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Radiological Impacts of Natural Radioactivity and Heavy Metal of Tobacco Plants in Iraqi Kurdistan Region, Iraq

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ABSTRACT

Cigarette smoking is a potential route for radiation exposure because tobacco leaves used in cigarette production contain radioactive elements. From a health perspective, Understanding the radioactivity levels in tobacco leaves and products is crucial for evaluating the radiological effects of smoking tobacco for positive and negative smokers. The study utilized a gamma-ray spectrometer (HPGe) to measure naturally occurring radionuclides, while X-ray fluorescence spectroscopy was used to analyze the levels of Cr, Ni, Zn, and Pb. The results indicate that the mean levels of ^{238}U, ^{232}Th, and ^{40}K activity levels in tobacco samples from all examined locations were below the global data. The mean values of the Raeq, Hin, and Hex indices in tobacco plant samples from all the studied sites were lower than the permissible global limit. The average values of the representative gamma index (Iγ) in the Samilan, Galala, and Qaerawan sites were lower than the permissible global limit. However, the average magnitudes of the Iγ index at the Qasre, Amadiya, Sarsang, Sheladeze, Sidakan, and Penjwin sites were higher than the permissible global limit. The levels of toxic substances in tobacco plants decrease in the following sequence: Cr > Ni > Zn > Pb. Furthermore, descriptive analyses assessing the relationship between radionuclides and heavy metals indicated a strong positive correlation between ^{238}U and ^{232}Th. Additionally, they demonstrate positive correlations between ^{238}U and heavy metals. A tenuous association was detected between ^{232}Th and heavy metals, as well as between ^{40}K and toxic substances.

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INTRODUCTION

Tobacco, despite its detrimental health effects and steep costs, remains the primary commodity purchased by daily smokers. Globally, its use is acknowledged as the leading cause of lethal diseases and early disability. Tobacco consumption is a substantial contributor to the occurrence of cancer and the subsequent mortality rates. The transmission of toxic substances from tobacco smoke to the human body poses a significant health risk. Exposure to this material leads to the development of many malignancies, encompassing a spectrum of cancer types,

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spanning from lung, oral, and throat to kidney, pancreatic, bladder, and stomach cancers, and additionally incorporating acute myeloid leukemia (Sasco et al., 2004). While other parameters may also contribute to the development of cancer in humans, the inclusion of radioactive in tobacco leaves used for cigarette manufacturing is a significant contributing factor (Nain et al., 2008). Tobacco belongs to the Salicaceae family and the Nicotine genus from a botanical standpoint. Tobacco smoke contains a multitude of cancer-causing substances, along with a substantial presence of naturally occurring radioactive elements, in addition to a huge number of poisonous chemicals (Al-Alawy et al., 2023; Kadhim et al., 2023).

Tobacco cultivation soil naturally contains radioactivity, which is heightened using phosphate fertilizers derived from uranium-rich apatite (Grupen, 2010; Abbady, 2005). These radionuclides, including radium, thorium, and their decay products (^{222}Rn, ^{210}Pb, and ^{210}Po), are absorbed by plants. Consequently, radionuclides pose risks during tobacco growth and cigarette production. Smoking cigarettes raises concerns due to naturally occurring radionuclides in tobacco leaves, which are present at higher levels than in typical food products (Salahel Din, 2021). The radioisotope levels in tobacco vary based on production location, cultivation practices, and curing methods (Shousha, 2012). Therefore, it is crucial to regularly measure the concentration of natural radioactive material and gamma dose rates in tobacco to assess the associated radiological risks.

Elements transfer to plants through air, water, and soil, with metals accumulating in soils and sediments presenting risks to human health (Ali et al., 2018; Castillo et al., 2011). Heavy metals like copper (Cu), cadmium (Cd), nickel (Ni), lead (Pb), and zinc (Zn) are notable pollutants due to their toxicity and carcinogenicity (Zeng et al., 2022). Cadmium, in particular, is highly toxic and can accumulate in tobacco plants, leading to exposure through smoking, which poses risks such as bone and kidney diseases and neurological disorders (Lei, et al., 2024; Devi, 2024; Verma et al., 2010; Sharma & Dubey, 2005; Nnorom et al., 2005). While some metals are essential for metabolic functions, excess amounts of copper and zinc can cause severe health issues (Stojanović et al., 2016; Zhang et al., 2005). Tobacco smoke is a significant source of these hazardous metals, affecting both smokers and non-smokers through passive smoking (Stojanović et al., 2016). The accumulation of metals in tobacco leaves depends on soil mineral content, geographical origin, and the use of fertilizers and irrigation methods. Notably, phosphate fertilizers commonly used in tobacco farming contain high levels of heavy metals (Hussein, 2023; Adeyeye, 2005; Lugon-Moulin, 2006).

