Presence of Heavy Metals in Vegetables Irrigated with Wastewater-Impacted Rivers and Its Health Risks in Ethiopia: Systematic Review

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ABSTRACT

BACKGROUND: Vegetables play critical role in human nutrition and overall health. However, consumption of vegetables cultivated through wastewater-impacted river can be source of potentially toxic heavy metals, which can cause detrimental health effects when their concentration exceeds the recommended maximum levels. Despite growing body of evidence highlighting the dangers associated with heavy metal accumulation in vegetables, there remains critical gap in systematic assessments within Ethiopian context. Therefore, objective of this review is to reveal heavy metals concentrations in vegetables grown with wastewater-impacted river and assess associated public health risks.

METHODOLOGY: Research articles published in English were identified through systematic searching using electronic databases including PubMed, Google Scholar, WHO/FAO library, and searching from Google manually. The outcomes of interest were mean concentration of heavy metals in vegetables and associated health risks. Cross-sectional studies that met inclusion criteria were considered. Data were extracted by independent reviewers. Methodological quality of included studies was assessed using critical appraisal tools. Moreover, health risks of consumers were assessed through evaluating estimated daily intakes (EDI), Health Risk Index (HRI), and Hazard Index (HI).

RESULTS: Nineteen articles were included in this systematic review. The findings revealed that the mean concentration of Pb, Cr, Cd, As, Hg, Cu, Ni, Zn, Mn, and Fe in tested vegetables ranged from: 0.28-7.68, 0.75-33.01, 0.14-3.93, 0.05-3.13, ND-4.25, 0.92-15.33, 2.13-13.1, 18.27-62.83, 8.83-331.8, and 177.8-1034.3 mg/kg (dry weight), respectively. The EDI of Pb, Cr, Cd, As, Hg, Cu, Ni, Zn, Mn, and Fe in vegetables was range from: 0.00104-0.0286, 0.00279-0.123, 0.00052-0.0146, 0.0000372-0.0116, 0.0124-0.0158, 0.00342-0.0439, 0.0079-0.0487, 0.068-0.23, 0.03-1.23, and 0.53-3.84 mg/kg/day, respectively. The HRI of toxic heavy metals for all vegetable types ranged as; Pb (0.26-7.15), Cr (0.00186-0.0820), Cd (0.52-14.6), As (0.12-38.7), and Hg (1.24-1.58). The HRI due to consumption of all vegetables was 35, 0.168, 46.6, 70, and 2.82 for Pb, Cr, Cd, As, and Hg, respectively indicating severe health impact except for Cr.

CONCLUSION: This review underscores health implications linked to consumption of vegetables cultivated using wastewater in Ethiopia. It revealed that the concentration of toxic heavy metals in vegetables grown with wastewater-affected water was higher than the maximum allowable safe limit set for edible vegetables by WHO that would be a public health risk.

KEYWORDS: Heavy metals, vegetables, wastewater-impacted river, health risks, Ethiopia

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Introduction

Vegetables, being a rich source of essential minerals, vitamins, dietary fibers, and phytochemicals, play a pivotal role in human nutrition and overall health.[1] The recommended daily intake of vegetables ranges from 3 to 5 servings, with a minimum requirement of 0.100 kg for adults and 0.05 kg for children.[2,3] The World Health Organization (WHO) further recommends a daily intake of 240 g of vegetables per person[4] and vegetarians may consume even higher amounts of vegetables.

However, vegetables can also be a source of potentially toxic elements like heavy metals, including Arsenic (As), Cadmium (Cd), Chromium (Cr), Lead (Pb), and Mercury (Hg). These elements, even at lower exposure levels, can cause systemic damage to multiple organs due to their high toxicity.[5] Heavy metals, such as Copper (Cu), Iron (Fe), Manganese (Mn), Nickel (Ni), and Zinc (Zn), are essential micronutrients for humans but can cause detrimental health effects when their concentration exceeds the WHO's recommended maximum level.[6]

The cultivation of vegetables through wastewater-impacted rivers is a primary source of these heavy metals.[7] Globally, up to 50% of all wastewater is released into the environment without any treatment, particularly into aquatic ecosystems.[8] This issue is especially prevalent in Sub-Saharan Africa, where 80% of wastewater is discharged untreated, jeopardizing the overall quality of the soil and water environment.[9,10]

Due to rapid urbanization and water scarcity, wastewater reuse in agriculture has become increasingly important. It is estimated that a minimum of 10% of the world's population consumes crops irrigated by wastewater.[11] While this practice offers benefits such as expanded agricultural potential and eased pressure on existing water sources, it also carries environmental and human health risks due to contaminants in wastewater, including heavy metals and organic pollutants like pharmaceuticals.[12]

In Ethiopia, for instance, vegetables in urban areas are often irrigated with wastewater.[13] Despite only 3% of all wastewaters being safely managed, the remaining 97% are discharged without treatment, leading to the cultivation of potentially contaminated produce.[9,12] The rapid expansion of chemical industries has introduced hazardous heavy metals into the environment through various pathways, including plants, air, soil, and water.[14] Urban wastewater, enriched with heavy metals from various sources, contributes to the contamination of vegetables irrigated with wastewater-affected water sources.[15-17]

