Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Assessment of Excess Lifetime Cancer Risk from Environmental Gamma Radiation in Ulaanbaatar City, Mongolia

Erdev Batjargal

erdevb@gmail.com

Mongolian University of Science and Technology

Enkhmaa Battogtvor

National University of Mongolia

Batmunkh Sereeter

Mongolian University of Science and Technology

Battogtokh Zagd

Mongolian University of Science and Technology

Research Article

Keywords: environmental gamma radiation, absorbed dose rate, annual effective dose, excess lifetime cancer risk (ELCR), Monte Carlo simulation

Posted Date: August 3rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9963384/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Assessment of Excess Lifetime Cancer Risk from Environmental Gamma Radiation in Ulaanbaatar City, Mongolia

B. Erdev[a]*, B.Enkhmaa[b], S. Batmunkh[a], Z. Battogtokh[a]

[a]*Institute of Thermal Engineering and Industrial Ecology, Mongolian University of Science and Technology, Ulaanbaatar, Mongolia*
[b]*School of Art and Science, National University of Mongolia, Ulaanbaatar, Mongolia*

**Corresponding author: Erdev Batjargal: erdevb@gmail.com*
Enkhmaa Battogtvor: enkhmaab@num.edu.mn
Batmunkh Sereeter: batmunkh_acad@yahoo.com
Battogtokh Zagd: battogtokh@must.edu.mn

Funding: *This research received no external funding.*

Abstract

This study assessed the excess lifetime cancer risk (ELCR) associated with environmental gamma radiation exposure among residents in densely populated areas of Ulaanbaatar city. Soil samples collected in 2025 from selected locations based on a 1-km grid sampling scheme were analyzed at the accredited gamma spectrometry laboratory of the Institute of Nuclear Science and Technology, National University of Mongolia. Based on the measurement results, the annual effective dose (E_{out}) and ELCR were calculated. Statistical analysis based on the Monte Carlo simulation method was conducted to evaluate the distribution characteristics of ELCR and its 95% confidence interval. The results showed that the mean ELCR in 2025 was estimated at $(0.261 \pm 0.035)\times10^{-3}$. This value was lower than the internationally accepted reference level of 0.290×10^{-3}, indicating a relatively low environmental gamma radiation risk in Ulaanbaatar City. The results provide updated baseline information for environmental radiation monitoring and future radiological risk assessment in Ulaanbaatar City.

Keywords: environmental gamma radiation, absorbed dose rate, annual effective dose, excess lifetime cancer risk (ELCR), Monte Carlo simulation

1. Introduction

Exposure to ionizing radiation is one of the important environmental factors that may affect human health over the long term. Natural radionuclides present in soil, rocks, water, and air continuously contribute to background radiation exposure. Although natural radiation is generally low, prolonged exposure may increase the probability of stochastic health effects, particularly cancer incidence. Therefore, the assessment of radiological risk associated with environmental gamma radiation has become an important component of environmental monitoring and public health protection [1,3].
Naturally occurring radionuclides, particularly ^{226}Ra, ^{232}Th, and ^{40}K, are the primary contributors to terrestrial gamma radiation. The concentrations of these radionuclides vary depending on geological and geochemical conditions, resulting in spatial variations in external radiation exposure. Consequently, the

evaluation of radiation dose and associated health risks is necessary to determine whether environmental radiation levels remain within internationally accepted limits.

The excess lifetime cancer risk (ELCR) is widely used as an indicator of the potential health impact of ionizing radiation exposure. ELCR estimates the probability of developing cancer over a lifetime as a result of exposure to radiation and is commonly calculated using the annual effective dose, average lifespan, and risk coefficients recommended by international radiation protection organizations [1,3,5]. This indicator provides a practical basis for comparing radiological risks among different regions and populations [1,3].