Radioactive nuclide activity concentration in agricultural plant fertilizers is important, especially in Iraqi Kurdistan. High-purity germanium (HPGe) detectors in gamma spectrometry have been used to quantify radionuclides in chemical and organic fertilizers. The activity concentrations for Ra-226, Th-232, K-40, and Cs-137 are 0.1 to 134 Bq/kg, 0.1 to 74 Bq/kg, 1 to 12,000 Bq/kg, and 0 to 1 Bq/kg, respectively. These measurements are critical for assessing fertilizer's radiation risks. The investigation found that several samples surpassed the OECD safety guideline of 370 Bq/kg for radium equivalent activity. This shows that some fertilizers carry radioactive dangers, requiring constant monitoring and strict regulations to protect agricultural safety and public health (Azeez et al., 2018).

This current study aims to evaluate the contents of natural radionuclides (U-238, Th-232, and K-40) in tobacco plant samples utilizing a gamma-ray spectrometer armed with a high-purity germanium (HPGe) detector. In addition, to evaluate the repercussions linked to the levels of natural radionuclide activity. Furthermore, the Kurdistan area of Iraq will employ an X-ray fluorescence spectrometer (XRF) to quantitatively identify the levels of toxic substances in tobacco plant samples.

MATERIALS AND METHODS

The Iraqi Kurdistan territory is an autonomous territory located in the northern part of Iraq. The region boasts diverse topography, including abundant plains, valleys, hills, plateaus, and numerous mountains. Forty-three (43) tobacco plant samples were collected from nine distinct locations in Iraqi Kurdistan. In the laboratory, the tobacco leaves were thoroughly washed with deionized water. Afterward, applied to the tobacco, samples were dried in an oven at 80 °C until they reached a constant weight.

Figure 1 displays the locations of the samples to ensure a representative sample from every location; the research team selected 4 to 6 points across each tobacco plantation field. Each sampling point covered an area of 2 m^2 × 2 m^2 (Guidebook, 1989). Subsequently, the collected samples were placed in standard-size containers referred to as Marinelli beakers, and they were securely sealed for a month to achieve secular equilibrium before conducting measurements. Subsequently, measurements were conducted (Wais et al., 2023) after 30 days to confirm achieving equilibrium in the decay products' radioactive state.

Analytical techniques using γ- ray spectroscopy

The assessment of natural radioactivity levels was conducted by utilizing an HPGe detector operating with a high voltage range 0-1500 V and coupled to a multichannel analyzer. A 5 cm thick lead barrier was employed to shield the HPGe detector from background radiation, thereby enhancing the accuracy of the radon measurements, which have an inner diameter of 10 cm and a height of 50 cm from a gamma background. Background radiation was gauged by employing an empty container of a similar size to the samples, which has an actual size of one liter (1000 cm^3). Figure 3 shows the dimensions of all sides for marinelli beaker. The samples were placed on the system for 24 hours, yielding a gamma spectrum with precise statistical data that aligns with results from previous studies (Alsaffar et al., 2015; Ademola et al., 2015). To minimize counting errors, each sample was placed on top of the detector. The detector's energy resolution was configured to 1.99 keV for the 1332 keV gamma-ray energy released by a ^{60}Co source, allowing for the distinction of different gamma-ray energy lines (Hussein, 2023).

