both indoor and outdoor settings induce these effects. This comparison considers statistics from several works across multiple countries.

Table 2. Indoor and outdoor absorbed gamma dose rates, AED, and ELCR for 30 sample sites.

Sample code	Absorbed gamma dose rate ($\mu\text{Sv} \cdot \text{h}^{-1}$)		Annual effective dose (AED) (mSv/y)		AED total	ELCR $\times 10^{-3}$
	Indoor	Outdoor	AED indoor	AED outdoor		
1	0.09	0.12	0.631	0.21	0.841	2.944
2	0.1	0.11	0.701	0.193	0.894	3.129
3	0.09	0.09	0.631	0.158	0.789	2.762
4	0.11	0.11	0.771	0.193	0.964	3.374
5	0.17	0.19	1.191	0.333	1.524	5.334
6	0.11	0.12	0.771	0.21	0.981	3.434
7	0.13	0.12	0.911	0.21	1.121	3.924
8	0.13	0.15	0.911	0.263	1.174	4.109
9	0.08	0.13	0.561	0.228	0.789	2.762
10	0.13	0.14	0.911	0.245	1.156	4.046
11	0.09	0.11	0.631	0.193	0.824	2.884
12	0.13	0.15	0.911	0.263	1.174	4.109
13	0.11	0.12	0.771	0.21	0.981	3.434
14	0.09	0.1	0.631	0.175	0.806	2.821
15	0.12	0.11	0.841	0.193	1.034	3.619
16	0.15	0.12	1.051	0.21	1.261	4.414
17	0.12	0.08	0.841	0.14	0.981	3.434
18	0.14	0.1	0.981	0.175	1.156	4.046
19	0.13	0.14	0.911	0.245	1.156	4.046
20	0.16	0.11	1.121	0.193	1.314	4.599
21	0.18	0.13	1.261	0.228	1.489	5.212
22	0.15	0.14	1.051	0.245	1.296	4.536
23	0.15	0.08	1.051	0.14	1.191	4.169
24	0.09	0.11	0.631	0.193	0.824	2.884
25	0.09	0.1	0.631	0.175	0.806	2.821
26	0.17	0.1	1.191	0.175	1.366	4.781
27	0.13	0.1	0.911	0.175	1.086	3.801
28	0.1	0.1	0.701	0.175	0.876	3.066
29	0.15	0.12	1.051	0.21	1.261	4.414
30	0.11	0.12	0.771	0.21	0.981	3.434

Table 2 and **Fig.3** present the gamma-absorbed dose rates for indoor and outdoor environments. The indoor gamma-absorbed dose rates were observed to range from 0.08 (Ayub Oil (sandwich panel wall)) to 0.18 (Teahouse in Bazaar) $\mu\text{Sv}\cdot\text{h}^{-1}$, with an average value of 0.123 $\mu\text{Sv}\cdot\text{h}^{-1}$. The average absorbed gamma dose rate in indoor air is twice as high as the global average of 0.084 $\mu\text{Sv}\cdot\text{h}^{-1}$ [10]. The observed outcome, when contrasted with the data provided by UNSCEAR 2000 from various nations, which had an average of 84 nSv within the range of 20–200 nSv $\cdot\text{h}^{-1}$, exhibits a notable increase.