Ulaanbaatar, the capital city of Mongolia, is home to more than half of the country's population and is characterized by diverse geological formations and rapidly expanding urban development. Although several studies have investigated natural radioactivity levels in Mongolian soils, comprehensive assessments of environmental gamma radiation risk in densely populated areas of Ulaanbaatar remain limited [6,7]. Furthermore, the uncertainty associated with radiological risk estimates has rarely been evaluated using probabilistic approaches.

Therefore, the present study aims to assess the ELCR associated with environmental gamma radiation in Ulaanbaatar City using soil samples collected from 180 locations based on a 1-km grid sampling scheme. Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were determined using high-purity germanium (HPGe) gamma spectrometry [2,4]. Annual effective dose and ELCR values were calculated, and Monte Carlo simulation was applied to evaluate uncertainty propagation and 95% confidence intervals. The results provide updated baseline information for environmental radiation monitoring and radiological risk assessment in Ulaanbaatar City.

2. Materials and Methods

2.1 Study Area and Sampling Design

The study was conducted in Ulaanbaatar City, Mongolia, the country's largest urban center and the residence of more than half of the national population. To evaluate environmental gamma radiation exposure in densely populated areas, a systematic sampling strategy was adopted using a 1-km grid network covering the major urban districts of the city. The spatial distribution of the sampling locations is shown in Figure 1.

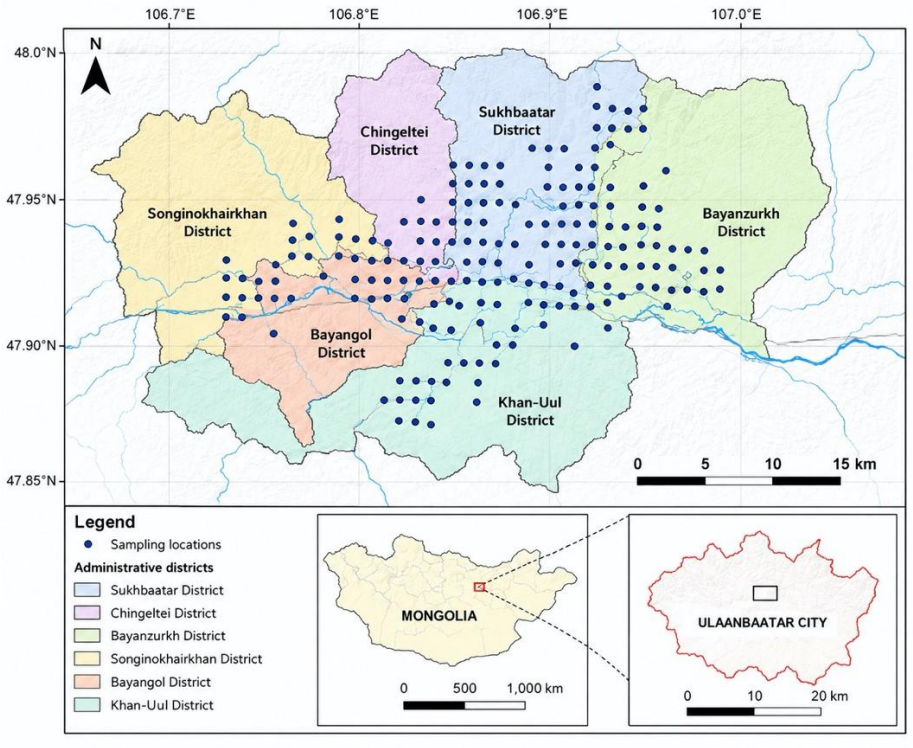


Figure 1. Spatial distribution of the 180 soil sampling locations used for environmental gamma radiation assessment in Ulaanbaatar City, Mongolia

A total of 180 soil samples were collected in 2025 from predetermined sampling locations. Geographic coordinates of all sampling points were recorded using a Global Positioning System (GPS) device. The sampling locations were selected to provide representative spatial coverage of the study area and to facilitate subsequent spatial analysis of radiological risk.