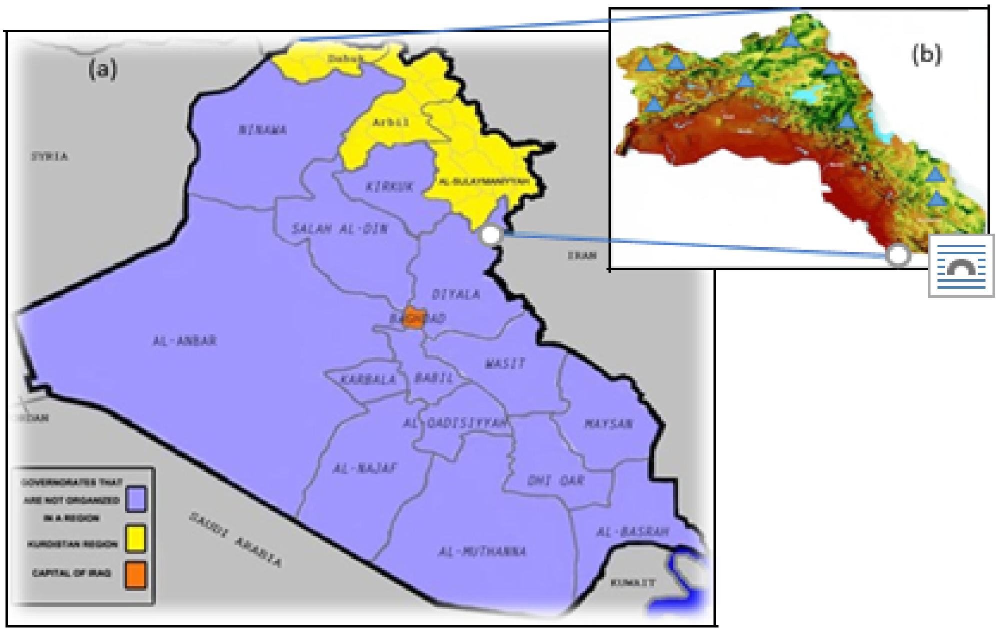

Fig. 1. 1a, Map of Iraq and 1b, Iraqi Kurdistan showing tobacco plant samples.

The detector's efficiency is characterized by the relationship between the pulses captured by the detector and the quantity of gamma-ray photons released by the source. For the examination of radionuclides in a sample, it is necessary to have a perfect calibration of the efficiency of a γ-ray spectrometry system since efficiency stands out as the most crucial attribute of detectors (Ismail et al., 2021). The system's efficiency calibrations were performed utilizing common gamma-ray point standard sources ^{60}Co (1173.2 - 1332.5 keV), ^{137}Cs (661.7 keV), and a daughter product of ^{238}U (186.1, 295, 351.9, 609, 665, 1120, and 1764 keV). Figure 2 represents the absolute efficiency curve obtained for each size and configuration used for the measurements.

The mean levels of radionuclides were detected through more intense lines of photo peak energies, such as ^{212}Pb (238.6 keV) and ^{228}Ac (911.1 keV), which were employed to estimate the content of ^{232}Th in the specimen. In contrast, the gamma lines of radionuclides ^{214}Bi (764.8 keV) were employed to determine the content of ^{238}U. The estimated amount of ^{40}K radionuclide was estimated by analyzing the 1461 keV gamma peak emitted by ^{40}K itself.

Due to the influence of coincidence summing, the determination of radioactive activity concentration involved the utilization of gamma lines at 609.3 keV and 1120 keV for the ^{238}U series, as well as 583.2 keV, 727.3 keV and 795 keV for the ^{232}Th series (Polouckova, 2021).

The minimum detection activity (MDA) for ^{238}U, ^{232}Th, and ^{40}K was calculated using the following equation (Othman et al., 2023; Hussein, 2019).

$$MDA = \frac{2.71 + (4.66 \times \sigma)}{\varepsilon(E) \times \beta \times t \times m} \tag{1}$$

Where ó is the background standard deviation over the specified energy. The MDA values were found to be (0.009, 0.0058, and 0.135) Bq kg^{-1} for ^{238}U, ^{232}Th, and ^{40}K, respectively.

Heavy metal analysis using X-ray fluorescence (XRF)

X-ray fluorescence spectrometry is commonly preferred by petrologists and geochemists for conducting particle analysis. Designed for swift and precise analysis, this methodology aims to examine major, minor, and trace components across diverse sample types, eliminating the need for extensive training or specialized expertise on the part of the analyst. Each sample was carefully chosen to have a mass of 3.5 g using a highly precise balance. Subsequently, the sample is inserted into the press machine's mold. A constant force of around 200 kN was applied for approximately 5 minutes. Ultimately, solid disk-shaped pellets were acquired from the powdered plant samples, as depicted in figure 4.

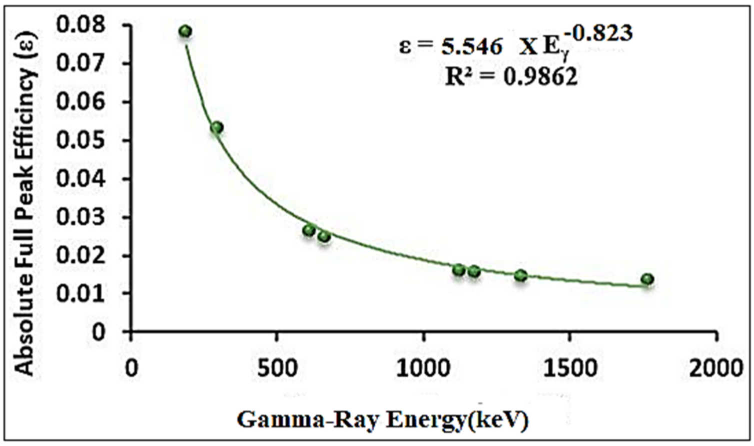

Fig. 2. Absolute efficiency in relation to gamma-ray energy.

