Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 6, 1875-1883
2025
Publisher: Learning Gate
DOI: 10.55214/25768484.v9i6.8265

Assessment of heavy metals and health risks of street vended foods in the Mangaung metro municipality, free State, South Africa

Ponts'o Letuka[1*], Sebolelo Jane Nkhebenyane[1], Zikhona Tywabi-Ngeva[2]
[1]Department of Environmental Health, Central University of Technology, Bloem-fontein 9301, South Africa; letlotloletuka@gmail.com (P.L) snkheben@cut.ac.za (S.J.N.K.).
[2]Department of Chemistry, Nelson Mandela University, Port Elizabeth, South Africa; Zikhona.Tywabi-Ngeva@mandela.ac.za (Z.T.N.).

Abstract: Street food vending is part of the informal sector that plays a significant role in improving the socio-economic status of vendors and the food security of consumers but faces safety challenges mostly due to anthropogenic activities and the lack of regulation. This study aimed to evaluate heavy metal contamination in commonly vended foods—pap, chicken, pork, and moroho/salads—in the Free State, South Africa, and assess the associated health risks to consumers. Shapiro-Wilk's normality test and Kruskal-Wallis H tests were used to compare means. Results indicated heavy metal contamination in all analyzed samples. The overall median and IQR in descending order: Fe 4.365(4.424), Zn 3.605(3.711), As 2.653(2.971), Pb 1.095(1.266), Cu 0.271(0.326), Cr 0.212(0.117), and Zn 0.023(0.027) mg/kg. A significant difference ($p < 0.05$) was found for As between all pairs, while other heavy metals showed some variations without statistical significance. The EDI values of all sample types were below the recommended dietary values, suggesting that the heavy metals may not pose a public health risk. The health risk assessment through ICLR and Hazard Index (HI) indicated potential cancer and non-cancer risks from heavy metals in street-vended foods, as ICLR $\geq 10^{-3}$ and HI > 1. This implies that habitual consumers are at risk of non-carcinogenic health conditions.
Keywords: *Cancer risk, Heavy metals, Non-cancer risk, Street vended foods.*

1. Introduction

Street food vending contributes to food security and social justice by nourishing communities, empowering vendors, and fostering cultural resilience. However, this sector faces safety challenges mostly due to anthropogenic activities. Studies have highlighted the prevailing contamination of various food substances and some street vended foods with heavy metals and various conditions leading to this contamination [1-3]. Some of the metals found in street vended foods in their reports include Pb, Cd, Hg, Sb, Mn and Al. Although consumers are advised to visually inspect food before purchasing, contamination of food with heavy metals which are present in parts per million (ppm) cannot be seen with the naked eye [4]. Food may intentionally (through adulteration) or unintentionally be contaminated with trace metals before, during or after processing.

Throughout the street food production and vending processes, the unintentional contamination with toxic metals can occur and influenced by numerous factors including environmental conditions during growth to post harvest handling, storage and preparation of meals, selection of raw materials and even the vending sites [5]. Heavy metal contamination may also arise from poor packaging, vehicular exhaust emissions, indiscriminate waste disposal, industrial pollutants and other environmental pollutants in the vicinity of the vending stalls Ankar-Brewoo, et al. [6] further adds that metals used for food processing equipment material may contribute to leaching of toxic metals into food.

History: Received: 16 April 2025; Revised: 20 May 2025; Accepted: 23 May 2025; Published: 21 June 2025
* Correspondence: letlotloletuka@gmail.com

Street vended food have also been found to have the potential to greatly contribute to the daily intake of essential trace elements otherwise known as essential minerals [7]. However, data on bioavailability of these essential minerals is not widely known. Sufficient intake of essential minerals throughout the human life is necessary- about 1-2500 mg per day depending on the mineral- is essential for immune functions and biochemical processes that facilitate growth and chronic disease prevention [8, 9]. The essential minerals are divided into two classifications, namely, macrominerals and microminerals. Macrominerals are those that are required in greater quantities and these include calcium, magnesium, potassium and sulphur, while micronutrients are those that are only necessary in smaller amounts, these include zinc, iron, selenium, manganese, copper, chromium, and boron [10]. These implies that the insufficient supply of macronutrients or over consumption of micronutrients could be problematic to human health and development. The objective of this study was to assess the level of heavy metals in ready-to-eat street vended foods in MMM, Free State, South Africa.

