Trace Element Risk Assessment in Medicinal Herbal Oils

Taif Muayad Jaleel and Muhanad Alrakabi
Department of Physics, College of Science, Mustansiriyah University, 10011 Baghdad, Iraq
taif99@uomustansiriyah.edu.iq,muhanad_alrakabi@uomustansiriyah.edu.iq

Keywords: Herbal Oil, Heavy Metal, ICP-OES, Estimated Daily Intake (EDI), Cancer Risk.

Abstract: This paper highlights the need for regular monitoring of heavy metal levels in herbal oils, as it assessed concentrations of trace metals (Cd, Cr, Pb, U, Zn) in nine herbal oil samples including olive, sesame, castor, peppermint and sidr oils, along with blends for joints, hair, colon health, and antibacterial use. Samples were analyzed using ICP-OES to determine metal levels. Health risk assessments were conducted through the computation of the Cancer Risk (CR), Hazard Quotient (HQ), Hazard Index (HI), and Estimated Daily Intake (EDI), based on recommended intake rates (Chinese Pharmacopoeia) and WHO body weight standards. Results showed uranium had the highest mean concentration (0.501 ppm), with other metals averaging below 0.03 ppm. All calculated EDI values were significantly below respective PTDI limits, suggesting low non-carcinogenic risk. HQ values for individual elements and cumulative HI remained well below the threshold of 1, indicating safe exposure levels. However, CR values for lead exceeded the widely accepted lifetime cancer risk benchmark of 1×10^{-6} set by the World Health Organization (WHO) in some samples, indicating a potential concern associated with long-term exposure. These findings highlight the need for routine monitoring and stricter regulation of heavy metal content, particularly uranium, in herbal oil preparations to ensure consumer safety and reduce potential long-term health risks.

1 INTRODUCTION

For thousands of years, medicinal plants have been widely used in traditional medicine, and recently they have been incorporated into many pharmaceutical, food, and cosmetic industries [1]. Despite their widespread use, there is increasing concern regarding the safety of these herbal products because of reports of elevated levels of heavy metals in certain herbal formulations. Although they contain various essential elements and trace elements that contribute to their therapeutic properties, they may pose health risks when present at elevated concentrations. This problem has been linked to various health complications, including acute kidney diseases [2]-[4]. Studies in both developed and developing countries have shown levels of toxic metals that have raised concerns in commercial herbal products. These metals can bioaccumulate in plants from contaminated soil and enter the food chain, thereby posing health risks to living organisms [5], [6], as the reduced renal clearance of many heavy metals exacerbates these risks through their accumulation in the body over time [7]. Plant uptake of metals is influenced by soil properties such as pH, redox potential, fertility, and organic matter content, and is distributed throughout all plant tissues depending on plant-specific characteristics [8], [9]. What underscores the need to measure uranium levels alongside other toxic elements in herbal products is that naturally occurring radioactive elements such as uranium are part of the soil and rock composition. Owing to its wide occurrence in natural soils and geological formations, it can contribute to environmental contamination. These elements, along with their decay products, such as radium and radon, can enter the soil–plant system and may be absorbed by medicinal plants. Thus, they represent an additional source of contamination [10]. In addition, contamination often results from environmental pollution, including industrial emissions, vehicle exhaust, and the use of agricultural chemicals [11]. In herbal oils, the presence of trace metals may accelerate oxidative degradation processes, producing free radicals and potentially carcinogenic by products [12].

This study focused on medicinal herbal oils available on the Iraqi market, including locally produced blended formulations and commonly used oils. Although there have been studies addressing heavy metals in herbal products, information on their levels in oil-based preparations remains limited. In addition to determining element concentrations, evaluating the potential long-term health risks associated with exposure to trace metals is important. In general, herbal oils are often used repeatedly over long periods; even minimal amounts of metal may accumulate in the body over time, raising safety concerns.