2.2 Gamma Spectrometric Analysis

The activity concentrations of naturally occurring radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in soil samples were determined using a HPGe gamma spectrometry system at the accredited Gamma Spectrometry Laboratory of the Institute of Nuclear Science and Technology, National University of Mongolia.

Sample preparation and measurements were performed following the requirements of MNS 5626:2006 and ISO 18589-3:2023 [2,4]. The measured radionuclides were selected because they are the principal contributors to terrestrial gamma radiation. Activity concentrations were expressed in Bq kg^{-1}.

2.3 Calculation of Absorbed Dose Rate

The absorbed gamma dose rate in outdoor air (D_{out}, nGy h^{-1}) was calculated from the measured activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K using the conversion coefficients recommended by UNSCEAR [1]:

$$D_{out} = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_{K}$$

where A_{Ra}, A_{Th}, and A_K represent the activity concentrations in Bq kg^{-1} of ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

2.4 Annual Effective Dose

The outdoor annual effective dose (E_{out}, mSv y^{-1}) was estimated from the absorbed dose rate using:

$$E_{out} = 1.4 \times 10^{-3} \times D_{out}$$

where E_{out} is the outdoor annual effective dose (mSv y^{-1}), and D_{out} is the outdoor absorbed dose rate in air (nGy h^{-1}). In this equation, the outdoor occupancy factor (OF) was taken as 0.23. This value was determined based on the behavioral patterns of Ulaanbaatar residents in the study area, considering that soil samples were collected during the warm seasons and taking into account other relevant local conditions. The dose conversion coefficient (CF) was assumed to be 0.7 Sv Gy^{-1}, and the annual exposure time was taken as 8760 hours per year [1].

2.5 Excess Lifetime Cancer Risk (ELCR)

The ELCR was used to estimate the probability of developing cancer over a lifetime due to exposure to environmental gamma radiation. ELCR was calculated as:

$$ELCR = E_{out} \times DL \times RF$$

where E_{out} is the annual effective dose (Sv y^{-1}), DL is the average lifespan 70 years, and RF is the fatal cancer risk coefficient recommended by the International Commission on Radiological Protection (ICRP) [3]. For the general population, a risk coefficient of 0.05 Sv^{-1} was adopted. Additional risk coefficients were applied for specific demographic groups, including adult males (0.04 Sv^{-1}), adult females (0.06 Sv^{-1}), children aged 0–10 years (0.08-0.10 Sv^{-1}), and elderly individuals over 60 years of age (0.02-0.03 Sv^{-1}) [3].

2.6 Monte Carlo Uncertainty Analysis

Monte Carlo simulation was employed to evaluate the propagation of measurement uncertainty and its influence on radiological risk estimates. Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were treated as normally distributed input variables. A total of 10,000 random iterations were generated using the measured means and standard deviations [8-10].

For each iteration, absorbed dose rate, annual effective dose, and ELCR values were recalculated. The resulting probability distributions were used to determine mean values, standard deviations, median values, 95% confidence intervals, relative standard uncertainty, and expanded uncertainty [8-10].

The relative standard uncertainty (u_r, %) was calculated as:

$$u_r(\%) = \frac{u(x)}{x} \times 100$$

where $u(x)$ is the standard uncertainty and $u(x)$ is the mean value of the simulated distribution.

Expanded uncertainty (U) at the 95% confidence level was determined as:

$$U = k \times u(x)$$

where k = 1.96 is the coverage factor corresponding to a 95% confidence level.
The 95% confidence interval of the mean was calculated using:

$$95\%\ CI = x \pm 1.96 \times \frac{SD}{\sqrt{n}}$$

where x is the sample mean, SD is the standard deviation, and n is the number of measurements (n = 180).

3. Results and Discussion

3.1 Activity Concentrations of Natural Radionuclides

The activity concentrations of naturally occurring radionuclides measured in soil samples collected from Ulaanbaatar City are presented in Table 1. The mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were 28.3 ± 11.3, 19.0 ± 3.6, and 682.5 ± 93.7 Bq kg^{-1}, respectively. The corresponding ranges were 16-93 Bq kg^{-1} for ^{226}Ra, 12–37 Bq kg^{-1} for ^{232}Th, and 437-1056 Bq kg^{-1} for ^{40}K.

