

An Investigation of Soil Radiation Levels in the Territory of Ulaanbaatar City

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Abstract — This study focuses on the gamma spectrometry analysis of soil samples collected from 180 locations across every kilometer in the densely populated areas of Ulaanbaatar city to determine the activity concentrations of natural radioactive isotopes, including radium-226, thorium-232, potassium-40, and the man-made radioactive isotope cesium-137. Following the analysis, the radium equivalent activity was calculated, and the equivalent dose rate of the soil was measured with a dosimeter at the locations, thereby revealing the background radiation level of the city's soil. The objective of the study was to establish the external and internal hazard indices, outdoor external dose rate, indoor external dose rate, annual outdoor effective dose rate, annual indoor effective dose rate, and excess lifetime cancer risk at selected locations across every kilometer within the densely populated areas of Ulaanbaatar city. It is important to note that the gamma spectrometry analysis of the samples was conducted by the accredited laboratory of the Nuclear Physics Research Center (NPRC) at the National University of Mongolia (NUM). The findings were processed, plotted on a map of Ulaanbaatar city, and published for each soil in Ulaanbaatar, indicating that the activity and content of the isotopes are generally

within the permissible limits. In the future, this study will be expanded to create an ecological atlas of soil radiation in the capital city of Ulaanbaatar. This investigation will be an important baseline for future monitoring of soil radiation levels.

Index Terms — Absorbed dose rate, equivalent dose rate, radiation hazard indices, radium equivalent activity.

I. INTRODUCTION

Numerous studies assessed soil radiation levels in Mongolia, focusing on the concentrations of natural radioactive isotopes such as uranium-238 (²³⁸U), thorium-232 (²³²Th), and potassium-40 (⁴⁰K) [1–3]. However, these investigations were geographically restricted. For example, measurements in the “Southern-Central zone” near Ulaanbaatar were limited to a few roadside locations and were not synthesized into comprehensive radiation maps [1–3]. Although soil geochemical maps for elements like As, Pb, Zn, and Mo exist for Ulaanbaatar, these datasets lack data on radioactive elements [4]. Furthermore, the studies conducted in 2001–2007 to measure gamma dose rates and soil radioactivity in Western Mongolia, Zuunmod (Central region of Mongolia), and Ulaanbaatar were also limited in scope and could not be regarded as a systematic survey [3, 5, 6]. Consequently, there is a significant lack of a comprehensive, multi-point radiation pollution map for the Ulaanbaatar area.

To address this gap, we propose a systematic study of previously un-surveyed areas within Ulaanbaatar, including the Songinokhairkhan and Nalaikh districts, as well as the surrounding ger areas [1–3, 6–9]. The methodology involves collecting multiple soil samples from various locations, with precise geolocation data

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recorded using GPS. These samples are analyzed by gamma spectrometry to determine the activity concentrations of ^{238}U , ^{232}Th , ^{40}K , and the anthropogenic isotope ^{137}Cs [3, 10, 11]. Gamma spectrometry is a crucial and well-established technique for environmental radiation monitoring, which facilitates the direct quantification of specific radioactive isotopes in soil and ensures accurate assessment of environmental radiation levels [1, 7, 8, 15–19, 24]. This method is already extensively applied in Mongolia for geophysical and environmental research, utilizing equipment with specifications tailored to the specific application.

This methodology provides reliable and sensitive detection of γ -emitting radio nuclides found in soil [7]. Its high sensitivity and precision, along with compliance with international standards, such as ISO 18589-3, make it the preferred technique for environmental monitoring, post-accident assessment, and evaluation of the impact of nuclear facilities [7, 8]. Crucially, the accurate radiation dose assessments offered by this method are fundamental for evaluating potential health risks to the human population.

Previous applications of this methodology in Ulaanbaatar involved measuring isotopes, including ^{226}Ra , ^{232}Th , ^{40}K , and ^{137}Cs , in soil samples [3, 11–14]. Key findings revealed that the activity concentration of ^{40}K in landfill areas was twice the global average. The radium equivalent activity (R_{eq}) ranged from 69 to 183 Bq/kg overall, reaching 338.3 Bq/kg at specific landfill sites. Associated hazard indices were reported as 0.2 for the external hazard index (H_{ex}) and 0.5 for the internal hazard index (H_{in}), with an estimated long-term cancer risk ranging from 0.8×10^{-3} to 1.58×10^{-3} [11]. These results underscore the necessity of systematic and repeated studies across multiple locations in Ulaanbaatar to thoroughly assess the effects on public health.

A critical area for such monitoring is the Songinokhairkhan district, particularly the soil near its ash ponds and landfills. While the Narangiin Enger landfill is studied, more detailed measurements are needed to analyze the soil around ash ponds and thermal power plants, focusing on multiple sampling sites within adjacent residential areas. In Mongolia, these activities are guided by national standards, including:

- **MNS 5626:2006:** A standard for the detection of radioactive isotopes in soil, ash, coal, and construction materials using gamma spectrometry [20].

- **MNS 5840:2008:** A standard for the calibration of ionizing radiation survey meters used for environmental monitoring [21].

- **MNS 5246:2003:** A standard for the of radon concentration assessment in air, applicable to traditional and modern dwellings [22].

The existing studies on soil radioactivity in Mongolia, which measure isotopes such as ^{238}U , ^{232}Th , and ^{40}K , are predominantly limited to the southern and western regions of the country. These investigations often focus on specific sites like uranium deposits or waste sites, relying on a limited number of samples, which leads to inadequate statistical analysis and constrained environmental assessment. Consequently, there is currently no integrated, spatially detailed radiation map for Ulaanbaatar city as existing knowledge is based solely on small-scale studies with limited sampling points [1–3, 6, 9–11].