The aim of this study was to determine the concentrations of selected heavy metals (cadmium, chromium, lead, uranium, and zinc) in four medicinal herbal blends used for joint treatment, hair problems, antibacterial and antifungal purposes, and colon health, in addition to olive oil, sesame oil, castor oil, peppermint oil, and sidr oil by calculating element levels and assessing the potential hazards to one's health from their use.

2 MATERIALS AND METHODS

2.1 Sample Collection

The therapeutic oils were purchased from local popular markets; four of them were herbal oil blends. The first blend, which is used for treating joint and muscle pain, consists mainly of clove, mint, and harmala oils as the primary components, in addition to small amounts of other carrier oils. The second blend was intended for hair problems and contained mainly castor, olive, and violet oils, with a small amount of rosemary oil and other oils. The third blend, designed to treat colonic issues, was composed of clove, mint, orange, and pumpkin oils as the main ingredients. The fourth and final blend, an antibacterial and antifungal mixture, included clove, cinnamon, bay leaf, and castor oils, along with small amounts of light carrier oils. In addition, four commonly used oils were purchased: olive, sesame, castor, mint and sidr. All the samples were stored in tightly sealed plastic containers in a suitable dry environment until analysis was performed.

2.2 Sample Preparation Method

The nine samples were prepared via wet thermal digestion to convert the mineral components into a form suitable for ICP–OES analysis. A one-gram portion of each sample was taken and placed in a glass beaker with 10 ml of sulfuric acid. The mixture was then heated on a hot plate until complete digestion in acid. After cooling, the sample was filtered through filter paper, and the filtrate was transferred to a digestion vessel. Then, 10 ml of nitric acid and 5 ml of hydrogen peroxide were added. The container was sealed tightly and placed in a microwave under high pressure, gradually increasing from 10 to 100 bar, and at a temperature ranging from 25°C to 200°C for 15 minutes, followed by holding at 200°C for another 15 minutes, resulting in a total digestion time of 30 minutes. The sample was then gently cooled, transferred to a glass beaker, and evaporated on a conventional heater to remove excess acid. Afterward, the sample was cooled again and filtered into a volumetric flask, and high-purity water was added to reach a final volume of 50 ml. The prepared solutions were stored until analysis.

2.3 ICP-OES Instrumentation and Analysis

An Agilent 5800 ICP–OES instrument, was used in this study to determine the composition of the samples. Inductively coupled plasma–optical emission spectrometry is widely used for many elements because of its high accuracy and sensitivity in detecting a wide range of elements, even at low levels. The instrument works by nebulizing the sample through a spray system to introduce it into plasma generated by inductive electromagnetic coupling at a power of 1.2 kW. The sample is ionized inside the plasma at a temperature exceeding 6000 K, causing the elements in the sample to emit characteristic optical spectra. After these emission lines are detected, they are analyzed via spectrometers and detectors integrated into the system.

Table 1: Type and code of the samples.

No.	Sampel name	Code
1.	Oliv oil	Yt1
2.	Sesame oil	Yt2
3.	Castor oil	Yt3
4.	Peppermint oil	Yt4
5.	Joint Oil Blend	Yt5
6.	Hair Nourishing Oil Blend	Yt6
7.	Herbal Oil Blend for Colon	Yt7
8.	Antibacterial Oil Blend	Yt8
9.	Sidr oil	Yt9

2.4 Health Risk Assessment of Heavy Metals in Herbal Oils

The health risk of the ingestion of heavy metal-contaminated herbal oils was evaluated via exposure assessment (EDI), noncarcinogenic risk assessment (HQ, HI) and carcinogenic risk assessment (CR). These methods provide tools for assessing the possible health consequences of heavy metal exposure in relation to herbal oils [13]. Acceptable daily consumption (TDI) "An estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious effects during a lifetime" is the definition of the reference dose (RfD) for hazard dose, which was introduced by the U.S. Environmental Protection Agency (EPA). Importantly, that the use of RfD eliminates the implication that any exposure level is entirely safe or acceptable [14].