Table 1. Activity concentrations of natural radionuclides and radiological parameters in soil samples collected from Ulaanbaatar City compared with worldwide average values.

Parameter	*Ulaanbaatar Mean ±SD*	*Worldwide average*	*Ulaanbaatar (2025) Range*	*Worldwide range*	*Ulaanbaatar (2025) Median*
^{226}Ra, Bq kg^{-1}	28.3 ± 11.3	35	16-93	10-200	26
^{232}Th, Bq kg^{-1}	19.0 ± 3.6	30	12-37	7-50	19
^{40}K, Bq kg^{-1}	682.5 ± 93.7	400	437-1056	100-700	675
D_{out}, nGy h^{-1}	52.974 ± 7.090	59	41.5-84.9	18-93	52
E_{out}, mSv y^{-1}	0.075 ± 0.010	0.07	0.061-0.142	0.02-0.11	0.074
ELCR (×10^{-3})	0.261 ± 0.035	0.290	0.202-0.481	0.08-0.40	0.257

The measured activity concentrations of ^{226}Ra and ^{232}Th were lower than the worldwide average values reported by UNSCEAR [1], whereas ^{40}K exhibited relatively higher concentrations. The elevated ^{40}K activity concentration may be attributed to the geological and mineralogical characteristics of the study area. Overall, the measured radionuclide concentrations were comparable to natural background levels reported worldwide.

3.2 Absorbed Dose Rate and Annual Effective Dose

The absorbed gamma dose rate in outdoor air was calculated from the measured radionuclide activity concentrations using UNSCEAR conversion coefficients. The mean absorbed dose rate was 52.974 ± 7.090 nGy h^{-1}, with values ranging from 41.5 to 84.9 nGyh^{-1}. This value is comparable to the worldwide average value of 59 nGy h^{-1} reported by UNSCEAR and ICRP [1,3].
The annual effective dose was estimated to be 0.075 ± 0.010 mSv y^{-1}, ranging from 0.061 to 0.142 mSv y^{-1}. These results indicate that external exposure to environmental gamma radiation in Ulaanbaatar City

remains within the range generally associated with natural background radiation and does not represent a significant radiological concern for the general population.

3.3 Excess Lifetime Cancer Risk (ELCR)

The ELCR was calculated using the annual effective dose, an average lifespan of 70 years, and the cancer risk coefficient recommended by the ICRP [3]. The mean ELCR was estimated at $(0.261 \pm 0.035) \times 10^{-3}$, with values ranging from 0.202×10^{-3} to 0.481×10^{-3}. The calculated ELCR values for the general population are presented in Figure 2.

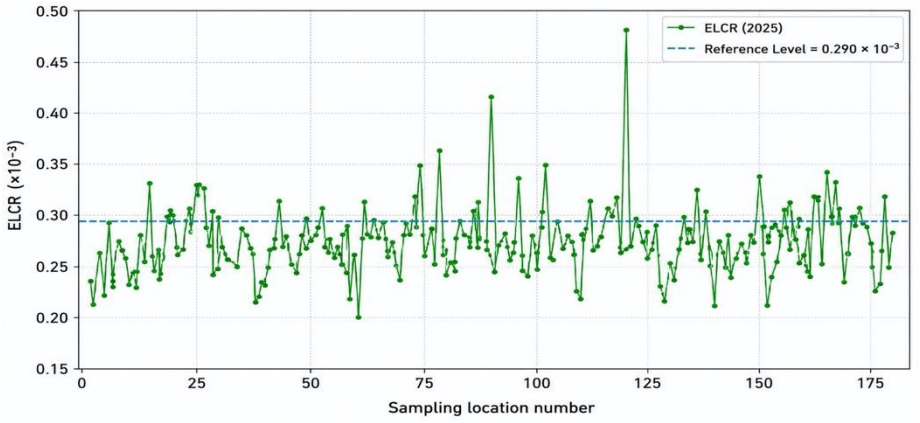


Figure 2. ELCR values at individual sampling locations compared with the internationally accepted reference level (0.29×10^{-3}).