Generating a reliable radiation map of Ulaanbaatar requires a substantially larger and more representative dataset. In response to this gap, the Institute of Thermal Engineering and Industrial Ecology (ITEIE) at the Mongolian University of Science and Technology (MUST) initiated a systematic research program in 2014 [12–14]. This ongoing effort involves multi-point sampling, repeated measurements, and strict adherence to national and international standards [8, 20–23]. In line with this initiative, our study collected and analyzed samples according to IAEA recommendations, implementing rigorous quality control protocols. A key priority was to utilize the resulting data for assessing a social risk and evaluating the long-term health effects on the local population.

Radioactivity is a natural phenomenon originating from terrestrial radio nuclides found in rocks, soil, sediments, and construction materials. The naturally occurring radioactive materials (NORMs), such as radium decay products, are typically long-lived and contribute significantly to the overall radioactivity of soil, which is primarily determined by the parent rock composition. The concentration of radioactive isotopes in soil serves as a key indicator of environmental radioactivity, which has direct implications for the health of humans, flora, and fauna. Ulaanbaatar presents a unique environmental landscape. In the ger districts of the city, raw coal is the primary source of thermal energy, producing a significant amount of waste ash. Estimates reveal that less than 50% of this ash is disposed of in designated containers. The remainder is often indiscriminately dumped in streets and ravines,

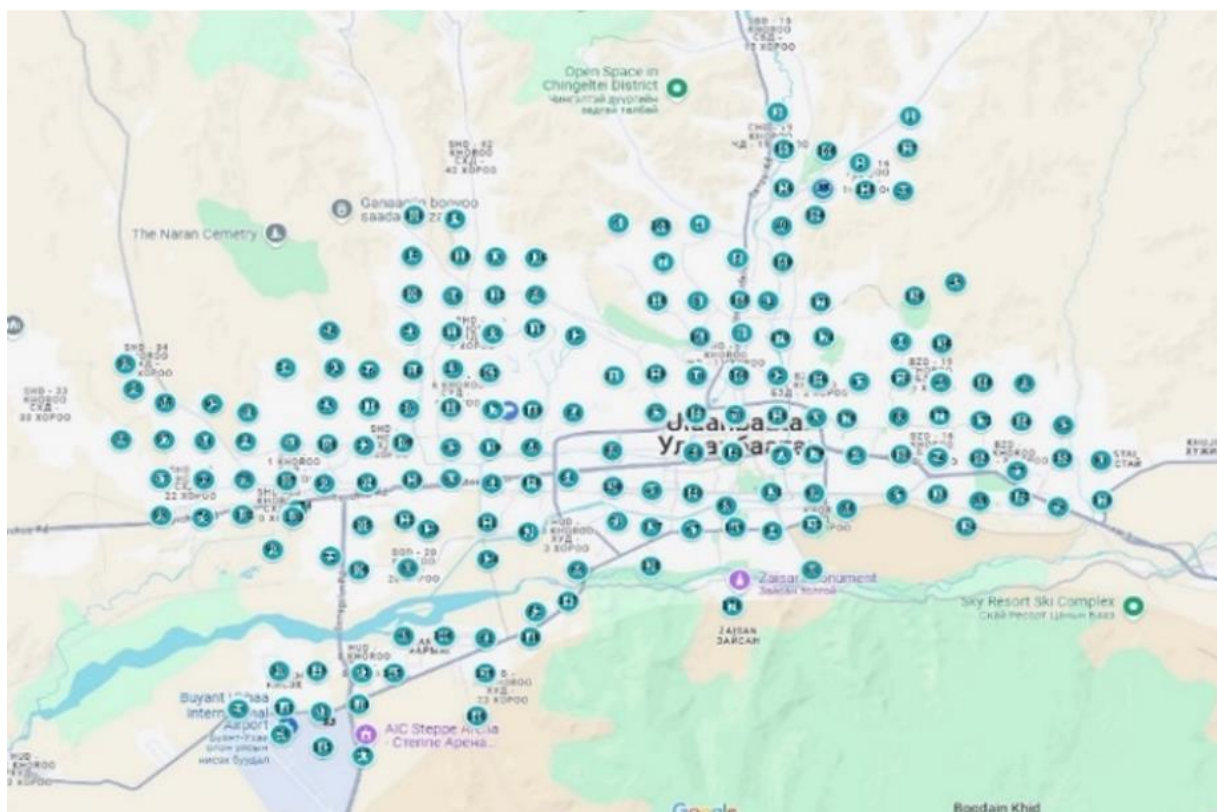


Fig. 1. Sampling locations for soil radiation measurement in the densely populated areas of Ulaanbaatar city.

creating potential point sources of contamination, which is a result of insufficient public awareness of the consequences. In this study, the activity concentrations of ^{226}Ra , ^{232}Th , ^{40}K , and ^{137}Cs in soil samples are measured using gamma-ray spectrometry with a high-purity germanium coaxial detector (HPGe). The mean values of specific activities are estimated at 24.7 ± 8.2 Bq/kg (with a range of 13 to 79) for ^{226}Ra , 18.5 ± 3.9 Bq/kg (with a range of 2 to 40) for ^{232}Th , and 720.2 ± 88.1 Bq/kg (with a range of 422 to 966) for ^{40}K . These results indicate that the mean activities of ^{226}Ra and ^{232}Th are below the world average of 35 Bq/kg and 30 Bq/kg, respectively. The presence of the anthropogenic isotope ^{137}Cs was found to be low in most locations.