2. Materials and Methods

2.1. Food Sample Characterization

A variation of 4 different food samples were collected around marketplaces and taxi ranks in the 7 towns within the Mangaung Metropolitan Municipality (MMM), namely: Thaba Nchu, Bloemfontein, Botshabelo, Wepener, Soutpan, Van Stadensrus and Dewetsdorp. These samples consisted of pap, chicken, pork and moroho/salads. Samples were collected from 6 vendors in each town, thereby resulting in 168 food samples in total.

Table 1.
Types of food samples collected.

Food sample	Composition and preparation
Pap	Maize meal cooked to a stiff consistency with water. Sometimes salt is added for taste
Chicken	Seasoned chicken portions/cuts grilled on an open flame, often using coal or wood.
Pork	Seasoned pork portions/cuts grilled on an open flame, often using coal or wood
Moroho/ salads	Fried green vegetables such as kale, with spices, or varied mixtures of raw vegetables such as lettuce, tomatoes, onions etc

2.2. Sample Preparation

The concentration of HMs in the street-vended samples was determined using ICPE (ICPE-9820, Shimadzu, Japan) and sample preparation was done following the method of Kaushik, et al. [11]. All reagent solutions were prepared using analytical-grade reagents dissolved in deionized water. The samples (168) were dried at 105 °C for 3–4 h in a hot-air oven, followed by manual crushing using a mortar and pestle and sieving. A sample of 0.5 g was then digested using a closed vessel microwave digestion method (model to be confirmed) with a mixture of 65 % HNO_3, 36 % HCl, and 30 % H_2O_2. The digestion parameters were as follows: 130 °C for 10 min, 150 °C for 5 min, 180 °C for 5 min, and 210 °C for 15 min, with a power of 400 w. After digestion, the sample was filtered, and the volume was adjusted to 50 mL without further dilution.

2.3. Determination of Heavy Metals USING ICP-OES

The amount of arsenic, cadmium, chromium, lead, iron, copper and zinc in prepared solutions was then determined using inductively coupled plasma optical emission spectrometer (ICP-OES), IRIS Interpid II XSP Model and using five standard solutions (10, 50, 100, 500 and 1000 µg L–1) for each heavy metal.

2.4. Health Risk Assessment

To determine the health risk posed by the heavy metals, concentrations of carcinogenic and non-carcinogenic metals obtained from various food samples were used. Oral reference doses (RfD) of heavy metals were obtained from United States Environmental Protection Agency (US EPA) and the Agency

DOI: 10.55214/25768484.v9i6.8265

for Toxic Substances and Disease Registry [12, 13]. The health risk assessment was done following methods by Muhammad, et al. [14]; Bamuwamye, et al. [15] and Onyele and Anyanwu [16]. The presumption was made that the amount of contaminant ingested equals the dose adsorbed, and cooking was considered to have no impact on the toxicity of the heavy metals in the street vended foods.

Table 2.
Oral reference doses of heavy metals.

Metal	RfD (mg/kg/day)
Arsenic	0.0003
Cadmium	0.0005
Chromium	0.0003
Copper	0.04
Lead	0.0035
Iron	0.007
Zinc	0.3

Source: United States Environmental Protection Agency (USEPA) [12] and Agency for Toxic Substances and Disease Registry (ATSDR) [13].

2.5. Estimated Daily Intake

The estimated daily intake depends on the metal concentration, ingestion/consumption rate and body weight. The EDI was determined using equation 1:

$$EDI = \frac{C_{metal} \times D_{food\ intake}}{BW_{average}} \quad (1)$$

Where C is the metal concentration in food (mg/kg) and D represents the daily intake of food in kg per person, and BW is the average body weight in kg (70 kg for adults).

2.6. Carcinogenic Risks

To assess both the cancer and non-cancer risk presented by exposure to heavy metals, the Chronic Daily Intake (CDI) was calculated following equation 2. However, the probable cancer risk associated with exposure to a measured dose of a heavy metal can be estimated using Incremental Lifetime Cancer Risk (ILCR). The ICLR was worked out using the Cancer Slope Factor (CSF), which is considered as the risk produced by lifetime average dose of 1 $mgkg^{-1}$ $BWday^{-1}$ and is contaminant specific. ICLR was calculated for As, Cd, Pb and Cr using respective slope factors (mgkg-1day-1) following equation 3 [15, 17].

$$CDI = \frac{C_W \text{ x IR x EF x ED}}{B_W \text{x AT}} \quad (2)$$

$$ICLR = CDI \text{ x } CSF \quad (3)$$

Table 3.
Parameters used for calculating CDI and ICLR.