Comparison with the internationally accepted reference level of 0.290×10^{-3} showed that most sampling locations exhibited ELCR values below the reference threshold. However, a limited number of locations approached or slightly exceeded this level, indicating localized areas with relatively elevated radiological risk. Continued monitoring of these locations is therefore recommended.

The ELCR values obtained in this study were substantially lower than those reported for the Narangiin Enger waste disposal area in Ulaanbaatar, where ELCR values ranged between 0.8×10^{-3} and 1.3×10^{-3} [7]. This comparison suggests that the investigated urban areas are characterized by relatively low radiological risk.

3.4 Age- and Gender-Dependent Risk Assessment

Age- and gender-specific ELCR values were estimated using demographic risk coefficients recommended by ICRP [3]. The mean ELCR values were 0.208×10^{-3} for adult males, 0.313×10^{-3} for adult females, 0.130×10^{-3} for elderly individuals, and 0.469×10^{-3} for children. Age- and gender-dependent ELCR statistics are summarized in Table 2 and illustrated in Figure 3.

Table 2. Descriptive statistics of age- and gender-dependent ELCR values

Statistics	*2025*			
	Male	Female	Elderly	Children
Sample number	180	180	180	180
Mean ($\times 10^{-3}$)	0.208	0.313	0.130	0.469
Median ($\times 10^{-3}$)	0.205	0.308	0.128	0.462

SD ($\times 10^{-3}$)	0.027	0.040	0.017	0.060
Min ($\times 10^{-3}$)	0.163	0.244	0.102	0.366
Max ($\times 10^{-3}$)	0.380	0.570	0.238	0.855

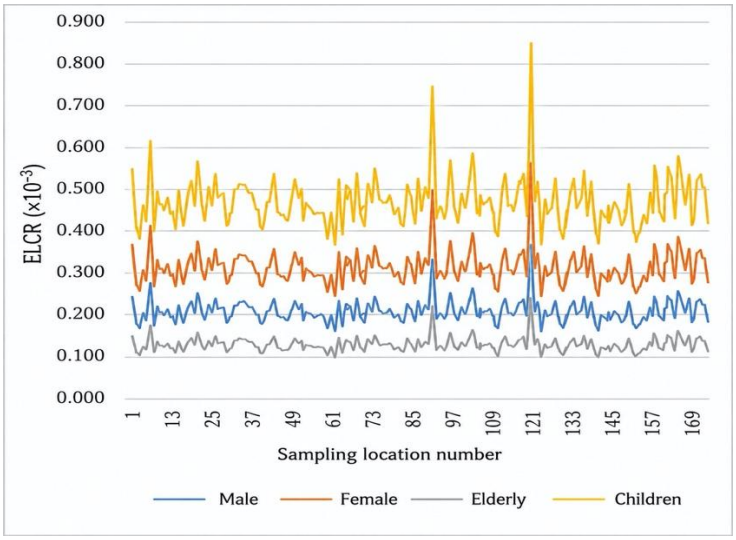


Figure 3. Comparison of ELCR values among age and gender groups based on demographic-specific risk coefficients.

Children exhibited the highest ELCR values among all demographic groups, whereas the elderly population showed the lowest values. Similarly, ELCR values for females were consistently higher than those for males across all sampling locations. These differences reflect variations in age- and gender-dependent radiation risk coefficients and indicate greater susceptibility of children and females to long-term radiation exposure.

The results emphasize the importance of incorporating demographic characteristics into radiological risk assessments and environmental health protection strategies.

3.5 Monte Carlo Uncertainty Analysis

Monte Carlo simulation was performed to evaluate the uncertainty associated with the radiological risk assessment. Using 10,000 iterations, probability distributions of absorbed dose rate, annual effective dose, and ELCR were generated from the measured activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K [8-10].