II. METHODS, SAMPLE COLLECTION AND PREPARATION

1. Gamma Spectrometry Analysis

Soil radioactive isotopes were analyzed in the accredited gamma spectrometry laboratory of the Nuclear Physics Research Center (NPRC) at the National University of Mongolia (NUM). The method involves detecting gamma quanta emitted from natural and man-made radioactive isotopes using a gamma spectrometer equipped with a

high-resolution semiconductor detector, and determining the activity concentration of the isotope by the number of impulses recorded by the detector of these gamma lines, using the detector's absolute detection efficiency. The study aimed to assess the radiation level at selected points across every kilometer within the densely populated areas of Ulaanbaatar city. This involved measuring the gamma radiation dose and the specific activity of the isotopes, including ^{226}Ra , ^{232}Th , ^{40}K , and ^{137}Cs . The analysis also included assessing the content of uranium and thorium per tonne and potassium per percentage at 180 points across each kilometer. The samples were analyzed using gamma spectrometry, with the results processed, plotted on a map of Ulaanbaatar city, and published for each element. For each sample, the precise location of collection was established by GPS. The points selected for sampling are shown in Fig. 1 [12–14].

2. Sample Collection and Preparation

In the 180 locations selected for sampling, 1–2 kg of samples, were excavated from a 0.15×0.15 m² area, removing large rocks from the surface, and from a depth of 5 cm of soil. To reduce gamma radiation scattering, the samples were ground to a diameter of less than 1 mm,

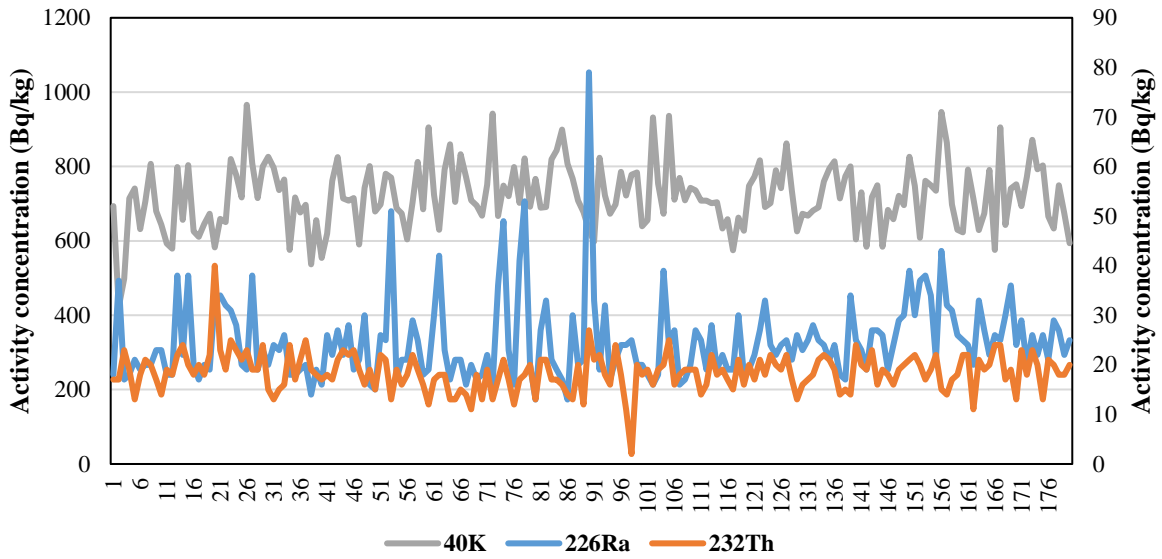


Fig. 2 Activity concentrations of ²²⁶Ra, ²³²Th, and ⁴⁰K in the soil of Ulaanbaatar city.

dried, placed in a Marinella container, weighed, and prepared for measurement in a germanium detector [23].

III. RESULTS AND DISCUSSION

1. Activity concentrations of ²²⁶Ra, ²³²Th, and ⁴⁰K in the soil of Ulaanbaatar

The activity concentrations of ²²⁶Ra, ²³²Th, ⁴⁰K, along with their values for the 180 soil samples, are shown in Fig. 2. The activity concentration of ⁴⁰K is shown using the left-hand axis, while the activity concentrations of ²²⁶Ra and ²³²Th are plotted using the right-hand (secondary) axis. This was done to make the graph easier to read because

their values differ greatly. All values are given in Bq/kg. The mean values and ranges of the activities for ²²⁶Ra, ²³²Th, and ⁴⁰K, respectively, are 24.7 ± 8.2 Bq/kg (with a range of 13 to 79 Bq/kg), 18.5 ± 3.9 Bq/kg (with a range of 2 to 40 Bq/kg) and 720.2 ± 88.1 Bq/kg (with a range of 422 to 966 Bq/kg). The highest value of ²²⁶Ra activity concentration was observed in the southeastern part of the ash pond of power plant No. 4, located at 47.53°43.7' N latitude and 106.53°43.7' longitude in the territory of the 20th Khoroo of Songinokhairkhan district (point 90, sample 5180). The man-made radioactive isotope ¹³⁷Cs was almost absent in the soil samples, and at some