Calculation of activity concentration

The activity levels A (Bq kg^{-1}) for ^{238}U, ^{232}Th, and ^{40}K in the samples were calculated using the equation below (Saleh et al., 2018; Hussien et al., 2023; Abd El-Azeem & Mansour, 2021):

$$A\left(Bq\,kg^{-1}\right)=\frac{C_{net}}{\varepsilon\left(E\right)\times\beta\times t\times m} \tag{2}$$

In the given equation, C_{net} is the rate of counting for a particular gamma line (calculated in counts per second) after background correction, ε(E) is the absolute efficiency, β is the peak intensity of the specific γ-ray line, t is the counting time in seconds, and m is the sample's mass in kilograms.

Calculation of radiological parameters

Numerous parameters were calculated to evaluate the external radiation levels and associated hazards to the activity of radionuclides detected in tobacco samples. Include Radium Equivalent Activity (Ra_{eq}), Internal and External Hazards Index (H_{in} and H_{ex}), Representative Gamma Index (Iγ), and Dose Effective (H_E). These calculations incorporated the activity of ^{238}U, ^{232}Th, and ^{40}K (Lee et al., 2023; UNSCEAR, 2016).

The radium equivalent Ra_{eq} (Bq/kg) was calculated using the following equation in order to assess the potential dangers of gamma radiation exposure associated with materials containing ^{238}U, ^{232}Th, and ^{40}K radionuclides (Sabr et al., 2023; Alnagran et al., 2022):

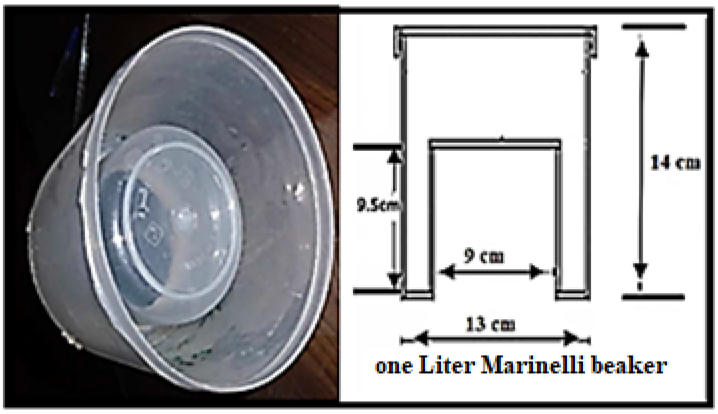

Fig. 3. Marinelli beaker dimensions, which is used for gamma ray spectroscopy.

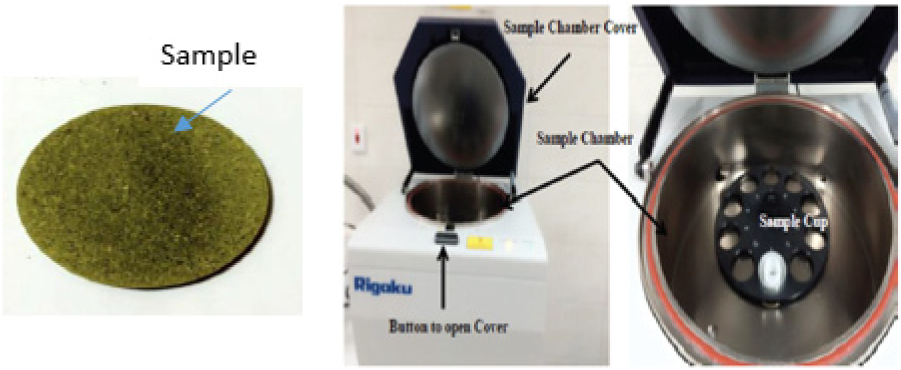

Fig. 4. X-ray fluorescence illustrates the sample.