Factor/parameter	Symbol	Units	Adult
Exposure duration	ED	Years	30
Lifetime		Years	70
Exposure frequency	EF	days/year	365
Average time	AT: Lifetime x 365 or ED x 365	Days	25 550 or 10 950
Body weight	B_w	Kg	70
Oral Cancer Slope Factor	CSF	(mg/kg/day)^-1	As- 1.5; Cd- 0.38; Cr- 0.5; Pb-0.0085
Ingestion rate	IR: Pap Chicken Pork Moroho/salad	kg/day	 0.366 0.105 0.105 0.252

2.7. Non Carcinogenic Risk

2.7.1. Hazard Quotient

HQ values were used to determine the potential for non-carcinogenic health risk that could occur as a result of heavy metal oral exposure. The HQ was determined using equation 4 as the human exposure to a metal of interest (mg/kg/day) divided by its reference dose (mg/kg/day) [18].

$$HQ = \frac{CDI}{RfDo} \qquad (4)$$

The chronic hazard index (HI) was calculated as a sum of all hazard quotients (HQ) calculated for individual heavy metals for a particular exposure pathway [19]. This was to allow for evaluation of potential risk to consumer health as a result of exposure to more than one heavy metal. The HI was determined using equation 5.

$$HI = HQ_1 + HQ_2 + \cdots + HQ_n \qquad (5)$$

It is assumed that the overall impact on human health increases in direct proportion to the sum of different heavy metals on is exposed to [20]. According to standards, the population is considered safe when HI<1 and at risk when HI>1 [21].

2.8. Statistical Analysis

Quantitative data was captured on excel in preparation for statistical analysis. Various statistical analyses were carried out on the quantitative data using computer-based SPSS software version 26. A normality test was performed for the continuous variables in order to ascertain which methods would be appropriate for analyzing the variables. Visual inspection i.e., looking at the histogram and Q-Q plots, was used to investigate normality of the data. However, since the visual inspection may not be reliable, the Shapiro-Wilk's normality test was also used to establish whether the data followed a normal distribution. The Kruskal-Wallis H tests was carried out to evaluate differences between mean of different heavy metals in different food types and sampling areas. Subsequently, the Pairwise Comparison with significance values having been adjusted for by the Bonferroni correction for multiple tests was done for both food types and sampling areas. The significance level was 0.05. Data did not have a normal distribution and the assumption of equality of variance was not fulfilled, hence the need to use non-parametric test.

3. Results and Discussions

The test for normality indicated that all the data sets were not normally distributed (p< 0.01). Therefore, the median and interquartile range have been reported on. The results obtained indicated that there was heavy metal contamination in all analysed samples. The overall median and IQR from all food samples were as follows: of As, Cd, Cr, Cu, Fe, Pb, and Zn were As-2.653(2.971), Cd-0.023(0.027), Cr0.212(0.117), 0.271(0.326), 4.365(4.424), 1.095(1.266), and 3.605(3.711) mg/kg respectively. Iron had the highest overall concentration, 4.365(4.424) mg/kg, while cadmium had the lowest concentration 0.023(0.027) mg/kg. Furthermore, a Kruskal-Wallis test was done and results showed that there was a statistically significant difference in the amount of As, Cd and Cu where p<0.001 between different food types. However, no statistically significant differences were observed among different food types for Cr, Fe, Pb and Zn. Table 4 below depicts the mean concentrations of heavy metals obtained from the street vended foods in MMM.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 6: 1875-1883, 2025
DOI: 10.55214/25768484.v9i6.8265

Table 4.
Means of heavy metal concentration (mg/kg) in MMM street vended foods.