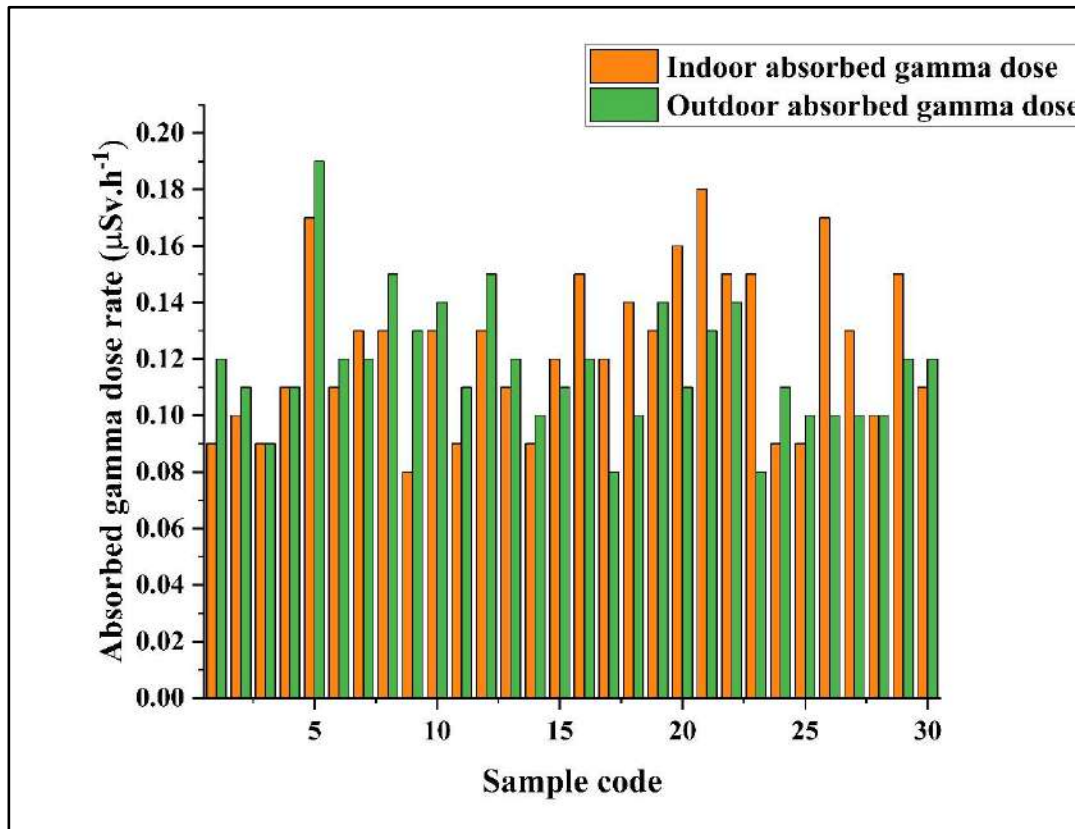


Fig. 3. Indoor and outdoor mean gamma dose rate in selected locations.

In the same way, the study found that the outdoor absorbed gamma dose rate ranged from 0.08 $\mu\text{Sv}\cdot\text{h}^{-1}$ (according to Shaqlawa View Residential Community and the Barbershop from Azadi Neighborhood) to 0.15 $\mu\text{Sv}\cdot\text{h}^{-1}$, with 0.117 $\mu\text{Sv}\cdot\text{h}^{-1}$ being the average. The mean outdoor absorbed gamma dose rate is approximately twice as high as the global average of 0.059 $\mu\text{Sv}\cdot\text{h}^{-1}$.

The current study reveals that numerous geological factors, primarily the quantity of naturally occurring radionuclides in the nearby rocks and soils, influence the natural absorbed gamma dose rates in Shaqlawa City. Radioactive elements are prevalent in the Earth's crust, with their concentrations fluctuating based on the mineral composition of the underlying geology [29]. Regions abundant in uranium- and thorium-bearing minerals generally exhibit elevated gamma dose rates. The research sites, known for their significant natural radioactivity, demonstrated this pattern through their elevated absorbed gamma dose rate. Moreover, the Zhian location (S6) recorded the highest absorbed gamma dose rate in indoor air due to the use of specific construction materials like granite in walls and earth surfaces with poor ventilation. These materials contain elevated concentrations of these radionuclides, leading to increased indoor gamma radiation levels (Othman et al., 2023 [30]). In some areas of this inquiry, ventilation systems and gamma radiation absorption are indirect factors. The current analysis demonstrates that in many places, the increased absorbed dosage rate can be ascribed to poor ventilation, which largely affects indoor air quality by lowering radon gas levels, which are a major source of indoor radiation exposure. Radon decay produces gamma-emitting progeny; therefore, proper ventilation can reduce gamma exposure rates indoors by preventing radon buildup [31, 32].

We observed that the indoor absorbed dose rates exceeded those in the outdoor environment, except for some locations. The elevated absorbed dose rate in indoor environments is mostly due to the use of rocks and construction materials in buildings. These materials typically exhibit high levels of natural radionuclides, such as ^{226}Ra , ^{232}Th , and ^{40}K (Gholami et al., 2011, Rangaswamy et al., 2015). Adding gneissic granites, ceramics, soil, and other decorative stones to walls and floors, along with buildings that do not have sufficient airflow, raises both the concentration of radon and that of its daughter gas. As a result, this phenomenon leads to an increase in the absorbed dosage of gamma radiation [33].