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \tag{3}$$

The variables A_U, A_{Th}, and A_K represent the concentration activities of ^{238}U, ^{232}Th, and ^{40}K in Bq kg^{-1}, respectively. The internal and external hazard index is derived using the R_{eq} expression, assuming its maximum permissible values align with the upper threshold of 370 Bq/kg. The index value must remain below unity to maintain the insignificance of the radiation hazard. The term refers to the evaluation index, which is calculated assuming an annual effective dose of 1 mSv/y. The definition of the external hazard index is as follows (Sayyed et al., 2024):

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{4}$$

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{5}$$

Natural radionuclides' gamma radiation hazard was estimated using the gamma level index (Iγ). This indicator also correlates with the annual exposure rate from superficial materials' excess external gamma radiation (Sabr et al., 2023; Lee et al., 2023).

$$I_\gamma = \frac{A_U}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \tag{6}$$

The conversion coefficient from air absorbed dose to adult effective dose must be considered to estimate the annual effective dose rate. A conversion ratio of 0.7 Sv/Gy was used to convert the absorbed rate to the human effective dose to compute the annual estimated average effective dose (H_E). The following formulae calculates annual effective dose (Sabr et al., 2023).

$$H_E = D_R \times T \times F \tag{7}$$

Where (D_R) is calculated dose rate in nGy/h, occupancy time (T), and conversion factor (F) are given in UNSCEAR 2000.

RESULTS AND DISCUSSION

Activity concentration of ^{238}U, ^{232}Th, and ^{40}K in tobacco plants

The activity levels of ^{238}U, ^{232}Th, and ^{40}K were computed in 43 tobacco plant samples collected from 9 regions in the Kurdistan territory of Iraq. The results are presented in table 1. In the Samilan study area, 6 tobacco plant samples were collected, with activity levels of ^{238}U, ^{232}Th, and ^{40}K measuring 20.45 ± 3.14, 12.33 ± 2.42, and 62.12 ± 14.84 Bq kg^{-1}, respectively. In the Qasre area, 5 samples were collected, and the average activity for the mentioned radionuclides was 18.62 ± 2.95, 9.92 ± 1.84, and 54.74 ± 14.96 Bq kg^{-1}, respectively. Additionally, in the Galala district, the mean activity levels of ^{238}U, ^{232}Th, and ^{40}K in 4 collected samples were 19.55 ± 2.84, 10.77 ± 2.14, and 50.33 ± 15.96 Bq kg^{-1}, respectively. Amadiya district, totaling 5 samples, the average activity of ^{238}U, ^{232}Th, and ^{40}K were found to be 22.94 ± 4.72, 11.75 ± 2.16, and 48.16 ± 12.92 Bq kg^{-1}, respectively. The average levels of radionuclides in 6 samples collected from the Sarsang district were 16.92 ± 2.74, 8.95 ± 1.94, and 52.18 ± 15.16 Bq kg^{-1}, respectively. In the samples collected from the Sheladeze area, comprising 4 samples, the average activity levels of ^{238}U, ^{232}Th, and ^{40}K in these samples were 28.77 ± 4.92, 13.28 ± 1.98, and 85.28 ± 15.88 Bq kg^{-1}, respectively. In the Qaerawan area, 4 tobacco plant samples were collected; the average activity level of ^{238}U was found to be 12.96 ± 2.34 Bq kg^{-1}, while the mean activity level of ^{232}Th was 7.12 ± 1.85 Bq kg^{-1}, the average activity level of ^{40}K was 46.12 ± 12.84 Bq kg^{-1}. The results clearly show that the average activity levels of ^{238}U, ^{232}Th, and ^{40}K in the 5 samples collected from Sidakan were 15.88 ± 3.86, 8.64 ± 1.48, and 49.12 ± 14.78 Bq kg^{-1}, respectively. In the study area of Penjwin, 4 tobacco plant samples were collected, the activity of ^{238}U, ^{232}Th, and ^{40}K were found to be 21.86 ± 4.78, 10.12 ± 2.18, and 55.84 ± 15.58 Bq kg^{-1}, respectively.

It is evident that the levels of ^{238}U, ^{232}Th, and ^{40}K in tobacco plants were comparable, emphasizing their soil origin through root absorption. Furthermore, these concentrations were lower than the global mean values of ^{238}U, ^{232}Th, and ^{40}K, which were 35, 30, and 400 Bq kg^{-1} (UNSCEAR, 2000), respectively.