The simulation results showed that the mean absorbed dose rate, annual effective dose, and ELCR were 52.974 nGy h^{-1}, 0.075 mSv y^{-1}, and 0.261 × 10^{-3}, respectively. The 95% confidence interval of the mean ELCR was estimated to range from 0.256 × 10^{-3} to 0.265 × 10^{-3}. The median ELCR value (0.257 × 10^{-3}) was very close to the mean value, indicating a nearly symmetric distribution with no substantial skewness. The probability distribution of ELCR obtained from the Monte Carlo simulation is presented in Fig. 4. The histogram shows the mean value, median value, 95% confidence interval, and the internationally accepted reference level.

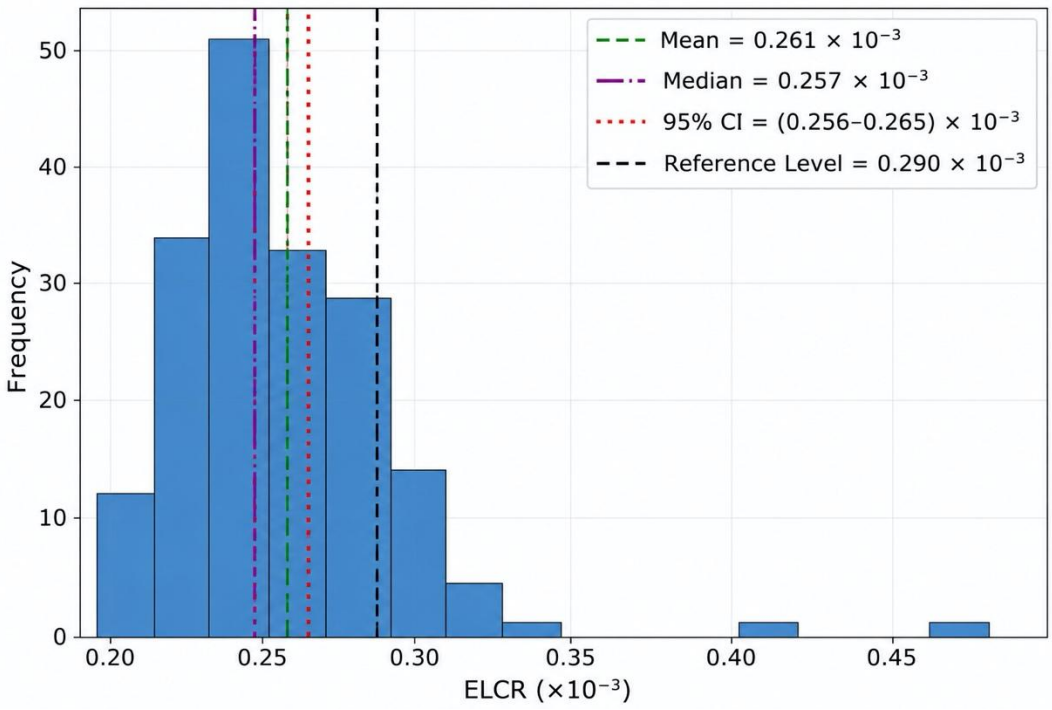


Figure 4. Probability distribution histogram of ELCR obtained from Monte Carlo simulation, showing the mean value, median value, 95% confidence interval, and internationally accepted reference level.

The relative standard uncertainty of ELCR was estimated at 6.4%, while the expanded uncertainty at the 95% confidence level (k = 1.96) was 12.5%. These results indicate that the uncertainty associated with the radiological risk assessment is within an acceptable range and that the estimated ELCR values are statistically reliable [8,9]. The Monte Carlo simulation results and the corresponding 95% confidence intervals for the radiological parameters are summarized in Table 3.