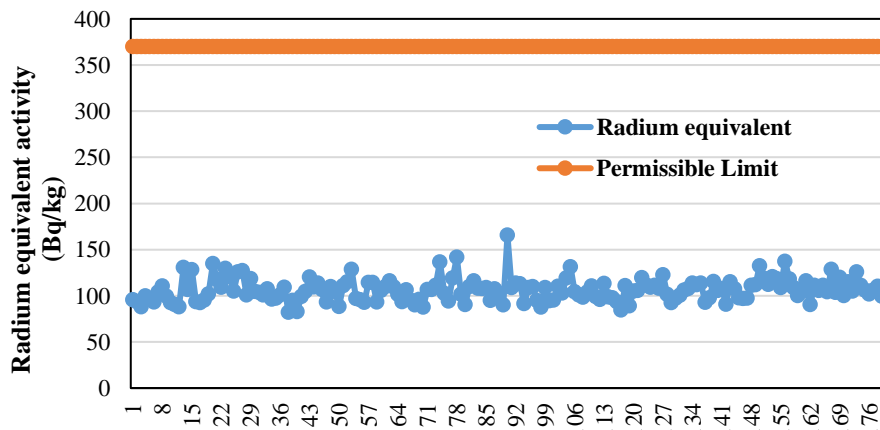


Fig. 3 Radium equivalent activity of soil in Ulaanbaatar city.

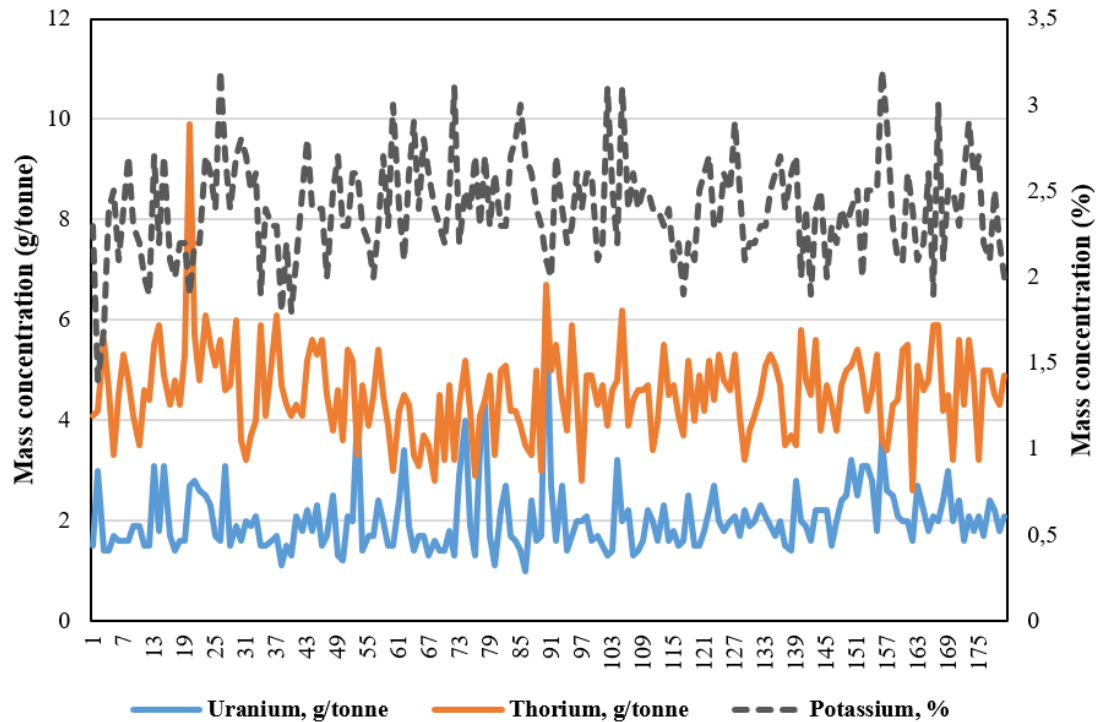


Fig. 4. Mass concentrations of uranium, thorium, and potassium in the soil of Ulaanbaatar city.

locations, it was very low, which is why it is not discussed further.

2. Radium Equivalent Activity

The method of calculating the activity of natural radioactive nuclei based on radium equivalent activity, which was proposed by Beretka and Matthew [15], is widely used to assess radiation hazards.

Radium equivalent activity is defined by the following formula:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.77A_{K}, \quad (1)$$

where A_{Ra} , A_{Th} , and A_{K} are the activity concentrations of ^{226}Ra , ^{232}Th , ^{40}K in Bq/kg, respectively [15–17, 19, 24]. Radium equivalent activity is the sum of the activities of naturally radioactive ^{226}Ra , ^{232}Th , and ^{40}K isotopes converted to radium activity and is the main measure for assessing radiation levels. The maximum permissible level of radium equivalent activity is 370 Bq/kg. The mean radium equivalent activity is 106.6 ± 12.3 Bq/kg ranging from 82.5 to 166.0 Bq/kg, which is 2.2 times lower than the permissible level [12–14]. This value corresponds to a dose rate of 1.5 mGy/year at about 1 m above the ground level. The assessment results for radium equivalent activity are shown in Fig. 3.

Figure 3 shows that the mean radium equivalent activity is 106.6 ± 12.3 Bq/kg, ranging from 82.5 to 166.0 Bq/kg.

The highest value of radium equivalent activity (166.0 Bq/kg) was observed in the southeastern part of the ash pond of power plant No. 4 (point 90, sample 5180). This high level is due to the radioactive contamination of coal ash in the environment, while radium equivalent activity is normal compared to the maximum permissible level. This investigation provides crucial information for future monitoring of the soil radiation level.