Heavy Metals	Food type			
	Pap	Chicken	Pork	Moroho/salad
As	2.034±0.037	6.117±1.011	1.022±0.529	4.367±0.645
Cd	0.018±0.013	0.168±0.218	0.022±0.012	0.028±0.023
Cr	0.2±0.061	0.197±0.079	0.227±0.124	0.196±0.076
Cu	0.208±0.062	0.172±0.072	0.577±0.223	0.423±0.174
Fe	4.467±2.402	4.477±2.454	4.529±2.518	4.325±2.568
Pb	1.2±0.707	1.108±0.693	1.192±0.699	1.141±0.673
Zn	3.678±1.972	3.574±2.072	3.519±1.987	3.458±2.021

A Kruskal-Wallis Test (one-way non-parametric ANOVA) was done on the concentration of heavy metals present in the different food types. For this test, a comparison between groups based on the mean rank of the dependent variable (heavy metal concentration) was done. The null hypothesis stated that concentration distributions across different food types is the same. The multiple pairwise comparisons between different food types is presented in Table 5. For As, there was a statistically significant difference ($p < 0.05$) between all pairs. However, for Cd, a significant difference was observed only among the following pairs: pap and chicken, pork and chicken, and moroho/salad and chicken. Copper concentrations were significantly different only among the following pairs: chicken and moroho/salad, chicken and pork, pap and moroho/salad, and pap and pork. Notably, no significant differences ($p > 0.05$) were observed among all pairs for Cr, Fe, Pb and Zn concentrations.

This analysis suggests that for some heavy metals, there is a real and meaningful difference in the levels of contamination between the compared food samples. Considering the location of the sampling areas (urban areas with busy traffic), this difference can be attributed to various anthropogenic activities such as industrial activities, motor vehicle emissions, choice of cooking utensils, as well as some environmental factors [22].

3.1. Health Risks

To quantitatively evaluate the likely health risks posed to street vended food consumers within the Mangaung Metro Municipality, a health risk assessment was carried out. The results of which are presented in Tables 6 to 9 below.

Table 6.
EDI of heavy metal for adults through consumption of street vended foods (mg/kg/day).

Food type	As	Cd	Cr	Cu	Fe	Pb	Zn
Pap	0.01	0.0007	0.001	0.001	0.02	0.006	0.02
Chicken	0.0002	0.0002	0.001	0.0003	0.007	0.002	0.005
Pork	0.002	0.003	0.003	0.0009	0.007	0.002	0.005
Moroho/salad	0.02	0.00009	0.0007	0.002	0.02	0.004	0.01
Recommended daily dose (mg/kg/day)	0.13 [23]	0.062 [24]	0.035 [25]	2-3 [26]	18 [27]	0.21 [23]	14-20 [26]

Table 6 shows the Estimated Daily Intake (EDI) of heavy metals for adults with a body weight of 70kg. The EDI of As ranged between 0.0002 and 0.02 mg/kg/day with the highest value being obtained from mohoro/salad. The EDI of Cr and Cd from the street foods was highest in pork (0.003) mg/kg/day). Moroho/salad, among all other food types, had the highest EDI of both Cu and Fe, 0.002 and 0.02 mg/kg/day respectively. Daily intake rate of Pb and Zn ranged from 0.002 to 0.006 mg/kg/day and 0.005 to 0.02 g/kg/day respectively. These results indicate that the EDI values for the examined food samples are below the recommended dietary values. Therefore, the heavy metals assessed in this study through the consumption of the selected food samples do not pose a public health risk.

Table 7.
The Chronic Daily Intake of heavy metals in adults (mg/kg/day).

Heavy Metal	Food type			
	Pap	**Chicken**	**Pork**	**Moroho/salad**
Copper	0.001	0.0003	0.0001	0.002
Iron	0.023	0.007	0.007	0.016
Zinc	0.019	0.005	0.005	0.013
Arsenic	0.011	0.009	0.002	0.016
Cadmium	<0.0000	0.0003	<0.0000	0.0001
Chromium	0.001	0.0003	0.0003	0.0007
Lead	0.006	0.002	0.002	0.004

Table 7 indicates the CDI of heavy metals which was used to calculate the ICLR. The CDI data obtained suggests that regular consumption of these ready-to-eat foods could result in cumulative exposure to heavy metals, thereby warranting continuous monitoring and control measures. According to USEPA, a one in a million chance of cancer over a 70 year lifetime period (ICLR=10^{-6}) is considered acceptable, while ICLR of or greater than 10^{-3} (one in a thousand) is said to be serious and is a cause for remediation [28]. In this study, cancer risk was computed as $2.44\text{x}10^{-2}$ for highest and $3.17\text{x}10^{-3}$ for lowest risk for moroho/salad and pork respectively. Cumulatively, all ICLR was found to be equal to greater than what is considered to be increased risk of cancer (10-3) as reflected in Table 8. The chronic exposure to low concentrations of heavy metals such as Pb, As and Cd has the potential to result in many forms of cancers and other toxic effects [29, 30]. For chromium, its toxicity is dependent on its chemical composition. The health effects of chromium exposure can include, but are not limited to respiratory problems, lung cancer and skin effects [31].