Table 3. Monte Carlo simulation results and 95% confidence intervals for radiological parameters

Parameter	D_{out}, nGy h^{-1}	E_{out}, mSv y^{-1}	ELCR ($\times 10^{-3}$)
Mean	52.974	0.075	0.261
SD	7.090	0.010	0.035
Median	52.133	0.074	0.257
Lower 95% CI (coverage interval)	42.315	0.060	0.209
Upper 95% CI(coverage interval)	66.171	0.093	0.327

The probability distribution of ELCR further demonstrated that most simulated values were concentrated below the internationally accepted reference level of 0.290×10^{-3}. Although a small proportion of locations exhibited elevated values, the overall radiological risk remained within the range generally considered acceptable for natural background radiation environments.

3.6 Spatial Distribution of ELCR

The spatial distribution of ELCR across Ulaanbaatar City is presented in Figure 5. Spatial interpolation of the calculated ELCR values revealed a heterogeneous distribution of radiological risk throughout the study area. Areas with relatively elevated ELCR values were observed at several isolated locations, whereas most sampling sites exhibited values within the internationally accepted reference range.

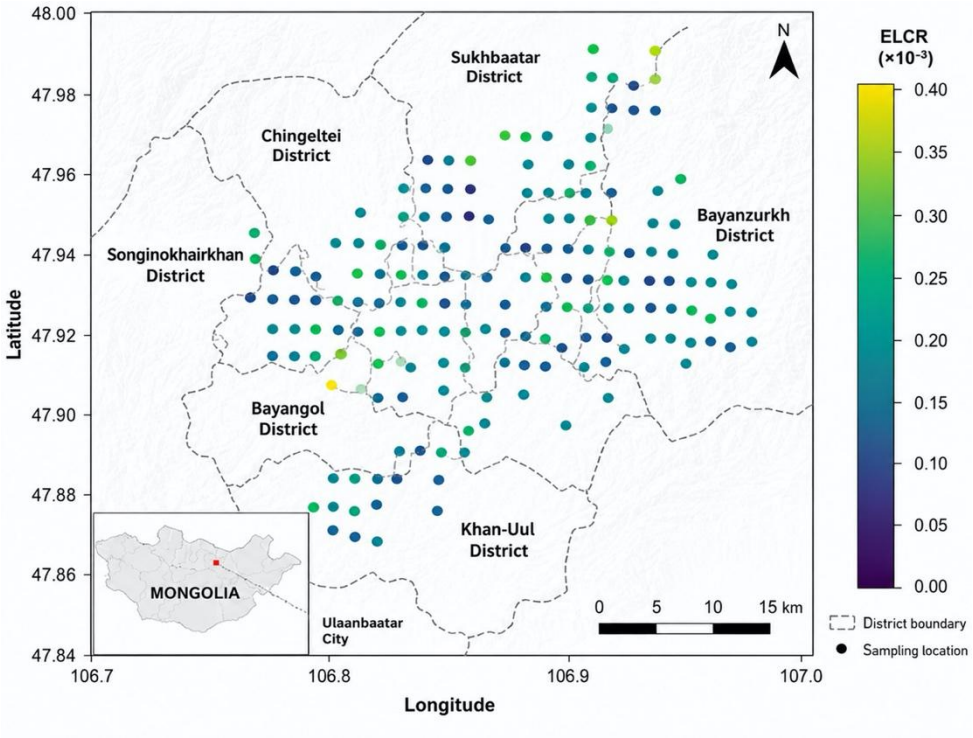


Figure 5. Spatial distribution of Excess Lifetime Cancer Risk (ELCR) in Ulaanbaatar City based on 180 soil sampling locations.

The observed spatial variability is likely associated with differences in geological composition, soil characteristics, and the distribution of naturally occurring radionuclides. Despite these local variations, the majority of the study area was characterized by low to moderate radiological risk.

The integration of radiological measurements with geographic information systems (GIS) provides an effective approach for identifying areas that may require additional environmental monitoring. Such spatial information is valuable for environmental management, radiation protection planning, and public health decision-making.