3. Mass Concentrations of Uranium, Thorium, and Potassium

The following equation is used to calculate the mass concentration of naturally occurring radioactive elements (Fig. 4) in a sample based on the specific activity concentration of their isotopes [20]:

$$\begin{aligned} 1\% (\text{K}) &= 310 \text{ Bq/kg of } ^{40}\text{K}, \\ 1 \text{ g/tonne (U)} &= 12.35 \text{ Bq/kg of } ^{226}\text{Ra}, \\ 1 \text{ g/tonne (Th)} &= 4.06 \text{ Bq/kg of } ^{232}\text{Th}. \end{aligned} \quad (2)$$

Figure 4 displays the mass concentrations of uranium and thorium in g/tonne on the primary (left) axis, while the mass concentration of potassium, expressed in percent, is shown on the secondary (right) axis. The uranium mass concentration varies from 0.7 to 6.4 g/tonne, with the mean value of 2.0 ± 0.7 g/tonne. The thorium mass concentration is in the range of 0.5 to 9.9 g/tonne, with the mean value of

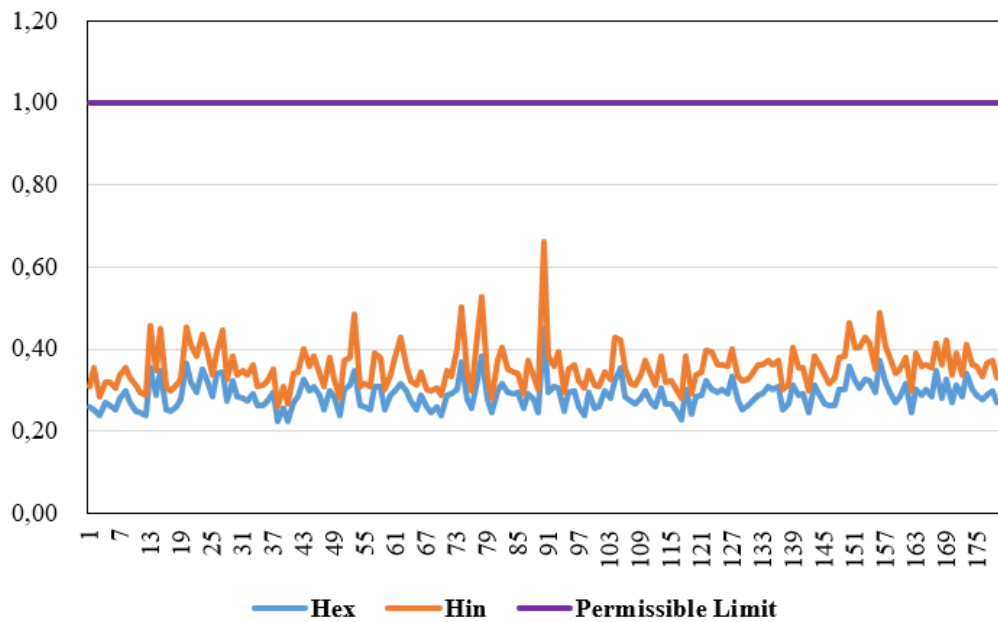


Fig. 5 External (H_{ex}) and internal (H_{in}) radiation hazard indices in Ulaanbaatar city.

4.6 ± 1.0 g/tonne, and the potassium mass concentration lies within the range of 0.3 to 3.1 %, with the mean value of 2.3 ± 0.3 %.

4. External and Internal Indices

Radiation resulting from decay is absorbed by the human body, producing external radiation, while radioactive dust penetrates the body through the respiratory and digestive systems, where it decomposes, causing internal radiation. Directly dependent on the amount of external and internal radiation, ionization processes that occur in body tissues change human biochemical and functional processes, increasing the probability of various diseases. Additionally, radiation sickness leads to genetic changes and lifelong infertility. The effects on humans when the dose rate is less than 1.00 mSv/year were calculated using the equation derived by Krieger [18]. He proposed the model for calculation of external hazard index H_{ex} based on infinitely thick walls without windows and doors to serve as a criterion. The external hazard index due to gamma radiation was calculated using following formula [15]:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1, \quad (3)$$

where 370 Bq/kg of ^{226}Ra , or 259 Bq/kg of ^{232}Th , or 4 810 Bq/kg of ^{40}K produce the same gamma dose rate, Ra_{eq} is

related to the external γ -dose and internal dose due to radon and its daughters [8, 19]. The assessment results for external (H_{ex}) and internal (H_{in}) radiation hazard indices in Ulaanbaatar city for the soil samples are demonstrated in Fig. 5.

The mean value of the external hazard index obtained in the study is 0.29 ± 0.03 mSv/y, ranging from 0.22 to 0.44 mSv/yr, which is 2.3 times lower than the permissible limit [12–14, 19].