Table 8.
ICLR for the adult population of MMM through the consumption street vended foods.

Heavy Metal	Food type			
	Pap	**Chicken**	**Pork**	**Moroho/salad**
Arsenic	$1.65\text{x}10^{-2}$	$1.35\text{x}10^{-2}$	$3.00\text{x}10^{-3}$	$2.40\text{x}10^{-2}$
Cadmium	0	$1.14\text{x}10^{-4}$	0	$3.80\text{x}10^{-5}$
Chromium	$5.00\text{x}10^{-5}$	$1.50\text{x}10^{-4}$	$1.50\text{x}10^{-4}$	$3.50\text{x}10^{-4}$
Lead	$5.10\text{x}10^{-5}$	$1.70\text{x}10^{-5}$	$1.70\text{x}10^{-5}$	$3.4\text{x}10^{-5}$
∑ICLR	$1.66\text{X}10^{-2}$	$1.38\text{x}10^{-2}$	$3.17\text{x}10^{-3}$	$2.44\text{x}10^{-2}$

Table 9.
The Hazard Quotient of Heavy Metal for Oral Ingestion in Adults.

Heavy Metal	Food type			
	Pap	**Chicken**	**Pork**	**Moroho/salad**
Copper	0.025	0.008	0.003	0.05
Iron	3.286	1	1	2.286
Zinc	0.063	0.017	0.017	0.043
Arsenic	36.67	30	6.67	53
Cadmium	<0.001	0.6	<0.001	0.2
Chromium	0.33	1	1	2.33
Lead	1.71	0.57	0.57	1.14
HI=∑HQ	*42.085*	*33.195*	*9.261*	*59.019*

Aina, et al. [32] describes hazard quotient as "a proportion of the probable exposure to an element or chemical at such a level with no expected negative impacts when the quotient is less than 1, but an indication of potential health risks resulting from and exposure, when it is greater than 1". The hazard quotients (HQ) were worked out to determine the non-cancer risk for all metals evaluated in this study and presented in table 9. The HQ in decreasing order or As, Fe, Pb, Cr, Zn, Cu and Cd for pap; As, Fe, Cr, Cd, Pb, Zn and Cu for chicken; As, Fe, Cr, Pb, Zn, Cu, and Cd for pork and As, Cr, Fe, Pb, Cd, Cu, and Zn for moroho/salad. The HQ was less than 1 in 86% (6 out of 7) of the heavy metals in chicken and pork, with As being the only heavy metal with a HQ >1. Similar observations were reported by Bamuwamye, et al. [15].

The hazard index (HI) for individual food types was calculated and the results in descending order were as follows: $HI\Sigma_{moroho/salad}$ 50.019, $HI\Sigma_{pap}$ 42.085, $HI\Sigma_{chicken}$ 33.195 and $HI\Sigma_{pork}$ 9.261. The HI of all sampled food types as per their daily ingestion rate indicated that consumers were at a significant non-carcinogenic health risk. From table 4.11, it can be noted that As THQs are the major contributors to the very high HI in all food types. Contrary to the findings of this study, Kaushik, et al. [11] reported a target hazard quotient and hazard index of <1 for all analyzed metals, which was indicative of health risks being lower.

4. Conclusions

All food samples analysed in this study tested positive for all heavy metals tested. Although some of the metals are essential trace elements, exposure to them in concentrations exceeding safety standards can be detrimental to the health of consumers. The estimated daily intake obtained for all heavy metals was below recommended limits, thereby indicating no real risk to public health. The results portrayed by the incremental lifetime cancer risk indicate a necessity for remediation. Moreover, the hazard index of different food types was high (HI>1). This implies that habitual consumers are at risk of non-carcinogenic health conditions. The high HI observed could be a result of various reasons such as low RfD and the cumulative exposure to multiple heavy metals.

Funding:
This research was funded by the Central University of Technology Research Fund and the Lesotho Manpower Development Secretariat. The APC was funded by Central University of Technology Research Fund.