Overall, the spatial analysis confirms that environmental gamma radiation levels in Ulaanbaatar City are generally low, although several localized hotspots may warrant further investigation and periodic monitoring.

4. Conclusions

This study evaluated the radiological risk associated with environmental gamma radiation in Ulaanbaatar City, Mongolia, using activity concentrations of naturally occurring radionuclides measured in 180 soil

samples collected in 2025. The absorbed dose rate, annual effective dose, and ELCR were calculated, and uncertainty analysis was performed using Monte Carlo simulation.

The mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were generally comparable to worldwide natural background levels, although ^{40}K exhibited relatively elevated concentrations. The calculated mean absorbed dose rate and annual effective dose were 52.974 ± 7.090 nGy h^{-1} and 0.075 ± 0.010 mSv y^{-1}, respectively, indicating that environmental gamma radiation levels in Ulaanbaatar City remain within the range of natural background radiation.

The mean ELCR was estimated at $(0.261 \pm 0.035) \times 10^{-3}$, which is below the internationally accepted reference level of 0.290×10^{-3}. Although a limited number of locations exhibited relatively elevated ELCR values, the majority of sampling sites were characterized by low radiological risk.

Age- and gender-dependent risk assessment demonstrated that children and females exhibited higher ELCR values than elderly individuals and males, highlighting the importance of considering demographic characteristics in radiological risk evaluations.

Monte Carlo simulation indicated a relative standard uncertainty of 6.4% and an expanded uncertainty of 12.5%, confirming the reliability of the calculated risk estimates. Spatial analysis further revealed that environmental gamma radiation is not uniformly distributed throughout the city, although most areas remain within acceptable radiological safety limits.

Overall, the results suggest that environmental gamma radiation in Ulaanbaatar City does not pose a significant radiological health risk to the general population under current conditions. The findings provide updated baseline information for future environmental radiation monitoring, radiological risk assessment, and environmental health management in Mongolia.

5. References

[1] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). (2000). *Sources and effects of ionizing radiation*. Report to the General Assembly, with scientific annexes. United Nations, New York, USA.

[2] MNS 5626:2006. (2006). *Radiation protection: Laboratory gamma spectrometry method*. Mongolian Agency for Standardization and Metrology, Ulaanbaatar, Mongolia.

[3] International Commission on Radiological Protection (ICRP). (2007). *The 2007 Recommendations of the International Commission on Radiological Protection*. ICRP Publication 103. *Annals of the ICRP*, 37(2–4).

[4] ISO 18589-3:2023. (2023). *Measurement of radioactivity in the environment—Soil—Part 3: Gamma spectrometry for the determination of radionuclides*. International Organization for Standardization (ISO), Geneva, Switzerland.

[5] Nuclear Energy Commission of Mongolia. (2015). *Radiation Safety Standards*. Ulaanbaatar, Mongolia.

[6] Batmunkh, S., Battogtokh, Z., & Erdev, B. (2025). An investigation of soil radiation levels in the territory of Ulaanbaatar City. *Energy Systems Research*, 8(4). doi:10.25729/esr.2025.04.0004

[7] Dorjsuren, B., et al. (2022). Radioactive levels and human health effects in a dumpsite in Ulaanbaatar City, Mongolia. *Journal of Hazardous, Toxic, and Radioactive Waste*, 26(4).

[8] Gallardo, S., et al. (2015). Uncertainty analysis in environmental radioactivity measurements using the Monte Carlo code MCNP5. *Applied Radiation and Isotopes*, 105, 35–41.

[9] JCGM 101:2008. (2008). *Evaluation of measurement data—Supplement 1 to the Guide to the Expression of Uncertainty in Measurement—Propagation of distributions using a Monte Carlo method*. Joint Committee for Guides in Metrology (JCGM).

[10] Taylor, J. R. (1997). *An introduction to error analysis: The study of uncertainties in physical measurements* (2nd ed.). University Science Books, California, USA.