



Variation of Air Dose Rate Between Residual Moist Soil and Host Rocks in a Dried Hamamok Small Dam Environment, Koy Sanjaq District, Kurdistan Region, Iraq

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ABSTRACT

Naturally occurring radioisotopes (radionuclides) such as ^{238}U , ^{232}Th , and ^{40}K , along with their decay products, contribute significantly to external gamma radiation in the environment. The present geological study investigates the variation of outdoor gamma air dose rates in the drought-affected Hamamok Dam basin soil compared to surrounding virgin soils (weathered host rocks) in the Koy Sanjaq District-Iraq. Due to extremely low rainfall in the past two years, the dam is nearly empty, exposing extensive soil deposits and enabling direct field assessment. Air dose rate measurements were conducted using a thermo scientific RIIDEye-G handheld detector along two transects: Accumulated soils within the dam basin (Dip direction) and undisturbed virgin soils (Strike line). Results showed that dose rates in the dam basin ranged from 40.8 to 55.3 nSv h⁻¹, with a mean of 47.53 nSv h⁻¹, while virgin soils recorded 30.2–45.3 nSv h⁻¹, averaging 34.83 nSv h⁻¹.

Radiological risk analysis revealed that the mean annual effective dose AED (0.083 mSv yr⁻¹) and excess lifetime cancer risk ELCR (2.91×10^{-4}) remain below international safety thresholds, though slightly elevated compared to natural background levels. These findings highlight the influence of upstream sediment deposition and current mineral composition on radionuclide accumulation in dam environments. This study underscores the importance of regular monitoring of natural radionuclide activity in upstream deposits to ensure consumer safety.

Keywords: Residual moist soil, Air dose rate, Hamamok dam, Upstream deposits, Radiological risk.

INTRODUCTION

The presence of radionuclides (radioisotopes) in environmental matrices such as soil, water, and sediments has long been recognized as a key factor influencing natural background radiation levels and human exposure. Naturally occurring radionuclides such as ^{238}U , ^{232}Th , and ^{40}K , along with their decay products, contribute significantly to external gamma dose rates. Their distribution is not uniform but depends on multiple environmental and geological factors (Duong *et al.*, 2025a).

Human activities, including nuclear weapons testing, industrial operations, and nuclear power generation, have further altered the natural distribution of these radionuclides in many regions of the world (Aidarkhanova *et al.*, 2022a). Studies conducted in the Fukushima Dai-ichi accident zone have shown that dam reservoirs not only trap radionuclide-contaminated sediments but also provide valuable records of time-dependent contamination, highlighting their importance in reconstructing radionuclide migration and dose assessment (Konoplev *et al.*, 2022). Similarly, assessments of large artificial reservoirs, such as Lake Nasser in Egypt, demonstrated that radium-bearing sediments can release radon gas, which contributes to both air dose rates and potential human health risks (Ali *et al.* 2025).

Globally, the characterization of radionuclide distribution in soils and sediments is considered essential for understanding environmental radiation hazards. For example, recent investigations in Vietnam and India emphasized the role of soil composition and mineralogy (e.g., monazite, zircon, apatite) in elevating natural dose rates, sometimes exceeding UNSCEAR recommended limits.

Coastal and shelf sediment studies have further confirmed that geological variations strongly influence the spatial heterogeneity of dose rates and radionuclide concentrations, making site-specific monitoring indispensable (Bramha *et al.*, 2025; Duong *et al.*, 2025b).

The variation of radionuclide concentrations from one place to another is primarily attributed to differences in geological formations composition, soil mineralogy, hydrological processes, and climatic factors. For example, Parent rock types, such as granite or basalt, determine the baseline abundance of uranium and thorium series radionuclides, while weathering, erosion, and sedimentation processes control their redistribution into soils and reservoirs. Sediment grain size, clay content, and organic matter further influence the adsorption and retention of radionuclides. In addition, anthropogenic contributions, including nuclear accidents, mining, and dam operations, introduce heterogeneities in radionuclide deposition. These factors collectively explain why elevated activity levels may be observed in one location, while nearby areas with different geological and environmental settings may show much lower activity. Moreover, soil and sediments, air pathways must also be considered. Radon exhalation and gamma emissions from radionuclide-rich sediments have been shown to elevate ambient air dose rates near water bodies, agricultural zones, and areas of human settlement. This underlines the importance of coupling soil and sediment radioactivity assessments with air dose rate monitoring to provide a comprehensive evaluation of environmental exposure (Aidarkhanova *et al.*, 2022b; Ali *et al.*, 2025; Bramha *et al.*, 2025; Kuzmanović, 2025; Othman, *et al.*, 2023; Saleh *et al.*, 2025; Saleh *et al.*, 2024).