Transparency:
The authors confirm that the manuscript is an honest, accurate and transparent account of the study that no vital features of the study have been omitted and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Acknowledgments:
The authors would like to thank and acknowledge Ms Motena for the role she played during the analysis of samples.

References

[1] O. Ekhator, N. Udowelle, S. Igbiri, R. Asomugha, Z. Igweze, and O. Orisakwe, "Safety evaluation of potential toxic metals exposure from street foods consumed in mid-West Nigeria," *Journal of Environmental and Public Health*, vol. 2017, no. 1, p. 8458057, 2017. https://doi.org/10.1155/2017/8458057

[2] N. Soliman, "Metals contents in black tea and evaluation of potential human health risks to consumers," *Health Economics & Outcome Research: Open Access*, vol. 2, no. 1, pp. 1-4, 2016.

[3] K. Goswami and I. Mazumdar, "Lead: The silent killer in our favourite street food," *Group*, vol. 3, no. 4.1, pp. 3.8-0.42, 2016.

[4] S. Malhotra, *Food safety issues related to street vendors. In Food safety in the 21st century*. Cambridge, MA: Academic Press, 2017.

[5] B. J. Birgen, L. G. Njue, D. M. Kaindi, F. O. Ogutu, and J. O. Owade, "Determinants of microbial contamination of street-vended chicken products sold in Nairobi County, Kenya," *International Journal of Food Science*, vol. 2020, no. 1, p. 2746492, 2020. https://doi.org/10.1155/2020/2746492

[6] G. M. Ankar-Brewoo *et al.*, "Health risks of toxic metals (Al, Fe and Pb) in two common street vended foods, fufu and fried-rice, in Kumasi, Ghana," *Scientific African*, vol. 7, p. e00289, 2020. https://doi.org/10.1016/j.sciaf.2020.e00289

[7] J. Hill, Z. Mchiza, T. Puoane, and N. P. Steyn, "Food sold by street-food vendors in Cape Town and surrounding areas: a focus on food and nutrition knowledge as well as practices related to food preparation of street-food vendors," *Journal of Hunger & Environmental Nutrition*, vol. 14, no. 3, pp. 401-415, 2019. https://doi.org/10.1080/19320248.2018.1434104

[8] C. S. Silva, C. Moutinho, A. Ferreira da Vinha, and C. Matos, "Trace minerals in human health: Iron, zinc, copper, manganese and fluorine," *International Journal of Science and Research Methodology*, vol. 13, no. 3, pp. 57-80, 2019.

[9] M. Mostafidi, F. Shirkhan, M. T. Zahedi, P. Ziarati, B. Hochwimmer, and L. Cruz-Rodriguez, "Bioaccumulation of the heavy metals contents in green leafy vegetables," *Journal of Nutrition Food Science and Technology*, vol. 2, no. 1, pp. 1-7, 2021.

[10] B. K. Lere, I. Basira, S. Abdulkadir, S. M. Tahir, H. A. Ari, and A. Y. Ugya, "Health risk assessment of heavy metals in irrigated fruits and vegetables cultivated in selected farms around Kaduna metropolis, Nigeria," *Egyptian Journal of Basic and Applied Sciences*, vol. 8, no. 1, pp. 317-329, 2021. https://doi.org/10.1080/2314808X.2021.1992956

[11] R. Kaushik *et al.*, "Determination of heavy metals in vended Indian street foods: Application of advanced multivariate analysis," *Journal of Food Composition and Analysis*, vol. 123, p. 105592, 2023. https://doi.org/10.1016/j.jfca.2023.105592

[12] United States Environmental Protection Agency (USEPA), *IRIS: Integrated risk information system.* Washington, DC: U.S. Environmental Protection Agency, 2014.

[13] Agency for Toxic Substances and Disease Registry (ATSDR), *Toxicological profiles.* Atlanta, GA: U.S. Department of Health and Human Services, 2024.

[14] S. Muhammad, M. T. Shah, and S. Khan, "Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan," *Microchemical Journal*, vol. 98, no. 2, pp. 334-343, 2011. https://doi.org/10.1016/j.microc.2011.03.003

[15] M. Bamuwamye, P. Ogwok, and V. Tumuhairwe, "Cancer and non-cancer risks associated with heavy metal exposures from street foods: Evaluation of roasted meats in an urban setting," *Journal of Environment Pollution and Human Health*, vol. 3, no. 2, pp. 24-30, 2015.