2.4.1 Exposure Assessment

The estimated daily intake (EDI, $mg \cdot kg^{-1} \cdot day^{-1} \cdot bw$) of each metal in the analyzed samples was calculated to evaluate potential health risks [15]. In these calculations, C ($mg \cdot kg^{-1}$) represents the concentration of the metal in the oil. IRD ($kg \cdot day^{-1}$) is the daily intake rate, which is set at 0.02 kg/day. Ef ($days \cdot year^{-1}$) denotes the frequency of exposure, which is thought to be 350 days annually. The exposure length is indicated by Ed (years), which is set at 30 years. BW (kg) represents body weight, which is assumed to be 70 kg [5]. The estimated daily intake (EDI) is calculated according to the following formula:

$$\mathrm{EDI} = \frac{\mathrm{C} \times \mathrm{IRD} \times \mathrm{Ef} \times \mathrm{Ed}}{\mathrm{BW}} \quad (1)$$

2.5 Noncarcinogenic Risk Assessment

Noncarcinogenic health risks associated with heavy metal exposure through herbal oils were evaluated via the hazard quotient (HQ) and hazard index (HI). The HQ for each metal was calculated by comparing the estimated daily exposure with the oral reference dose (RfD) according to the following equation [16]:

$$\mathrm{HQ} = \frac{\mathrm{EDI}}{\mathrm{AT} \times \mathrm{RfD}} \quad (2)$$

where EDI is the estimated daily intake and AT is the averaging time for noncarcinogenic effects, which is calculated as days. RfD values ($mg \cdot kg^{-1} \cdot day^{-1}$) were adopted as follows: Cd=0.001, Cr=1.5, Pb=0.004, and Zn=0.3[17], [18].

The HQ values for each metal were calculated for all the samples. The sum of individual HQs provided the hazard index (HI) for each sample:

$$\mathrm{HI} = \Sigma \mathrm{HQ} \quad (3)$$

An HQ or HI below 1 indicates no significant noncarcinogenic risk for the exposed population, whereas values equal to or exceeding 1 suggest potential health concerns based on the World Health Organization (WHO).

2.6 Carcinogenic Risk Assessment

The carcinogenic risk (CR) was estimated for selected heavy metals in the herbal oils via the following equation [16]:

$$\mathrm{CR} = \frac{\mathrm{EDI} \times \mathrm{SFo}}{\mathrm{AT}} \quad (4)$$

where EDI is the estimated daily intake, AT is the averaging time for carcinogenic effects, calculated as 70 years × 350 days/year, and SFo is the oral slope factor ($mg^{-1} \cdot kg \cdot day$) indicating cancer potency. The oral slope factor (SFo) values adopted for this assessment were: Cd=100, Cr=10, Pb=100, and Zn=3 on the basis of data provided by the ATSDR (Agency for Toxic Substances and Disease Registry).

3 RESULTS AND DISCUSSION

Table 1 presents the types and codes of the analyzed herbal oil samples. Each sample was assigned a specific code (Yt1–Yt8) for identification and reference throughout the study.

The concentrations of Cd, Cr, Pb, U, and Zn in the analyzed herbal oil samples are shown in Table 2 below, and are expressed in ppm. Table 3 presents the estimated daily intake (EDI) values for these elements in $mg \cdot kg^{-1} \cdot day^{-1} \cdot bw$, scaled by 10^{-6}, together with the corresponding provisional tolerable daily intake (PTDI) limits.

Table 2: Elemental concentrations in herbal oil samples.

Code	Element Concentration (ppm)				
	Cd	Cr	Pb	U	Zn
Yt1	LOD	0.02	0.01	0.29	0.01
Yt2	0.01	0.03	0.07	0.48	0.01
Yt3	LOD	0.01	0.01	0.44	0.01
Yt4	LOD	0.01	0.01	0.40	LOD
Yt5	LOD	0.02	0.02	0.48	LOD
Yt6	0.01	0.02	0.05	0.59	LOD
Yt7	LOD	0.01	0.03	0.68	0.01
Yt8	LOD	0.02	0.02	0.65	LOD
Yt9	LOD	0.02	0.01	0.57	LOD
Max	0.01	0.03	0.07	0.68	0.01
Min	LOD	0.01	0.01	0.29	LOD

LOD: Limit of detection.