These conditions create an ideal setting to explore how variations in dose rates are simultaneously influenced by rock type and soil water content (Amestoy *et al.*, 2021; Nakanishi *et al.*, 2023). The Hamamok Dam, located northwest of Koy Sanjaq in the Kurdistan Region of Iraq, is an earthfill dam constructed in 2011 with a height of 25 m and a length of about 120–125 m. It is built across a deep valley formed along the southeastern plunge of the Bana Bawi anticline, part of the Zagros Fold-Thrust Belt. The dam's reservoir capacity is about 250,000 m³, with steep slopes on both banks covered by limestone riprap to resist erosion. Geologically, the site is characterized by the soft reddish-brown clastics of the Gercus Formation overlain by hard carbonate rocks of the Pila Spi Formation, while Khurmala and Kolosh formations are exposed upstream. These lithological contrasts, together with steep gradients and active weathering, have contributed to slope instability problems, particularly plane sliding on the right bank and toppling on the left bank (Ghafour *et al.*, 2024).

Due to the severe drought and very low rainfall in the past two years, the Hamamok small dam is now almost empty, exposing most of its soil deposits and creating a unique opportunity for scientific investigation. This study takes advantage of these conditions to examine the variation in air dose rates between residual moist soils and the surrounding host rocks in this arid environment. By combining on-site measurements with geological and environmental data, the research aims to clarify how lithological diversity and soil moisture together affect ambient gamma radiation. The outcomes are expected to establish reliable radiological baselines, enhance environmental monitoring strategies, and contribute to public health risk assessments in dam-affected areas.

MATERIALS AND METHODS

Study area and stratigraphy (rock materials) of Koy Sanjaq district

The geology of the Koy Sanjaq District is dominated by Paleogene rocks belonging to the High Folded Zone of the Zagros Mountains Fig. (1). At the base of the succession lies the Kolosh Formation (Paleocene), which is composed mainly of dark shale, marl, and fine-grained sandstone, with occasional thin conglomeratic layers. These deposits are interpreted as the product of deep-marine sedimentation within the foreland basin that developed during the early stages of Zagros orogeny. In certain parts of the district, the Kolosh Formation is overlain by the Khurmala formation, a relatively thin carbonate unit that signals a shift from deep-marine to shallower depositional conditions. Above this, the gercus formation (Paleocene–Eocene) appears, consisting chiefly of reddish shale and silt with minor sandstone, reflecting deposition in a shallow marine to continental setting. The sequence is capped by the Pila Spi Formation (Middle–Late Eocene), a resistant limestone unit that is regionally extensive and responsible for the prominent ridges surrounding Haibat Sultan Mountain (Balaky and Mahmud, 2021; Ghafour *et al.*, 2024; Sissakian and Youkhanna, 1979).

It is mainly composed of well-bedded limestone and dolomitic limestone, with local thicknesses exceeding 100 m (Sissakian and Youkhanna, 1979). Because the Pila Spi limestones are mechanically strong, they commonly shape the crests of anticlines, while the weaker Gercus and Kolosh units underlie the slopes and valleys. This contrast explains why many valley sides in the district, including those near the Hamamok Small Dam, are prone to erosion and instability (Ghafour *et al.*, 2024).

Taken together, this stratigraphic record illustrates the gradual shift from deep-marine clastics to shallow-water carbonates during the Paleogene, while also highlighting the close link between geology and landscape evolution in the Koy Sanjaq region.