Results of Radiological Parameters

Understanding the radionuclides contents of different radionuclides in the examined samples is crucial for evaluating the potential radiological parameters to human health using radiological indexes. Table 2 displays the radiological risk indicators for tobacco plant samples. The average of radium equivalent (Ra_{eq}) in tobacco plant samples at the studied locations of Samilan, Qasre, Galala, Amadiya, Sarsang, Sheladeze, Qaerawan, Sidakan, and Penjwin is 142.54, 154.92, 145.96, 175.12, 162.96, 182.44, 124.74, 158.84, and 165.72 Bq kg^{-1}, respectively. These mean values are less than the global average of radium equivalent value of 370 Bq kg^{-1} (Purnama & Damayanti, 2020).

The average internal hazard index (H_{in}) for the investigated samples from the Samilan, Qasre, Galala, Amadiya, Sarsang, Sheladeze, Qaerawan, Sidakan, and Penjwin sites was 0.15, 0.18, 0.16, 0.24, 0.21, 0.28, 0.08, 0.18, and 0.22, respectively. Meanwhile, the average external hazard index (H_{ex}) was 0.12, 0.15, 0.13, 0.19, 0.17, 0.22, 0.02, 0.12, and 0.16, respectively. Those sites' average values of the internal and external parameters are lower than the worldwide mean magnitude of 1 or equal to it (Watson, 1985; Papastefanou, 2009).

Table 1. The average activity levels of radionuclides in tobacco plants.

		Mean activity levels (Bq kg^{-1})		
	Location	^{238}U	^{232}Th	^{40}K
1	Samilan	20.45 ± 3.14	12.33 ± 2.42	62.12 ± 14.84
2	Qasre	18.62 ± 2.95	9.92 ± 1.84	54.74 ± 14.96
3	Galala	19.55 ± 2.84	10.77 ± 2.14	50.33 ± 15.96
4	Amadiya	22.94 ± 4.72	11.75 ± 2.16	48.16 ± 12.92
5	Sarsang	16.92 ± 2.74	8.95 ± 1.94	52.18 ± 15.16
6	Sheladeze	28.77 ± 4.92	13.28 ± 1.98	85.28 ± 15.88
7	Qaerawan	12.96 ± 2.34	7.12 ± 1.85	46.12 ± 12.84
8	Sidakan	15.88 ± 3.86	8.64 ± 1.48	49.12 ± 14.78
9	Penjwin	21.86 ± 4.78	10.12 ± 2.18	55.84 ± 15.58

Table 2. The average radiological parameters in Tobacco Plants.

	Radiological parameters			
Location	Ra_{eq} Bq kg^{-1}	H_{in}	H_{ex}	I_{γ}
Samilan	142.54	0.15	0.12	0.45
Qasre	154.92	0.18	0.15	1.08
Galala	145.96	0.16	0.13	0.65
Amadiya	175.12	0.24	0.19	1.42
Sarsang	162.96	0.21	0.17	1.22
Sheladeze	182.44	0.28	0.22	1.88
Qaerawan	124.74	0.08	0.02	0.24
Sidakan	158.84	0.18	0.12	1.14
Penjwin	165.72	0.22	0.16	1.26

The average representative gamma index ($I_{\gamma)}$ values in tobacco plant samples at the locations of Qasre, Amadiya, Sarsang, Sheladeze, Sidakan, and Penjwin are 1.08, 1.42, 1.22, 1.88, 1.14, and 1.26, respectively. It is due to numerous scientific aspects. Soil composition and natural radionuclides in these areas may be a factor. These areas may also employ more radionuclide containing phosphate fertilizers, raising gamma index values. Local farming practices, irrigation water sources, and climatic factors like rainfall and temperature may also affect tobacco plant radionuclide uptake and accumulation. Thus, these factors likely contribute to the observed increased Iγ values at these sites. These average values are higher than permissible global limit for representative gamma index, which is equal to or less than 1. Furthermore, the average representative gamma index values in the samples at the locations of Samilan, Galala, and Qaerawan are 0.45, 0.56, and 0.24, respectively. These average magnitudes are less than the global mean magnitudes referenced by UNSCEAR.

In light of the fact that each cigarette contains 0.82 g of tobacco, and an individual consumes 30 cigarettes daily, the daily intake of tobacco is 24.6 g. Therefore, the yearly intake of tobacco through cigarettes is predicted to be 8.985 kg yr^{-1}. Approximately 75% of the radionuclide activity in tobacco leaves is transferred to cigarette smoke. This means that about 75% of the radioisotopes present in cigarette tobacco are inhaled by the smoker and subsequently deposited in lung tissues. Table 3 shows dose conversion coefficients for ^{238}U, ^{232}Th and ^{40}K.