The maximum permissible activity concentration of ^{226}Ra is 185 Bq/kg. When studying the possibility of developing cancer in internal organs, the internal hazard index is calculated. The index is assessed to reduce the maximum permissible concentration of ^{226}Ra to half the values appropriate for the external exposure alone. The gaseous short-lived decay product of ^{226}Ra , called Radon (^{222}Rn), poses a threat to the respiratory organs. In addition to the external hazard index, internal exposure to radon and its products is quantified by estimating the H_{in} . If the maximum concentration of ^{226}Ra is half that of the permissible limit, then H_{in} is less than unity. The H_{in} due to the radio nuclides was estimated using the formula proposed by Beretka and Matthew [15]. The internal hazard is expressed by the following formula:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1. \quad (4)$$

The internal radiation hazard index in Ulaanbaatar city is

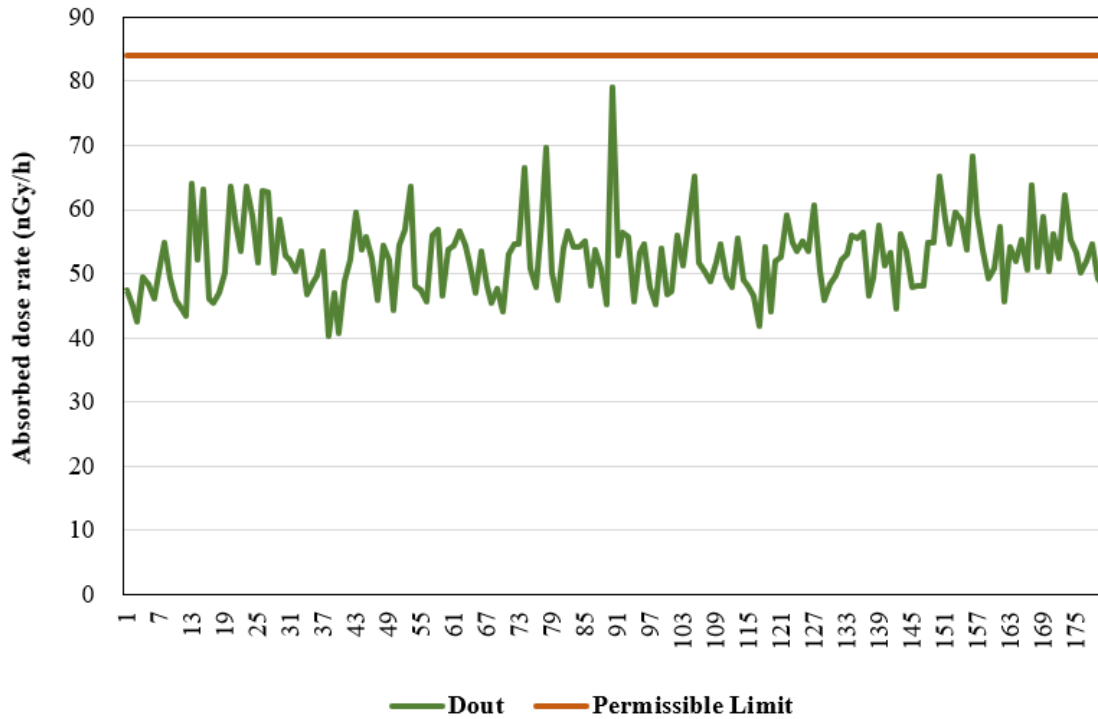


Fig. 6. Outdoor absorbed dose rate compared to permissible limit.

shown in Fig. 5. Our findings indicate that the internal radiation hazard index stands at a mean value of 0.34 ± 0.05 mSv/year (ranging from 0.19 to 0.43 mSv/yr), which is 2.3 times lower than the permissible limit.

5. Absorbed Dose Rate

The contribution of natural radio nuclides to the absorbed dose rate (D_{out} , D_{in}) in air depends on the natural specific activity concentrations of ^{238}U , ^{232}Th , and ^{40}K . The greatest part of the gamma radiation comes from terrestrial radio nuclides. There is a direct connection between terrestrial gamma radiation and radionuclide concentrations. If a radionuclide activity is known then its exposure dose rate in the air at 1 m above the ground can be calculated [19, 25]. The conversion factors used to compute the absorbed gamma dose rate (D_{out} , D_{in}) in air per unit activity concentration in Bq/kg corresponds to 0.462 nGy/h for ^{226}Ra , 0.604 nGy/h for ^{232}Th , and 0.0417 nGy/h for ^{40}K .

The dose rate absorbed in the air can be determined by the radioactivity in the soil. It was calculated for a height of 1 m above the ground surface. A computer program employed was based on the volume integral method using the following conversion factors:

$$D_{out} = (4.62A_{\text{Ra}} + 6.04A_{\text{Th}} + 0.417A_{\text{K}}) \times 10^{-1}, \quad (5)$$

where D_{out} is the absorbed dose rate in the outdoor air, nGy/h; A_{Ra} , A_{Th} , A_{K} are activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K , Bq/kg,

$$D_{in} = (9.2A_{\text{Ra}} + 11A_{\text{Th}} + 0.8A_{\text{K}}) \times 10^{-1}, \quad (6)$$

where D_{in} is the absorbed dose rate in the indoor air, nGy/h. The absorbed dose rate (D_{out}) values range between 40.3 nGy/h and 79.0 nGy/h with a mean value of 52.6 ± 5.9 nGy/h. This mean value is lower than the value of the world average absorbed dose rate of 84 nGy/h [8, 24]. The results of the D_{out} comparison with the permissible limit are shown in Fig. 6.