Table 3: Estimated Daily Intake (EDI) values for metals ($mg \cdot kg^{-1} \cdot day^{-1} \cdot bw \times 10^{-6}$) compared with PTDI.

Code	EDI ($mg\ kg^{-1}\ day^{-1} \cdot bw$) $\times 10^{-6}$				
	Cd	Cr	Pb	U	Zn
Yt1	LOD	5.71	2.86	82.9	2.86
Yt2	2.86	8.57	20	137	2.86
Yt3	LOD	2.86	2.86	126	2.86
Yt4	LOD	2.86	2.86	114	LOD
Yt5	LOD	5.71	5.71	137	LOD
Yt6	2.86	5.71	14.3	169	LOD
Yt7	LOD	2.86	8.57	194	2.86
Yt8	LOD	5.71	5.71	186	LOD
Yt9	LOD	5.71	2.86	163	LOD
Max	2.86	8.57	20	194	2.86
Min	LOD	2.86	2.86	82.9	LOD
PTDI	1×10-3	0.003	0.005	0.0006	0.3

ND = not detected. For calculation purposes, values below the detection limit (LOD) were replaced by the LOD value.

Table 2 shows that uranium had the highest mean concentration (0.501 ppm), which was significantly greater than that of the other elements, where the concentrations of the remaining elements did not exceed 0.03 ppm. This clear variation can be explained by the geochemical behavior of uranium and its tendency to accumulate in plant-derived materials. In contrast, cadmium, chromium, and zinc showed very slight variation among the samples ($\leq$ 0.01 ppm), indicating relative stability in their background levels. On the other hand, lead showed greater fluctuations in concentration (0.01–0.07 ppm), which may be attributed to differences in environmental pollution sources, processing conditions, or even storage factors. This variation in lead levels highlights the possibility of heterogeneous distribution in herbal oils, making monitoring of lead more important than monitoring to other elements with more stable behavior.

In Table 3, all the calculated EDI values were several orders of magnitude lower than their corresponding PTDI limits. For example, the maximum EDI for uranium was 194×10^{-6} $mg \cdot kg^{-1} \cdot day^{-1}$, whereas its PTDI was 0.0006 $mg \cdot kg^{-1} \cdot day^{-1}$ (600×10^{-6}), indicating that consumption remains below the tolerable limit. Lead (Pb) had a maximum EDI of 20×10^{-6} whereas its PTDI was 0.005 $mg \cdot kg^{-1} \cdot day^{-1}$ (5000×10^{-6}). For cadmium (Cd), chromium (Cr), and zinc (Zn), the highest EDIs ($2.86\text{-}8.57 \times 10^{-6}$) were also far below their respective PTDI values.

These results suggest that, on the basis of the estimated daily intake, the consumption of the tested herbal oils does not pose a significant noncarcinogenic health risk with respect to the assessed metals. However, the relatively high uranium concentrations warrant attention, given their bioaccumulative nature and potential for local variations in exposure.

The calculated HQ, HI, and CR values for Cd, Cr, Pb, and Zn in the analyzed herbal oil samples are presented in Table 4 below.

In Table 4, all HQ values for the studied elements in the samples clearly decreased (HQ < 1). These findings indicate that the daily consumption of these oils does not cause noncarcinogenic toxic effects. It was also found that lead is the most influential element due to its relatively greater contribution in most samples than the other elements, in addition to its higher toxicological relevance, which results in a lower reference value. Nevertheless, all HQ values for lead remained below the health concern threshold, indicating that the exposure level is still within the safe range. Moreover, the other elements contributed very low values, reflecting their weak impact.

Table 4: HQ, HI, and CR values for metals in herbal oils.