The AED for indoor exposure is shown in Fig.4. It ranges from 0.561 mSv.y^{-1} at the Ayub Oil (sandwich panel wall) location to 1.261 mSv.y^{-1} at the Teahouse in Bazaar location, with 0.864 mSv.y^{-1} being the average. In terms of outdoor exposure, the AED varies between 0.14 mSv/year (at the Shaqlawa View Residential Community and Barbershop from Azadi Neighborhood) and 0.263 mSv.y^{-1} (at the Yaran Mosque), with an average AED of 0.205 mSv.y^{-1} . The study shows that the total average AEDs are higher than the global averages for background radiation. The average AED for outdoor radiation is 0.205 mSv.y^{-1} , and for indoor radiation is 0.864 mSv.y^{-1} , for a total of 1.07 mSv.y^{-1} . The global average AED for normal background radiation is reported as 0.072 mSv (outdoor) and 0.41 mSv.y^{-1} (indoor), with a total average value of 0.48 mSv.y^{-1} [10].

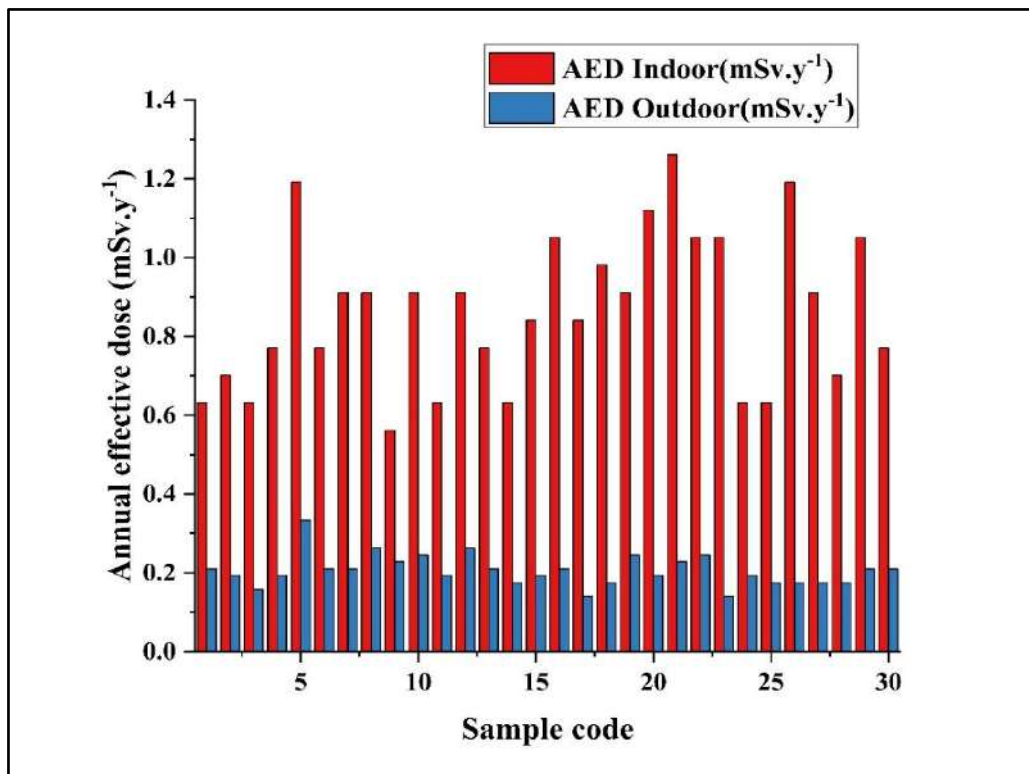


Fig. 4. Indoor and outdoor annual effective dose in selected locations.