6. Annual Effective Dose Rate, E_{eff}

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (2000) used the annual effective dose, E_{eff} (E_{out} , E_{in}), of 0.7 Sv/Gy for the conversion coefficient from absorbed dose in the air to effective dose received by adults, and 0.8 for the outdoor occupancy factor [25]. The annual effective dose in mSv/y, resulting from the absorbed dose values (D_{out} , D_{in}), was calculated using the following formulas [19, 25]:

$$E_{out} = 1.4 \times 10^{-3} D_{out}. \quad (7)$$

The annual effective dose obtained (Fig. 7) ranges between 0.07 mSv/y and 0.11 mSv/y with a mean value of 0.07 ± 0.01 mSv/y [13]:

$$E_{in} = 3.068 \times 10^{-3} D_{in} . \quad (8) \quad \text{ash pond of power plant No. 4 (point 90, sample 5180).}$$

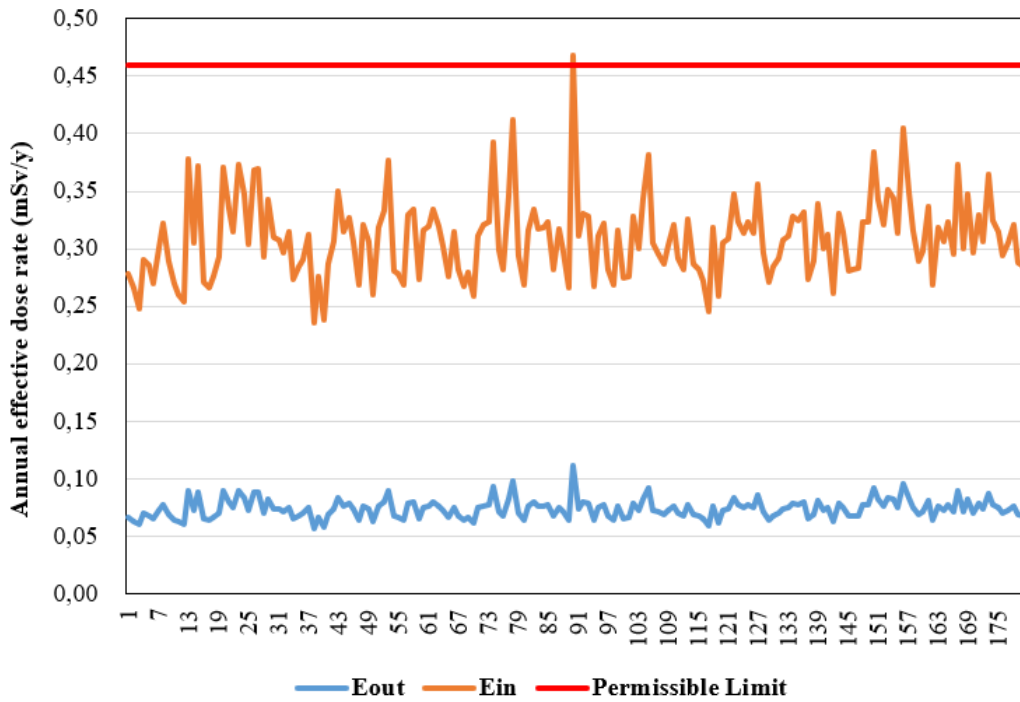


Fig. 7. Annual effective dose rate in different locations of Ulaanbaatar.

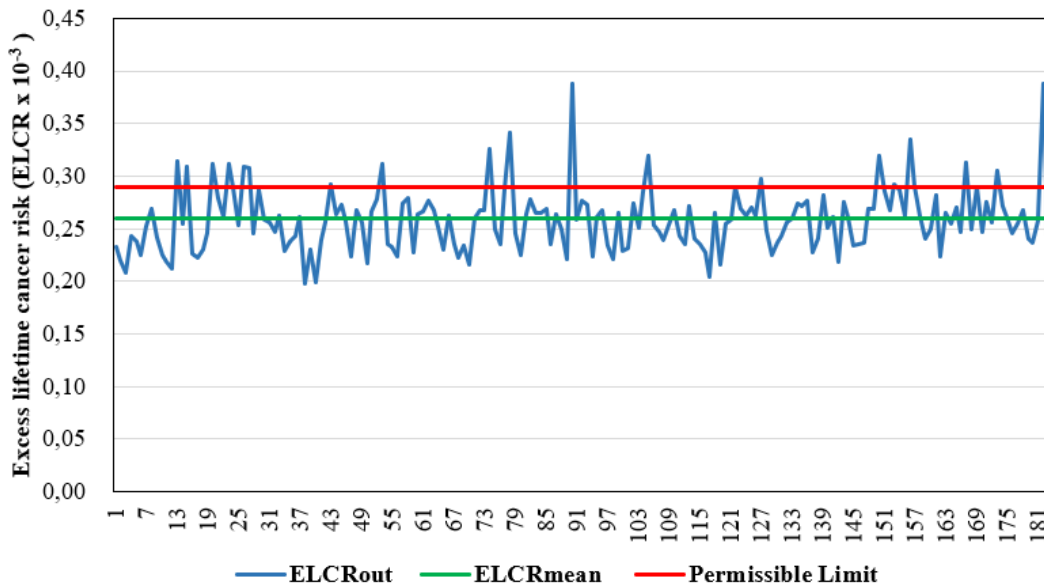


Fig.8. Excess lifetime cancer risk (ELCR) in Ulaanbaatar, Mongolia.

In normal background areas, the average annual indoor effective dose from terrestrial radio nuclides is 0.46 mSv/y [8, 25]. Therefore, the obtained mean value from this study area, 0.31 ± 0.04 mSv/y, ranging from 0.24 to 0.47 mSv/y, is lower than the world average value [8, 12–14]. The high value of E_{in} was observed in the southeastern part of the

Figure 7 shows variations in annual effective dose rate at different points of Ulaanbaatar and the permissible limit.