Code	HQ ($\times 10^{-3}$)				HI ($\times 10^{-3}$)	CR ($\times 10^{-4}$)			
	Cd	Cr	Pb	Zn		Cd	Cr	Pb	Zn
Yt1	LOD	0.004	0.714	0.010	0.001	LOD	0.234	0.117	0.004
Yt2	2.857	0.006	5	0.010	0.008	0.117	0.352	0.822	0.004
Yt3	LOD	0.002	0.714	0.010	0.001	LOD	0.117	0.117	0.004
Yt4	LOD	0.002	0.714	LOD	0.001	LOD	0.234	0.117	LOD
Yt5	2.857	0.004	1.429	LOD	0.001	0.117	0.234	0.235	LOD
Yt6	LOD	0.004	3.571	0.010	0.006	LOD	11.74	0.587	0.004
Yt7	LOD	0.002	2.143	LOD	0.002	LOD	0.234	0.352	LOD
Yt8	LOD	0.004	1.429	LOD	0.001	LOD	0.234	0.235	LOD
Yt9	LOD	0.004	0.714	LOD	0.001	LOD	0.117	0.117	LOD
Max	2.857	0.006	5	0.010	0.008	0.117	0.352	0.822	0.004
Min	LOD	0.002	0.714	LOD	0.001	LOD	0.117	0.117	LOD
WHO limit	1				1	1×10^{-6}–1×10^{-4}			

ND = Not Detected. For calculation purposes, values below the detection limit (LOD) were replaced by the LOD value.

The hazard index (HI) denotes the cumulative impact of the analyzed elements (Cd, Cr, Pb, and Zn), with all computed values for the examined samples significantly less than one (HI < 1). The HI values ranged from 0.001 $\times 10^{-3}$ to 0.008 $\times 10^{-3}$, demonstrating that the cumulative noncarcinogenic risk associated with the ingestion of these herbal oils is minimal and remains within globally established safety limits. These data demonstrate that the regular use of these oils is unlikely to induce adverse noncarcinogenic health effects. Variations detected in HI values among the samples are related mainly to changes in lead (Pb) concentrations, which had higher HQ contributions than did cadmium, chromium, and zinc, whereas the latter had very little effect on the total HI. This trend highlights the importance of monitoring lead levels to reduce cumulative noncarcinogenic health hazards.

In terms of carcinogenic risk (CR), lead had CR values between 0.117 $\times 10^{-4}$ and 0.822 $\times 10^{-4}$, indicating that some samples were close to the upper limit of the acceptable carcinogenic risk range (1×10^{-6}–1×10^{-4}) [19], In contrast, cadmium, chromium, and zinc consistently presented much lower CR values, remaining well within safe limits. This observation suggests that lead is the main contributor to the estimated carcinogenic risk among the analyzed elements. Although the calculated CR values do not exceed the recommended limits, the possibility of long-term exposure through repeated consumption should be carefully considered. Accordingly, greater attention should be given to controlling lead concentrations in herbal oils, alongside the implementation of stricter quality assurance measures and further studies focusing on the bioavailability and chemical behavior of lead. Such efforts would provide a more realistic evaluation of potential health risks associated with prolonged use.

Figure 1 shows the HQ values for Cd, Cr, Pb, and Zn in all the oil samples. Uranium has the highest HQ values across all samples, standing out clearly in the graph. The other elements have much lower HQ values, with small differences between samples. This visual comparison reveals that all HQ values remain well below the reference limit of 1, suggesting that there is no significant noncarcinogenic risk from these metals in the oils.

Figure 2 shows the CR values for the same elements in the samples. Lead again displays the highest CR values relative to the other elements, particularly in samples Yt2, Yt6, and Yt7, whereas cadmium, chromium, and zinc maintain continuously low cancer risk values. The figure also indicates modest changes in CR values among the samples, reflecting differences in element concentrations. Overall, the results indicate that the carcinogenic risk posed by Cd, Cr, and Zn is insignificant, but lead constitutes the dominant contributor to the projected cancer risk, although remains within the permissible reference range.