Table 4 revealed the annual effective dose from ^{238}U, ^{232}Th and ^{40}K in tobacco samples. The locations of Samilan, Qasre, Galala, Amadiya, Sarsang, Sheladeze, Qaerawan, Sidakan, and Penjwin is 12.54, 26.85, 35.82, 96.24, 98.46, 104.12, 42.74, 99.86, and 40.68 µSv y^{-1}, respectively. As for ^{232}Th, the average effective dose for the same mentioned locations is 52.18, 64.92, 70.14, 142.82, 146.86, 158.24, 98.12, 152.15, and 96.72 µSv y^{-1}, respectively. Regarding ^{40}K, the average effective dose resulting from ^{40}K in the samples under investigation at the locations of Samilan, Qasre, Galala, Amadiya, Sarsang, Sheladeze, Qaerawan, Sidakan, and Penjwin is 8.68, 22.14, 30.84, 91.75, 92.62, 99.18, 37.12, 95.28 µSv y^{-1}, and 35.22, respectively. These average magnitudes are lower than the worldwide average annual effective dose resulting from ^{238}U, ^{232}Th, and ^{40}K, which is 1260 µSv y^{-1} (UNSCEAR, 2016; UNSCEAR, 2000; ICRP, 2012). Table 4 presents the calculated data for the annual effective dose, H_E (µSv y^{-1}), resulting

Table 3. Dose conversion coefficients for adult inhalation.

	Conversion coefficients	
Radionuclide	Sv Bq^{-1}	Reference
^{238}U	3.5×10^{-6}	(Khater, 2004)
^{232}Th	4.5×10^{-5}	(Khater, 2004)
^{40}K	2.1×10^{-9}	(Khater, 2004)

Table 4. The annual effective dose for individuals smoking 30 cigarettes daily.

	Annual effective dose		
Location	^{238}U µSv y^{-1}	^{232}Th µSv y^{-1}	^{40}K µSv y^{-1}
Samilan	12.54	52.18	8.68
Qasre	26.85	64.92	22.14
Galala	35.82	70.14	30.84
Amadiya	96.24	142.82	91.75
Sarsang	98.46	146.86	92.62
Sheladeze	104.12	158.24	99.18
Qaerawan	42.74	98.12	37.12
Sidakan	99.86	152.15	95.28
Penjwin	40.68	96.72	35.22

from inhalation of radionuclides by adult smokers. The dose conversion coefficients (μSv Bq^{-1}) for inhalation, as shown in Table 3, and using in equation 7 (Sabr et al., 2023).

Heavy metal concentration in tobacco plants.

An analysis was conducted for four metals, chromium, nickel, zinc, and lead, in 43 samples of tobacco plants collected from 9 locations in the Kurdistan territory of Iraq using X-ray fluorescence spectrometry. Table 5 shows the average levels of the four toxic metals from the investigated samples. The content of heavy metals found in tobacco can vary, and various parameters, such as the growing conditions of tobacco plants and the soil composition, influence it. The soil's reaction, or pH level, is a significant factor that affects the level of heavy metals in tobacco leaves (Akinyose et al., 2018). The results indicate that the average levels of Cr, Ni, Zn, and Pb in tobacco plant samples from all the sites were within the recommended worldwide average values formed by the global Health Organization, which are 100, 40, 50, and 27 mg kg^{-1}, respectively, in the given order (PERI, 1992; Kinuthia et al., 2020).

Natural radionuclide and heavy metal correlation

The statistical evaluation of the association between substantial metals and naturally occurring radionuclides in tobacco plant samples utilized the ORIGIN PRO 2023 software. Employing bivariate analysis, we assessed the significance of the connections between the dissemination coefficients of radionuclides and toxic metals. Figure 5 illustrates the correlation coefficient values, providing insights into the relationships among radionuclides and toxic metals in tobacco plant samples. A strong and significant correlation was observed between ^{238}U and several heavy metals. The correlation coefficient (r) between ^{238}U and ^{232}Th was 0.91, signifying a robust and favorable correlation with a p-value of ≤ 0.01.