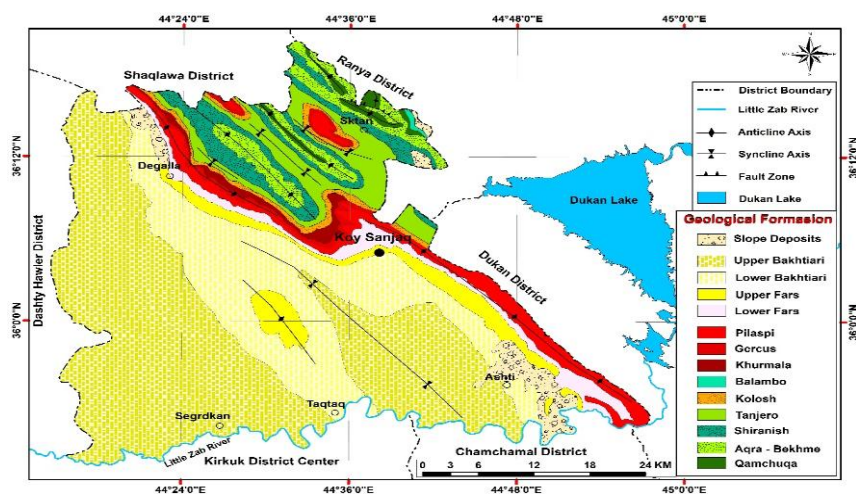


Fig. 1: Geological Formations of Koya District-Erbil

Methodology

Air dose rate measurements were conducted in the drought-affected areas of the Hamamok Dam using the Thermo Scientific RIIDEyeG handheld radiation isotope identifier, equipped with a $2'' \times 2''$ NaI(Tl) scintillation detector capable of measuring ambient dose rates in nSv/h and performing gamma spectral analysis, as shown in Fig. (2). All measurements were taken at a reference height of 1 m above ground level, corresponding to the level of sensitive human organs and consistent with international environmental radiation monitoring standards. The RIIDEyeG incorporates patented Quadratic Compression Conversion (QCC) technology for real-time isotope identification and applies continuous potassium (K-40) spectrum stabilization, which eliminates the need for a built-in Cs-137 check source and ensures accurate calibration even under variable field conditions (Scientific, 2012). For field convenience, the device features a high-resolution display readable in sunlight, one-handed ergonomic operation, and removable memory card storage for data logging.

Two transects were surveyed: the first in the accumulated soil zone at the deepest accessible part of the dam basin, where sediments from erosion and floods are deposited hereafter (Dip direction), with measurements taken at 9–10 m intervals between points; and the second in the virgin soil zone here after (Strike Line), a control area unaffected by flood-driven sediment deposition and representing natural background levels as shown in Fig. (3). At each site, the RIIDEye provided-time and date-stamped dose rate values in nSv/h, which were subsequently analyzed to compare external radiation exposure between accumulated and undisturbed soils within the dam environment (Altfelder *et al.*, 2024).



Fig. 2: RIID eye handheld radiation isotope identifier and the GPS recorder



Fig. 3: The paths of measurements blue line are for dip direction and red line is for strike line.

Radiological risk analysis

In this study, the measured outdoor gamma dose rates at the Hamamok Dam were used to estimate two important radiological indices: the annual effective dose (AED) and the excess lifetime

cancer risk (ELCR). The AED was calculated from the absorbed dose rate in air using the following equation (Salh *et al.*, 2021; Salh *et al.*, 2024):

$$AED_{out}(mSv.y^{-1}) = D_{out}(nGy.h^{-1}) \times 8760h \times 0.2 \times 10^{-6} \dots (1)$$

The value 8760 represents the total number of hours in a year, while 0.2 is taken as the outdoor occupancy factor. Using these parameters, the Excess Lifetime Cancer Risk (ELCR) was calculated as follows:

$$ELCR = AED_{out} \times LS \times RF \dots\dots\dots (2)$$

Here, $LS \approx 70$ years represents the average human life expectancy, while $RF \approx 0.05 \text{ Sv}^{-1}$ is the risk factor recommended by the ICRP. Together, these values are used to estimate the annual outdoor radiation dose for people living near or visiting the dam, and to assess the associated lifetime cancer risk (Fasanmi *et al.*, 2021; Taskin *et al.*, 2009; UNSCEAR, 2000)