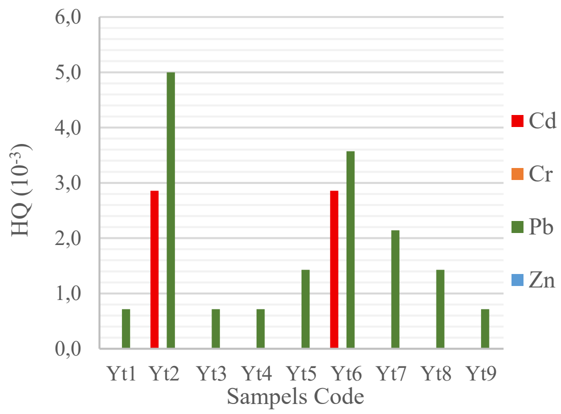

Figure 1: HQ Values of heavy metals (Cd, Cr, Pb, Zn) in nine herbal oil samples.

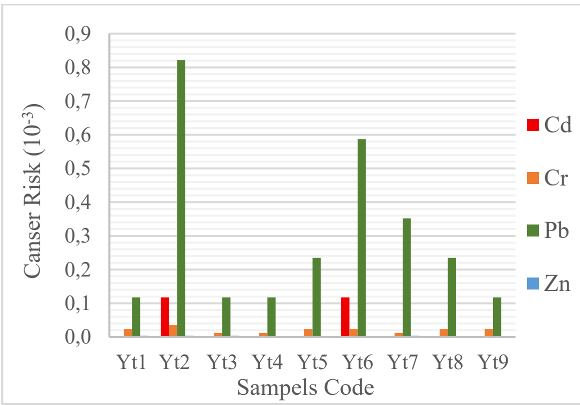

Figure 2: Cancer Risk (CR) of heavy metals (Cd, Cr, Pb, Zn) in nine herbal oil samples.

Although uranium demonstrated the greatest quantity among the investigated elements, its potential health impact cannot be properly estimated via chemical carcinogenic risk models. The health issue linked with uranium exposure is principally radiological and related to internal alpha radiation following ingestion. Consequently, no chemical carcinogenic risk value was provided to uranium in this investigation. The detected uranium levels imply the necessity for future investigations focused on activity concentration measurements and radiological dose assessment to accurately determine the long-term health repercussions of uranium.

4 CONCLUSIONS

The results of this study revealed that the investigated herbal oils contained varying concentrations of the heavy metals Cd, Cr, Pb, and Zn. The concentrations of cadmium, chromium, lead, and zinc generally remained at relatively low levels across all the samples. The estimated daily intake (EDI) calculations indicated that all values were significantly lower than the permissible limits on the basis of the provisional tolerable daily intake (PTDI). In addition, the hazard quotient (HQ) and hazard index (HI) values were below the reference limit of unity, confirming the absence of significant noncarcinogenic health risks associated with the regular consumption of these oils.

In contrast, the carcinogenic risk (CR) assessment revealed that lead exceeded the acceptable reference level in some samples, indicating the possibility of long-term carcinogenic risks associated with chronic exposure. These findings demonstrate that the absence of noncarcinogenic risk does not necessarily eliminate the potential for long-term health concerns arising from prolonged exposure to toxic elements.

This study emphasizes the necessity of regular monitoring of heavy metal concentrations in herbal oils, with particular attention given to lead. Furthermore, future studies should focus on evaluating the bioavailability and chemical speciation of these elements to provide a more accurate assessment of their potential health impacts. Increasing consumer awareness regarding the safety of herbal products is also essential to ensure their safe use in both food and medicinal applications.

REFERENCES

[1] H. S. Kim, B.-H. Seo, J.-S. Bae, W.-I. Kim, G. Owens, and K.-R. Kim, "An integrated approach to safer plant production on metal contaminated soils using species selection and chemical immobilization," Ecotoxicol. Environ. Saf., vol. 131, pp. 89-95, 2016.

[2] N. Jasima, Z. G. Hussiena, H. F. Abd-Alrazackb, and M. A. Majidc, "Estimation of the total amounts of manganese ions in some of the medicinal plants leaves using flow injection technique combined with photometric detection method," Commun., 2022.

[3] A. Maiga, D. Diallo, R. Bye, and B. S. Paulsen, "Determination of some toxic and essential metal ions in medicinal and edible plants from Mali," J. Agric.