[16] O. G. Onyele and E. D. Anyanwu, "Human health risk assessment of some heavy metals in a rural spring, southeastern Nigeria," *African Journal of Environment and Natural Science Research*, vol. 1, no. 1, pp. 15-23, 2018.

[17] Y. Qing *et al.*, "Cancer risk and disease burden of dietary cadmium exposure changes in Shanghai residents from 1988 to 2018," *Science of the Total Environment*, vol. 734, p. 139411, 2020. https://doi.org/10.1016/j.scitotenv.2020.139411

[18] C. Benson *et al.*, "The effect of iron deficiency and anaemia on women's health," *Anaesthesia*, vol. 76, pp. 84-95, 2021. https://doi.org/10.1111/anae.15405

[19] A. Badeenezhad *et al.*, "Comprehensive health risk analysis of heavy metal pollution using water quality indices and Monte Carlo simulation in R software," *Scientific Reports*, vol. 13, no. 1, p. 15817, 2023. https://doi.org/10.1038/s41598-023-43161-3

[20] M. S. Sultana, S. Rana, S. Yamazaki, T. Aono, and S. Yoshida, "Health risk assessment for carcinogenic and non-carcinogenic heavy metal exposures from vegetables and fruits of Bangladesh," *Cogent Environmental Science*, vol. 3, no. 1, p. 1291107, 2017. https://doi.org/10.1080/23311843.2017.1291107

[21] Agency for Toxic Substances and Disease Registry (ATSDR), *Calculating hazard quotients and cancer risk estimates.* United States: U.S. Department of Health and Human Services, Public Health Service, 2022.

[22] A. Abas, A. Awang, and K. Aiyub, "Analysis of heavy metal concentration using transplanted lichen Usnea misaminensis at Kota Kinabalu, Sabah (Malaysia)," *Applied Ecology & Environmental Research*, vol. 18, no. 1, pp. 1175–1182, 2020.

[23] Z. Ullah, A. Naz, U. Saddique, A. Khan, W. Shah, and S. Muhammad, "Potentially toxic elements concentrations and human health risk assessment of food crops in Bajaur Agency, Pakistan," *Environmental Earth Sciences*, vol. 76, no. 11, p. 482. , 2017. https://doi.org/10.1007/s12665-017-6824-1

[24] S. Satarug, D. A. Vesey, and G. C. Gobe, "Health risk assessment of dietary cadmium intake: Do current guidelines indicate how much is safe?," *Environmental Health Perspectives*, vol. 125, no. 3, pp. 284–288, 2017. https://doi.org/10.1289/ehp108

[25] Harvard T.H. Chan School of Public Health, *Nutrition source: Food features — Heavy metals in foods.* . Boston, MA: Harvard University, 2023.

[26] Food and Agriculture Organization of the United Nations & World Health Organization, "Evaluation of certain food additives and contaminants," WHO Technical Report Series No. 859. Geneva: World Health Organization, 1995.

[27] National Research Council, *Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc.* Washington, DC: National Academies Press, 2001.

[28] X. Li, Y. Li, and Z. Li, *Assessment of cancer risk from heavy metals in food items: A case study on moroho/salad and pork consumption*. Beijing, China: Environmental Protection Press, 2013.

[29] T. Bhattacharjee, S. Bhattacharjee, and D. Choudhuri, "Hepatotoxic and nephrotoxic effects of chronic low dose exposure to a mixture of heavy metals-lead, cadmium and arsenic," *International Journal of Pharmaceutical, Chemical & Biological Sciences*, vol. 6, no. 1, pp. 48–56, 2016.

[30] S. J. Flora and S. Agrawal, *Arsenic, cadmium, and lead. In Reproductive and developmental toxicology*. USA: Academic Press, 2017.

[31] A. Teklay, "Physiological effect of chromium exposure: A review," *International Journal of Food Science, Nutrition and Dietetics*, vol. 7, pp. 1-11, 2016. https://doi.org/10.19070/2326-3350-si07001

[32] O. Aina, L. Mugivhisa, J. Olowoyo, and C. Obi, "Nutritional quality assessment and safety evaluation of food crops," *Applied Ecology & Environmental Research*, vol. 21, no. 6, pp. 1-18, 2023.