RESULTS AND DISCUSSION

Air dose rate results

The results of outdoor gamma dose rate measurements for both the Hamamok Dam basin soil and the surrounding virgin soils are summarized in (Table 1) and (Table 2). These datasets highlight clear variations that can be linked to differences in mineralogical composition, stratified rocks and depositional history, which together control the distribution of natural radionuclides in the area. In total, 27 measurements were collected from the deepest accessible sections of the Hamamok Dam basin, providing a representative picture of the radiological conditions within the reservoir. The absorbed dose rates ranged from 40.8 to 55.3 nSv h⁻¹, with an average value of 47.53 nSv h⁻¹. The median (46.9 nSv h⁻¹) and mode (46.4 nSv h⁻¹) were very close to the mean, indicating a well-balanced distribution of values. The standard deviation was relatively small (3.52 nSv h⁻¹), confirming limited variability across the sampled locations. The distribution was slightly positively skewed (0.22) and showed a near-normal shape (kurtosis = -0.33). These results demonstrate that radiation levels within the dam basin are relatively stable, reflecting the uniform accumulation of radionuclides in sediments deposited through erosion and flooding.

Table (1): Gamma dose rates for the Hamamok Dam basin soil (Dip direction).

Sample	Latitude	Longitude	DR (nSv/hr)	Elevation (m)
D1	36°06.169'	44°35.958'	42.9	789
D2	36°06.172'	44°35.963'	40.8	787
D3	36°06.170'	44°35.968'	44.2	788
D4	36°06.165'	44°35.973'	46.4	788
D5	36°06.162'	44°35.976'	46.4	787
D6	36°06.159'	44°35.981'	46.2	788
D7	36°06.151'	44°35.982'	44.3	789
D8	36°06.152'	44°35.989'	48.7	791
D9	36°06.144'	44°35.993'	49.9	790
D10	36°06.143'	44°35.994'	52.4	790
D11	36°06.139'	44°35.004'	45.6	792
D12	36°06.132'	44°36.002'	50.1	790
D13	36°06.125'	44°36.999'	48.4	793
D14	36°06.122'	44°35.995'	55.3	792
D15	36°06.115'	44°35.991'	46.9	790
D16	36°06.112'	44°35.985'	48.9	790
D17	36°06.116'	44°35.975'	42.9	790
D18	36°06.119'	44°35.970'	48.8	788
D19	36°06.125'	44°35.968'	45.5	791
D20	36°06.130'	44°35.967'	46.4	791
D21	36°06.136'	44°35.964'	43	792
D22	36°06.142'	44°35.961'	44.6	792
D23	36°06.147'	44°35.951'	50.1	791
D24	36°06.158'	44°35.953'	49.9	790
D25	36°06.161'	44°35.955'	49.7	791
D26	36°06.171'	44°35.952'	51.3	791
D27	36°06.135'	44°36.006'	53.6	790

In contrast, in the surrounding virgin soil, 16 measurements were recorded. The absorbed dose rates varied between 30.2 and 45.3 nSv/h, with a mean of 34.83 nSv/h. The median (33.5 nSv/h) and mode (30.2 nSv/h) were both lower than the mean, reflecting a positively skewed distribution (skewness = 1.22). The dataset also showed higher variability, with a standard deviation of 4.51 nSv/h and a leptokurtic distribution (kurtosis = 0.76), suggesting the presence of occasional elevated values compared with the bulk of the data. This indicates that radionuclide levels in the virgin soil are more heterogeneous, likely due to natural background variation (stratigraphic columns) rather than concentrated deposition. Importantly, the absorbed dose rates in both environments remain below the worldwide reference level of 59 nGy h⁻¹ reported by UNSCEAR, indicating that measured radiation levels are within the safe global background range (Joel *et al.*, 2021).

Table (2): Gamma dose rates for the virgin soil surrounding Hamamok Dam (Strike line).

Sample	Latitude	Longitude	DR(nSv/hr)	Elevation (m)
V1	36°06.180'	44°35.941'	32.2	793
V2	36°06.183'	44°35.937'	36.3	793
V3	36°06.187'	44°35.932'	35.4	794
V4	36°06.192'	44°35.928'	45.3	795
V5	36°06.191'	44°35.917'	42.9	795
V6	36°06.199'	44°35.915'	40.1	795
V7	36°06.208'	44°35.912'	33.4	798
V8	36°06.208'	44°35.904'	32	799
V9	36°06.212'	44°35.899'	34.1	800
V10	36°06.222'	44°35.896'	30.5	801
V11	36°06.234'	44°35.891'	36.9	807
V12	36°06.234'	44°35.897'	32.6	808
V13	36°06.235'	44°35.908'	30.2	806
V14	36°06.228'	44°35.914'	30.2	803
V15	36°06.177'	44°35.919'	33.5	800
V16	36°06.167'	44°35.903'	31.7	808