The observed average value of 1.07 mSv is higher than the reported values of other countries worldwide. The average AED of ionizing radiation in various regions is as follows: Zanzan, Iran (1.117 mSv.y^{-1}); Malaysia (0.782 mSv.y^{-1}); Karnataka, India (0.75 mSv.y^{-1}); Pakistan (0.92 mSv.y^{-1}); and Abuja, Nigeria (0.914 mSv.y^{-1}) [4, 6, 34-36].

The lifetime cancer risks were computed based on the AED values, and the results are presented in Table 1 and Fig. 5. This was done so that the radiological risk could be evaluated. The lifetime risk of cancer in all of the residential dwellings ranges from 2.762×10^{-3} to 5.212×10^{-3} , with an average value of 3.74×10^{-3} . Notably, these values are greater than the global average of ELCR, which is 0.29×10^{-3} [10]. However, this needs further investigation for confirmation. One may draw the conclusion that a lifetime in such an environment significantly increases the likelihood of developing cancer.

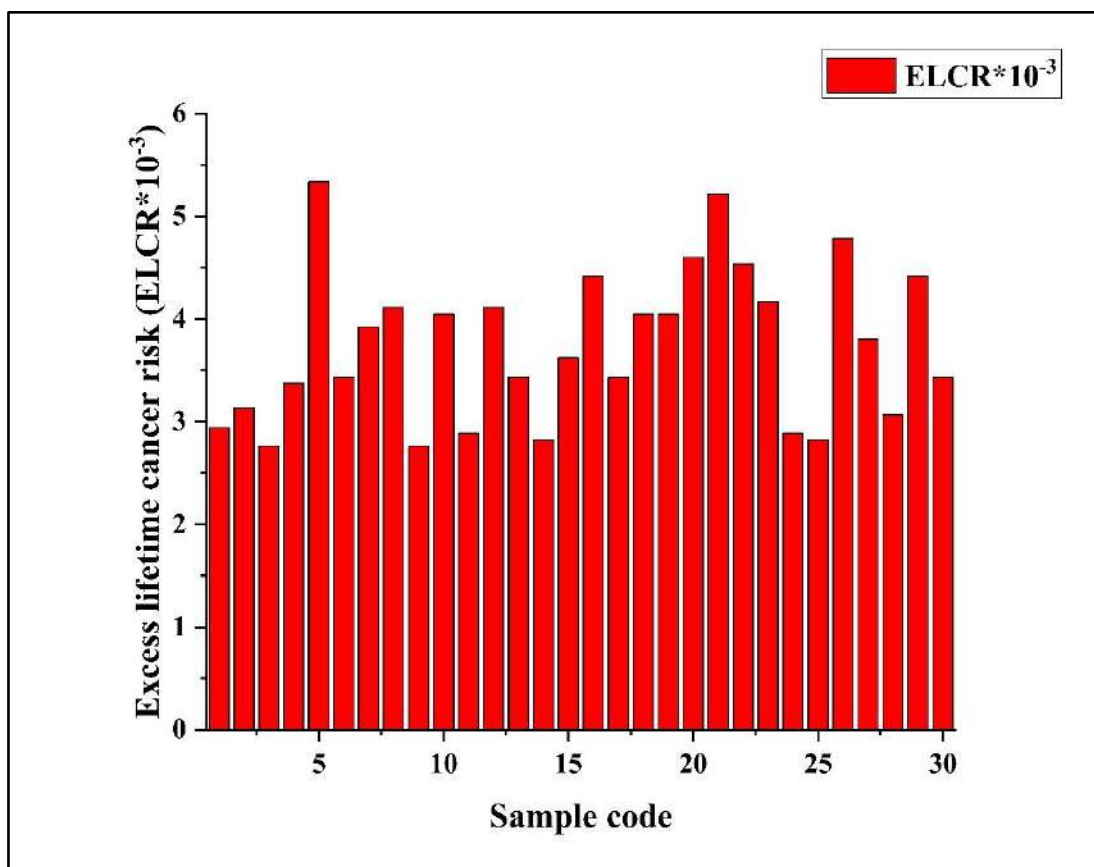


Fig. 5. Estimated lifetime cancer risk at selected locations.