7. Health Effects of Radiation

Radiation can damage human cells, causing skin burns, hair loss, and cancer. Pregnant women are particularly

TABLE 1. Comparative Results of Radiation Studies Conducted on Soil Samples from Ulaanbaatar City in 2014 and 2024

Parameters	Mean values		Range	
	2014	2024	2014	2024
1. Activity concentration of isotopes, Bq/kg				
^{226}Ra	21.2±5.9	24.7±8.2	11–40	13–79
^{232}Th	20.2±5.0	18.5±3.9	10–49	2–40
^{40}K	708.4±117.8	720.2±88.1	277–1002	422–966
Ra_{eq}	104.5±12.6	106.6±12.3	58–129	82–166
2. Content of elements				
U , g/ton	1.7±0.5	2.0±0.7	0.9–3.2	0.7–6.4
Th , g/ton	5.0±1.2	4.6±1.0	2.4–12.0	0.5–9.9
K , %	2.3±0.4	2.3±0.3	0.9–3.1	0.3–3.1
3. Radiation hazard indices – H				
H_{ex}	0.28±0.03	0.29±0.03	0.16–0.35	0.22–0.44
H_{in}	0.34±0.05	0.36±0.05	0.19–0.43	0.26–0.66
4. Absorbed dose rate – D , nGy/h				
D_{out}	51.4±6.1	52.6±5.9	28–64	40.3–79.0
D_{in}	98.4±11.8	100.7±11.4	52.8–123	77–153
5. Annual effective dose rate – E_{eff} , mSv/y				
E_{out}	0.07±0.01	0.07±0.01	0.04–0.09	0.07–0.11
E_{in}	0.30±0.03	0.31±0.04	0.16–0.38	0.24–0.47
6. Excess lifetime cancer risk ($ELCR$)				
$ELCR$, 10^{-3}	0.25±0.03	0.26±0.03	0.13–0.31	0.20–0.39

vulnerable to radiation, as fetuses are sensitive to radiation. The additional or extra risk of developing cancer stems from exposure to a toxic substance incurred over the lifetime of an individual. Excess lifetime cancer risk ($ELCR$) is calculated using the following formula:

$$ELCR = E_{out} \times DL \times RF, \quad (9)$$

where E_{out} , DL , and RF are respectively the annual effective dose, duration of life (70 years), and risk factor (0.05 Sv^{-1} for public exposure, ICRP-2007 [27]), i.e., fatal cancer risk per Sievert. The calculated range of $ELCR$ is 0.20×10^{-3} to 0.39×10^{-3} with a mean value of $(0.26 \pm 0.03) \times 10^{-3}$. The mean value of $ELCR$ in the study area is lower than the world average of 0.29×10^{-3} [24, 26]. Figure 8 shows the sampling points, excess lifetime cancer risk ($ELCR$), the permissible limit (PL), and the mean value determined in our study.

Table 1 presents a comparison between the findings from our study conducted across 180 locations in Ulaanbaatar in 2024 and the results from our earlier study carried out in 2014 [12–14].

The 2024 radiation survey at 180 sites in Ulaanbaatar showed generally slightly higher levels than the 2014 survey, all of the above figures as well as the average,

minimum, and maximum values in the text, are presented using the 2024 survey data.

IV. CONCLUSION

1. This study can be used as a baseline for future investigations while the data obtained in this study may be instrumental in natural radioactivity mapping. These findings can also be employed as reference data for future monitoring possible radioactive pollution. The activity levels of natural terrestrial radionuclides – ^{238}U , ^{232}Th , and ^{40}K – were measured using gamma-ray spectrometry system. The soil samples were collected from selected locations of Ulaanbaatar city.

2. The mean radium equivalent activity stands at $106.6 \pm 12.3 \text{ Bq/kg}$, ranging from 82.5 to 165.9 Bq/kg. Its maximum value is 2.2 times lower than the maximum permissible level. The uranium mass concentration lies in the range of 0.9 to 3.2 g/tonne, with the mean value of $1.75 \pm 0.5 \text{ g/tonne}$. The thorium mass concentration falls within the range of 2.4 to 12 g/tonne, with the mean value of $5.0 \pm 1.2 \text{ g/tonne}$. The potassium mass concentration ranges between 0.9% and 3.1%, with the mean value of $2.4 \pm 0.4 \%$. The activity concentrations and the content of

uranium, thorium, and potassium in the studied soils are found to be normal.

3. The highest value of radium equivalent activity (165.96 Bq/kg) was observed in the southeastern part of the ash pond of power plant No. 4, located at 47.53'43.7" latitude and 106.53'43.7" longitude in the territory of the 20th Khoroo of Songinokhairkhan district (point 90, sample 5180). This high level is due to the radioactive contamination of coal ash found in the environment. However, the radium equivalent activity remains within normal limits compared to the permissible level.

4. Our study shows that the mean value of the external hazard index is 0.28 ± 0.03 , varying between 0.16 and 0.35, which is 2.8 times lower than the permissible limit. The mean annual indoor effective dose obtained is 0.30 ± 0.03 mSv/y, ranging from 0.16 to 0.38 mSv/y, which is 1.2 times lower than the permissible limit.

5. The calculated range of *ELCR* is 0.20×10^{-3} to 0.39×10^{-3} with a mean value of $(0.26 \pm 0.03) \times 10^{-3}$. The mean value of *ELCR* in the study area is lower than the world average of 0.29×10^{-3} .

6. All measured radiological parameters are below the permissible limit. Hence the natural radioactivity of soil does not pose any harmful radiation risks to residents or tourists.

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