Comparing the two datasets highlights clear differences. The Hamamok Dam basin soil consistently exhibited higher dose rates (mean = 47.53 nSv/h) compared with the virgin soil (mean = 34.83 nSv/h). Moreover, the dam basin measurements were more uniform (SD = 3.52) than those of the virgin soil (SD = 4.51), where a wider spread of values was observed. These differences can be attributed to geological processes: Radionuclides are transported from the surrounding mountains and concentrated in the basin through erosion and flooding, while the undisturbed virgin soil reflects more variable natural background levels (Saito *et al.*, 2019).

Radiological assessment results

The statistical distribution of annual effective dose (AED) values for the dam and virgin soil series is shown in Fig. (4). The AED values (expressed in $\times 10^{-2}$ mSv/yr) range from 7.15 to 9.69, corresponding to 0.071–0.097 mSv/yr, with a mean of $8.33 \pm 0.62 \times 10^{-2}$ mSv/yr (0.083 mSv/yr). The data distribution is nearly symmetrical, as indicated by low skewness (0.22) and kurtosis (–0.33), while the median (0.082 mSv/yr) and mode (0.081 mSv/yr) are consistent with the mean. When compared with international benchmarks, the mean AED remains far below the public dose limit of 1.0 mSv/yr recommended by ICRP (2007). This means that exposure to soil radiation from the dam area does not pose a direct health risk but does indicate a relative elevation compared with natural background levels. The corresponding ELCR values for the dam soil series (expressed in $\times 10^{-4}$) vary between 2.50 and 3.39×10^{-4} , with a mean of $2.91 \pm 0.22 \times 10^{-4}$. These values represent the lifetime probability of developing cancer due to exposure to soil radiation in the dam area.

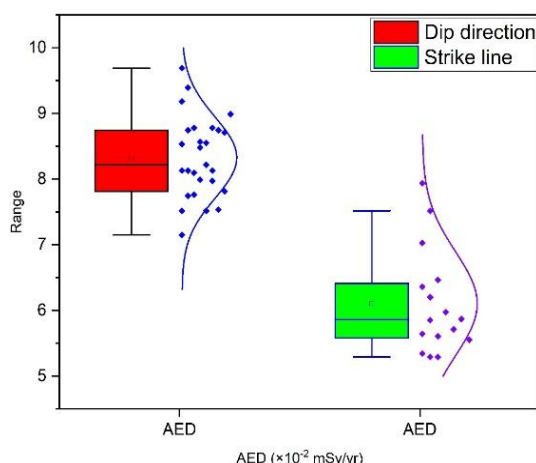


Fig. 4: Distribution of computed AED for the Hamamok Dam basin soil and virgin soil samples

The mean ELCR value of 2.91×10^{-4} indicates that the lifetime radiological risk remains within safe limits. Nonetheless, the consistently higher ELCR values in dam basin soil compared with virgin soil reflect the effect of radionuclide enrichment due to erosion and sedimentation processes, as shown in Figure 5. This study highlights the influence of geological and hydrological processes on the distribution of natural radionuclides in the Hamamok Dam basin environment. Air dose rate measurements showed consistently higher values in the dam basin compared with the surrounding virgin soils, confirming the role of erosion and flood-driven sediment deposition in concentrating radionuclides. The dam series not only exhibited higher mean dose rates but also greater uniformity, reflecting the homogenizing effect of sediment accumulation, whereas the virgin soil series displayed greater variability, representing natural background heterogeneity. The computed radiological indices provide additional insights (Duong *et al.*, 2025c; Popoola *et al.*, 2025). The annual effective dose (AED) values for both dam and virgin soil were slightly higher and remained well below the ICRP-recommended public dose limit of 1 mSv/yr. These values represent the lifetime probability of developing cancer due to soil radiation exposure in the dam environment. Importantly, the mean values of AED and ELCR obtained in this study are in good agreement with the standard reference levels reported by UNSCEAR (2000), 59 nGy/h for absorbed dose rate, 1 mSv/yr for AED, and 2.9×10^{-4} for ELCR (Khalaf *et al.*, 2025).