Conclusions

The current investigation quantified the natural indoor and outdoor background gamma radiation levels in residential locations across Shaqlawa City. The results indicated that the measured absorbed dose rates, AEDs, and excess lifetime cancer risk are higher than the global average values, signifying a potential radiological health concern for the local inhabitants. This study delivers significant baseline data for the region and highlights the necessity for continuous environmental radiation monitoring. Further investigations, including the radionuclide evaluation of soils, building materials, and indoor radon concentration, are suggested to better identify the sources of elevated exposure.

Recommendations

1. Management and radiation monitoring must consistently evaluate concentrations to ensure permissible radiation levels.
2. This study establishes a baseline for monitoring natural background radiation in Erbil City and advocates for a thorough survey to record health concerns, infertility, and congenital anomalies. If linked, it may propose compensation for impacted individuals under 'radiation victims' assistance programs.

References

- [1] Amatullah S., et al., Assessment of radiometric standard and potential health risks from building materials used in Bangladeshi dwellings, *International Journal of Environmental Analytical Chemistry*, 103 (2023) 3376–3388.
- [2] Othman S.Q., Ahmed A.H., Mohammed S.I., Radiological assessment of radon concentration, radon exhalation rate, and annual effective dose of building materials used in Erbil city Kurdistan region, Iraq, *International Journal of Environmental Analytical Chemistry*, (2022) 1–15.
- [3] Namq B.F., et al., Assessing environmental pollution and excess lifetime cancer risk via gamma dose monitoring in Rayhaniya, Iraq, *Nexus of Advanced Environmental Research*, 1 (2025) 592539.
- [4] Saghatchi F., Salouti M., Eslami A., Assessment of annual effective dose due to natural gamma radiation in Zanjan (Iran), *Radiation Protection Dosimetry*, 132 (2008) 346–349.
- [5] Othman S.Q., Ahmed A.H., Mohammed S.I., Natural radioactivity and radiological risk assessment due to building materials commonly used in Erbil city, Kurdistan region, Iraq, *Environmental Monitoring and Assessment*, 195 (2023) 140.
- [6] James I., et al., Assessment of indoor and outdoor radiation levels and human health risk in sheda science and technology complex and its environ, Abuja, Nigeria, *Journal of Applied Sciences and Environmental Management*, 24 (2020) 13–18.
- [7] Olarinoye I., et al., Measurement of background gamma radiation levels at two tertiary institutions in Minna, Nigeria, *Journal of Applied Sciences and Environmental Management*, 14 (2010).
- [8] Alharbi T., Establishment of natural radioactivity baseline, mapping, and radiological hazard assessment in soils of Al-Qassim, Al-Ghat, Al-Zulfi, and Al-Majmaah, *Arabian Journal of Geosciences*, 13 (2020) 415.
- [9] Yigitoglu I., et al., Determination of natural radioactivity levels in soil and travertine of the region of Tokat and Sivas, Turkey, *Arabian Journal of Geosciences*, 11 (2018) 1–7.
- [10] UNSCEAR, Sources and effects of ionizing radiation: Exposures from natural radiation sources, Annex B, United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations Publication, New York, USA (2000).
- [11] Khader R.B., Measure the background radiation in some parts of Nineveh Province, *Rafidain Journal of Science*, 21 (2010).
- [12] Al-Mayahi B., Exposure rate measurements of the natural background radiation in some Najaf regions, *Journal of Al-Qadisiyah for Pure Science*, 15 (2010) 1–8.
- [13] Alasadi A.H., et al., Survey of absorbed dose rates in air of buildings agriculture and sciences in University of Kufa at Al-Najaf Governorate, Iraq, *Journal of Chemical and Pharmaceutical Research*, 8 (2016) 1388–1392.
- [14] Haider Al-Taweel M., Alasadi L.A., Measurement of gamma radiation dose for selected samples of Kufa University at Al-Najaf Governorate, Iraq, 2nd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), IEEE (2018).
- [15] Abdulkareem N.K., et al., Distribution of radiation in Erbil city, *Diyala Journal of Medicine*, 8 (2015) 28–31.
- [16] Mohammed M.K., et al., Monitoring the environmental radiation levels for some regions in Iraq, *Journal of the College of Basic Education*, 20 (2014) 1065–1072.
- [17] Othman S.Q., Ahmed A.H., Mohammed S.I., Assessment of ^{222}Rn , ^{226}Ra , ^{238}U , ^{218}Po , and ^{214}Po activity concentrations in the blood samples of workers at selected building material factories in Erbil City, *Environmental Monitoring and Assessment*, 195 (2023) 673.
- [18] Awla H.R., et al., Evaluation of natural radioactivity and radiological risk indices in dust storm samples across Erbil City, Iraq, *Environmental Forensics*, (2025) 1–14.
- [19] Wais T.Y., et al., Investigation of natural radionuclide transfer from soil to wheat, *Scientific Reports*, 15 (2025) 35785.
- [20] Zakariya N.I., Kahn M., Benefits and biological effects of ionizing radiation, *Scholars Academic Journal of Biosciences*, 2 (2014) 583–591.
- [21] Othman S.Q., Ahmed A.H., Mohammed S.I., Environmental health risks of radon exposure inside selected building factories in Erbil city, Iraq, *International Journal of Environmental Analytical Chemistry*, (2022) 1–15.
- [22] Abduljaleel Z.A., Taha B.O., Review of seismic characteristics in Erbil city, the capital of the Kurdistan Region of Iraq, *Polytechnic Journal*, 9 (2019) 27.
- [23] Ofomola O.M., Ugbede F.O., Anomohanran O., Environmental risk assessment of background radiation, natural radioactivity and toxic elements in rocks and soils of Nkalagu quarry, Southeastern Nigeria, *Journal of Hazardous Materials Advances*, 10 (2023) 100288.