Moreover, there were significant and robust positive correlations observed between the presence of ^{238}U and the elements Cr (r = 0.79), Ni (r = 0.73), Zn (r = 0.77), and Pb (r = 0.75). The high association between ^{238}U and Pb is due to the radioactive decay of ^{238}U, which generates several Pb isotopes/elements, including ^{214}Pb, ^{212}Pb, ^{210}Pb, ^{208}Pb, and ^{206}Pb. Pb isotope is a by-product of the decay series of uranium, notably serving as the precursor of ^{226}Ra. Within the group of Pb isotopes, ^{214}Pb is a radioactive element that undergoes decay with a half-life of 26.8 min. On the other hand, ^{210}Pb has a much longer half-life of 22.3 yr. and finally transforms into the stable isotope ^{206}Pb. Pb isotope is a product that is formed as a result of the decay process of uranium, specifically acting as the precursor to ^{226}Ra. Among the Pb isotopes, ^{214}Pb is a radioactive substance that experiences decay with a half-life of 26.8 min. Exposure to beta radiation poses a risk when it enters the human body through inhalation or ingestion routes. A modest association was identified between ^{232}Th and heavy metals, with a correlation coefficient (r = 0.55, 0.51, 0.53, 0.56), as well as between ^{40}K and heavy metals. The computed correlation

Table 5. The average heavy metal levels in tobacco plant samples.

	Average concentration of heavy metals (mg kg^{-1})			
Location	Cr	Ni	Zn	Pb
Samilan	40.45	18.14	29.74	19.77
Qasre	38.94	19.78	32.88	20.65
Galala	42.94	20.56	33.62	22.45
Amadiya	49.64	22.14	35.86	23.15
Sarsang	45.76	21.46	30.48	22.95
Sheladeze	54.22	24.72	38.35	26.18
Qaerawan	37.12	16.12	28.52	17.18
Sidakan	44.95	21.86	34.72	22.98
Penjwin	50.74	22.86	36.92	23.18

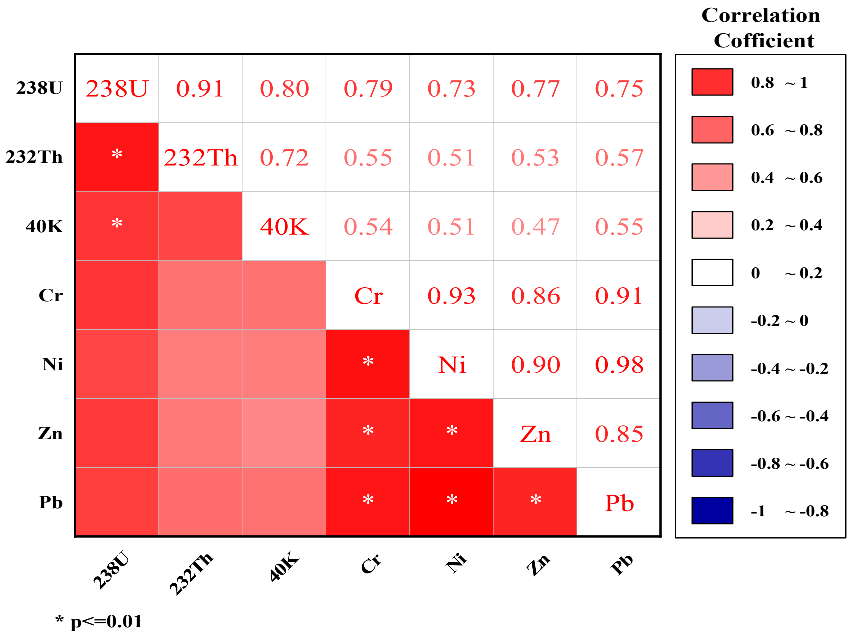

Fig. 5. Correlation coefficients between radionuclides (^{238}U, ^{232}Th, ^{40}K) and heavy metals.

between Cr, Ni, Zn, and Pb shows a strong positive linear relationship, indicating a high degree of linkage between these parameters. However, there is a modest correlation with ^{232}Th and ^{40}K.

CONCLUSION

An extensive evaluation was carried out to assess the presence of radionuclides and the associated radiological risks in tobacco plant samples in the Kurdistan area of Iraq. This assessment utilized gamma-ray spectroscopy employing an HPGe detector. In addition, the levels of toxic metals in the samples were computed by X-ray fluorescence (XRF). The results revealed the presence of minimal levels of radiation in the examined locations. Activity levels in tobacco plants are anticipated to arise from either root absorption or fertilizer application during the farming of tobacco plants. The results also indicated that the mean levels of Cr, Ni, Zn, and Pb in tobacco plants were below the acceptable thresholds established by the World Health Organization and global regulations for human intake via plant uptake. Tobacco contains high levels of toxic metals, which can produce severe health conditions, including cancer and organ dysfunction. Hence, it is necessary to stop consumption of tobacco. This work is essential for the ongoing surveillance of natural radionuclides and toxic metal contents in tobacco plants to safeguard the population from the destructive effects of tobacco smoking.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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