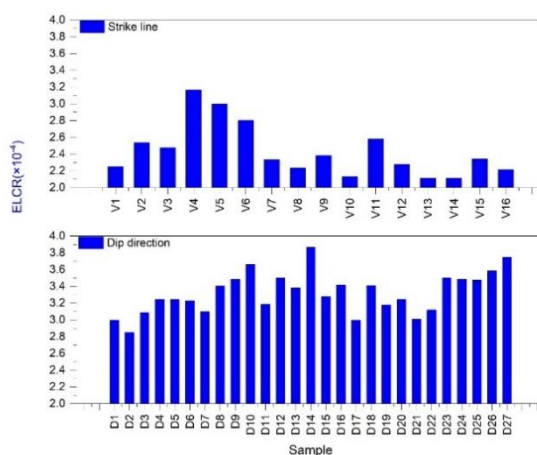


Fig. 5: Computed ELCR for the dam and virgin soil samples

Comparison with other Studied Areas

To contextualize the radiological conditions observed at the Hamamok Dam basin, the mean annual effective dose (AED) values calculated for the residual moist soils and the host rocks soils were compared with those reported in several international studies as shown in (Table 3).

Table (3): Comparison of mean annual effective dose (AED) values of the residual moist soils and surrounding host rocks virgin soils in Hamamok dam with selected international studies.

Study area/ Location	Mean AED _{out} (μSv/y)	Reference
Turkey – Lake Van	94.31	[1]
Iraq- Hamamok Dam Basin Soil Samples	83.27	Current study
Moscow (Urban)	70.0	[2]
Iraq- Hamamok Dam Virgin Soil Samples	61.02	Current study
Saudi Arabia – Ras Tanura	38.0	[3]
Najaf, Iraq	37.0	[4]
Egypt – Greater Cairo	32.0	[5]
Serbia – Novi Sad	33.0	[6]
Nigeria – Lagos	15.35	[7]

This comparison provides insight into how local geological strata, mineralogical composition, and sedimentary processes influence natural gamma radiation relative to other global environments.

Among the reviewed regions, the Lake Van basin in eastern Turkey shows the highest reported mean value (94.31 μSv/y); this elevated level is consistent with the region's volcanic and metamorphic rocks, particularly the influence of Mount Nemrut volcanism, which enriches surface soils with uranium-, thorium-, and potassium-bearing minerals (Kayakökü and Doğru, 2017). Such lithological units are well known for producing higher-than-normal terrestrial gamma fields. The Hamamok Dam basin (residual moist soils) exhibits the second-highest AED (83.27 μSv/y), reflecting the combined influence of upstream sediment inflow, episodic flooding, and lithological diversity within the Zagros Fold–Thrust Belt.

The basin acts as a natural trap for radionuclide-bearing clastic materials—particularly fine-grained sediments weathered from the Gercus, Kolosh, and Pila Spi formations (Ghafour *et al.*, 2024). These sediments accumulate over time and homogenize within the reservoir floor, resulting in a relatively uniform but elevated radiological signature. In contrast, the surrounding virgin soils (host rocks) show a lower mean AED (61.02 μSv/y), representing undisturbed background levels characteristic of mixed carbonate–clastic terrains typical of the High Folded Zone. These values fall well within the range of normal natural background radiation despite being moderately elevated compared with some global environments.

Other international datasets reveal lower AED values: Moscow urban soils (70 μSv/y) approximate global natural levels (Chaligava *et al.*, 2022), while studies from Saudi Arabia (38 μSv/y) (Alshahri and El-Taher, 2019), Najaf (37 μSv/y) (Dosh *et al.*, 2023), Serbia (33 μSv/y) (Janković *et al.*, 2023), Greater Cairo (32 μSv/y) (Taha *et al.*, 2025), and Nigeria (15.35 μSv/y) (Adedokun *et al.*, 2022) report substantially lower annual effective doses. These differences reflect variation in parent rock mineralogical composition (e.g., dominance of limestone, shale, or alluvium), sediment transport dynamics, soil maturation, and climatic effects. Overall, the comparison demonstrates that the Hamamok Dam basin soil occupies an intermediate-to-high position relative to global natural radiation levels, surpassed only by areas underlain by volcanic or high-radionuclide lithologies such as Lake Van. Although the AED values for both the basin and virgin soils remain far below the global natural annual dose of 470 μSv/year (UNSCEAR, 2000), the elevated levels observed in the basin highlight the important role of sediment accumulation, hydrological

fluctuations, and geological setting in shaping the radiological profile of dam environments. These findings underscore the need for continued monitoring, particularly in drought years when the exposed basin floor provides direct pathways for external gamma exposure.