- [24] Othman S.Q., Husen K.H., Ahmed A.H., Assessment of annual effective dose and excess lifetime cancer risk due to natural gamma radiation in selected residential buildings in Erbil City, Iraq, *International Journal of Nuclear Energy Science and Technology*, 18 (2025) 23–40.
- [25] Oladele B., Arogunjo A., Aladeniyi K., Indoor and outdoor gamma radiation exposure levels in selected residential buildings across Ondo state, Nigeria, *International Journal of Radiation Research*, 16 (2018) 363–370.
- [26] Thomas J.R., et al., Outdoor and indoor natural background gamma radiation across Kerala, India, *Environmental Science: Atmospheres*, 2 (2022) 65–72.
- [27] WHO, Islamic Republic of Iran health profile 2015, World Health Organization Regional Office for the Eastern Mediterranean (2016).
- [28] ICRP, ICRP statement on radon, International Commission on Radiological Protection, Pergamon Press, Oxford (2009).
- [29] Hussein Z.A., Assessment of natural radioactivity levels and radiation hazards for soil samples used in Erbil governorate, Iraqi Kurdistan, ARO – The Scientific Journal of Koya University, 7 (2019) 34–39.
- [30] Othman S.Q., et al., Radiological impact of primordial radionuclides and radon rates in rock-based building materials: Kurdistan region of Iraq, *Environmental Earth Sciences*, 84 (2025) 1–21.
- [31] Mäkeläinen I., Arvela H., Voutilainen A., Correlations between radon concentration and indoor gamma dose rate, soil permeability and dwelling substructure and ventilation, *Science of the Total Environment*, 272 (2001) 283–289.
- [32] Abdulkhaleq Asaad H., Ahmed A.H., Radiological assessment of radon concentration in cooking plates available in Erbil city, Kurdistan Region of Iraq, *International Journal of Environmental Health Research*, (2025) 1–13.
- [33] Asaad H.A., Ahmed A.H., Natural radioactivity and radiological risk assessment in household meal dishes available in Erbil city, Kurdistan Region Iraq, *Applied Radiation and Isotopes*, (2025) 111948.
- [34] Abdullahi S., Ismail A.F., Samat S., Determination of indoor doses and excess lifetime cancer risks caused by building materials containing natural radionuclides in Malaysia, *Nuclear Engineering and Technology*, 51 (2019) 325–336.
- [35] Shashikumar T., et al., Estimation of indoor and outdoor effective doses and lifetime cancer risk from gamma dose rates in and around Mandya District, Karnataka, *Radiation Protection Dosimetry*, 198 (2022) 1540–1545.
- [36] Qureshi A.A., et al., Evaluation of excessive lifetime cancer risk due to natural radioactivity in the rivers sediments of Northern Pakistan, *Journal of Radiation Research and Applied Sciences*, 7 (2014) 438–447.