[4] Food Chem., vol. 53, no. 6, pp. 2316-2321, 2005. L. Luo et al., "Detection and risk assessments of multi-pesticides in 1771 cultivated herbal medicines by LC/MS-MS and GC/MS-MS," Chemosphere, vol. 262, p. 127477, 2021.

[5] O. Awodele, T. Popoola, K. Amadi, H. Coker, and A. Akintonwa, "Traditional medicinal plants in Nigeria – Remedies or risks," J. Ethnopharmacol., vol. 150, no. 2, pp. 614-618, 2013.

[6] J. Singh and A. S. Kalamdhad, "Effects of heavy metals on soil, plants, human health and aquatic life," Int. J. Res. Chem. Environ., vol. 1, no. 2, pp. 15-21, 2011.

[7] R. Dghaim, S. Al Khatib, H. Rasool, and M. Ali Khan, "Determination of heavy metals concentration in traditional herbs commonly consumed in the United Arab Emirates," J. Environ. Public Health, vol. 2015, no. 1, p. 973878, 2015.

[8] S. Lorenz, R. Hamon, S. McGrath, P. E. Holm, and T. H. Christensen, "Applications of fertilizer cations affect cadmium and zinc concentrations in soil solutions and uptake by plants," Eur. J. Soil Sci., vol. 45, no. 2, pp. 159-165, 1994.

[9] T. Al-Alawy, H. J. Nasser, and O. A. Mzher, "Natural radionuclide activity concentrations and radiological hazard in tea, coffee, wheat flour, and powder milk consumed in Iraqi markets," in AIP Conf. Proc., vol. 2213, no. 1, New York, USA: AIP Publishing LLC, 2020, p. 020225.

[10] M. H. Kheder, "Measurement of radon concentration using SSNTD in Bartella region," Al-Mustansiriyah J. Sci., vol. 29, no. 4, p. 110, 2019.

[11] D. Bakircioglu, N. Topraksever, S. Yurtsever, and Y. Kurtulus, "ICP-OES determination of some trace elements in herbal oils using a three-phase emulsion method and comparison with conventional methods," At. Spectrosc., vol. 39, no. 1, pp. 38-45, 2018.

[12] A. Szydłowska-Czerniak, K. Trokowski, G. R. Karlovits, and E. Szłyk, "Spectroscopic determination of metals in palm oils from different stages of the technological process," J. Agric. Food Chem., vol. 61, no. 9, pp. 2276-2283, 2013.

[13] L. Luo et al., "Heavy metal contaminations in herbal medicines: Determination, comprehensive risk assessments, and solutions," Front. Pharmacol., vol. 11, p. 595335, 2021.

[14] D. G. Barnes et al., "Reference dose (RfD): Description and use in health risk assessments," Regul. Toxicol. Pharmacol., vol. 8, no. 4, pp. 471-486, 1988.

[15] Patrick-Iwuanyanwu and N. C. Chioma, "Evaluation of heavy metals content and human health risk assessment via consumption of vegetables from selected markets in Bayelsa State, Nigeria," Biochem. Anal. Biochem., vol. 6, no. 332, pp. 2161-1009.1000332, 2017.

[16] K. Nduka, H. I. Kelle, and E. C. Ogoko, "Hazards and risk assessment of heavy metals from consumption of locally manufactured painkiller drugs in Nigeria," Toxicol. Rep., vol. 7, pp. 1066-1074, 2020.

[17] S. Giri and V. Jha, "Risk assessment (chemical and radiological) due to intake of uranium through the ingestion of drinking water around two proposed uranium mining areas, Jharkhand, India," Radioprotection, vol. 47, no. 4, pp. 543-551, 2012.

[18] R. Sawut et al., "Pollution characteristics and health risk assessment of heavy metals in the vegetable bases of northwest China," Sci. Total Environ., vol. 642, pp. 864-878, 2018.

[19] R. Assessment, Guidelines for Carcinogen Risk Assessment, 1999.