CONCLUSIONS

This study highlights the important role of sediment accumulation in shaping the radiological environment of the Hamamok Dam basin. Sediments act as natural repositories for radionuclides, concentrating materials transported by runoff and inflowing waters. As a result, the dam basin showed higher activity concentrations compared with the surrounding virgin soils. These elevated levels directly influenced the annual effective dose (AED) and the excess lifetime cancer risk (ELCR). Although both AED and ELCR values in the basin were above global natural background averages, they remained within the safety limits recommended by UNSCEAR and the ICRP. This indicates that, while sediments increase the potential for radiation exposure, the associated risks are still considered acceptable for public health. Nonetheless, the continuous operation of dams inevitably promotes the long-term accumulation of sediments, which may gradually alter radionuclide concentrations and dose rates. Additional factors, such as erosion, fluctuating water levels, and land-use changes within the catchment area, could further modify deposition patterns over time. For these reasons, systematic and long-term monitoring is strongly recommended to track changes in radionuclide behavior, ensure that exposure levels remain within safe limits, and provide early warning of any potential increase in radiological risks.

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تباين مُعدّل الجرعة الإشعاعية في الهواء بين التربة الرطبة المتبقية والصخورالأم في بيئة حماموك الجاف الصغير، قضاء كويسنجق/ إقليم كردستان/ العراق

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الملخص

تُسهّم النظائر المشعة الطبيعية (النويدات المشعة) مثل اليورانيوم-238 والثوريوم-232 والبيوتاسيوم-40، إلى جانب نواتج اضمحلالها، إسهامًا كبيرًا في الإشعاع الخارجي لأشعة غاما في البيئة. تتناول هذه الدراسة الجيولوجية الحالية تباين مُعدّلات الجرعة الإشعاعية الخارجية لأشعة غاما في تربة حوض سد حماموك المتضرر من الجفاف مقارنةً بالترب البكر المحيطة (الصخور الأم المتجوية) في قضاء كويسنجق، العراق. ونظرًا لهطول الأمطار الشديد الانخفاض في العامين الماضيين، أصبح السد شبه فارغ تقريبًا، مما أدى إلى كشف مساحات واسعة من الرواسب الطينية وأتاح إجراء تقييم ميداني مباشر. وقد أُجريت قياسات مُعدّل الجرعة الإشعاعية في الهواء باستخدام كاشف يدوي من طراز Thermo Scientific RIIDEye-G على امتداد مسارين: الأول للترب المتراكمة داخل حوض السد (باتجاه الميل)، والثاني للترب البكر غير المُتعرّضة للاضطراب (بمحاذاة خط الاتجاه). أظهرت النتائج أن مُعدّلات الجرعة الإشعاعية في حوض السد تراوحت بين 40.8 و 55.3 نانوسيفرت في الساعة، بمتوسط قدره 47.53 نانوسيفرت في الساعة، في حين سجلت الترب البكر قيمًا تراوحت بين 30.2 و 45.3 نانوسيفرت في الساعة، بمتوسط قدره 34.83 نانوسيفرت في الساعة. وقد كشف تحليل المخاطر الإشعاعية أن متوسط الجرعة الفعالة السنوية AED (0.083 ملي سيفرت سنويًا) وخطر الإصابة بالسرطان مدى الحياة ELCR (2.91×10^{-4}) يظلان دون الحدود الدولية للسلامة، رغم أنهما أعلى قليلًا من مستويات الخلفية الطبيعية. وتبرز هذه النتائج تأثير ترسب الرواسب القادمة من المناطق العلوية (أعالي المجرى) والتركيب المعدني الحالي على تراكم النويدات المشعة في بيئات السدود. وتؤكد هذه الدراسة أهمية المراقبة الدورية لنشاط النويدات المشعة الطبيعية في الرواسب العلوية لضمان سلامة المستهلكين.

الكلمات الدالة: التربة الرطبة المتبقية، مُعدّل الجرعة الإشعاعية في الهواء، سد حماموك، الرواسب العلوية، المخاطر الإشعاعية.