Heavy metals, due to their non-biodegradable properties, extended half-lives, and pronounced bioaccumulation potential, represent significant contaminants in vegetables.[18] These toxic elements can accumulate in both edible and non-edible parts of vegetables, reaching levels that pose clinical risks to consumers, including animals and humans.[17,19] Heavy metals can cause nutritional depletion by significantly reducing essential nutrients in the body and are associated with various diseases such as upper gastrointestinal cancer, cardiovascular disorders, kidney dysfunction, nervous system disorders, and bone diseases.[20]

In most developed nations, routine inspections and tracking programs have been implemented for decades to measure the levels of heavy metals in food items.[21] In Ethiopia, numerous studies have been conducted to ascertain the metal content in vegetables harvested from various regions in the last decade. Most of these studies, particularly those concerning vegetables irrigated with wastewater-impacted river water, have found high concentrations of heavy metals.[22-24]

Despite the consistent individual studies on the concentrations of heavy metals in vegetables and other agricultural products within the country, there is a notable scarcity of comprehensive, aggregated data. Therefore, the objective of this systematic review is to elucidate the concentrations of heavy metals in vegetables grown with wastewater-impacted river in Ethiopia and assess the associated public health risks. This information is vital for understanding the potential implications, enabling relevant stakeholders to implement appropriate interventions, and ultimately safeguarding public health.

Methodology

Source of information and search strategy

Two reviewers (BN and NES) independently searched from PubMed, Google Scholar, and other databases including Hinari, AGORA, and the Cochrane Library databases for articles published from 2019 to 2024. Initially, a preliminary search was conducted using Medical Subject Headings (MeSH terms). Following the initial search, keywords were created based on the key terms found in searched articles. Then, both MeSH terms and keywords were used to search for articles in databases (Supplemental S1 file).

Eligibility criteria

Articles that fulfilled the following specified criteria were incorporated into the systematic review:

- *Study area*: Research articles conducted in Ethiopia.
- *Study design*: Experimental cross-sectional studies.
- *Language*: Research articles published in English language.
- *Population*: Research articles conducted on any types of vegetable.
- *Publication*: Published full text articles from 2019 to 2024.
- *Outcome*: Research articles reported the quantitative outcome of any heavy metal concentration with appropriate unit.

Study selection

All searched articles from different electronic databases were exported to EndNote reference management software version x7.1 (Thomson Reuters, USA); where duplicated articles were removed. An initial review of the articles was performed by examining their titles and abstracts. Following this, a thorough assessment of the full-text articles was carried out against the inclusion criteria to confirm their relevance to the study. PRISMA (Preferred Report for Systematic Review and Meta-Analysis) guidelines was used to summarize the data collection methods.[25]

Data extraction

Data from the selected articles were extracted using a pre-established data extraction form, using Microsoft Excel 2010. Information pertaining to the author, publication year, research area, research design, sample size, and results were obtained from these articles. The compiled data, which included key findings such as the concentration of heavy metals in various types of vegetables, the study location, and the year of publication, was organized and displayed in tabular and textual formats.

Quality assessment

For each included study, all authors, (BN, SF, DD, and NES), separately assessed the quality of included study using standard tools. The Hoy et al[26] tool was used to address internal and external validity using 10 criteria to assess the risk of bias (Supplemental S2 file). The main components of the tool were as follows: (1) population representation; (2) sampling frame;

(3) participant selection procedures; (4) non-response bias; (5) direct data collection from subjects; (6) acceptability of case definition; (7) reliability and validity of study tools; (8) results adequately expressed and parameters established; (9) occurrence levels given with deviation and for type of vegetable, if appropriate; and (10) appropriateness of numerator and denominator. There were two categories for each item: low bias risk and high bias risk. Not clear was categorized as having a high bias risk. The overall bias risk score was graded on the basis of how many studies have a high bias risk: low (2), moderate (3-4), and high (5).

Outcome measures

This systematic review aimed to measure two outcome of interest: heavy metal concentration in vegetables and public health risks of the reviewed heavy metals as a result of vegetable consumption. The overall mean concentration of each heavy metal was calculated across all included study articles. The mean concentration of each heavy metal in vegetable was evaluated against FAO and WHO standard/guidelines for edible vegetables. The possible health risks of the target heavy metal was assessed through evaluating estimated daily intakes (EDI) based on mean concentration of heavy metals in vegetable and the estimated daily consumption of vegetables by consumers. The EDI value for each heavy metal was calculated using the following equation (1) as defined by Shaheen et al[27] and Mawari et al.[28]

$$\frac{F_{IR} \times C_M}{B_W} \tag{1}$$

Where, F_{IR} is the average daily consumption of vegetable per person (240 g/day),[4] C_M is the metal concentration (mg/kg dry weight), and B_W is the average body weight for Ethiopian adult people (64.5 kg).[29]

The Health Risk Index (HRI), also referred to as the Hazard Quotient (HQ), was calculated using the ratio of the estimated exposure (EDI) from vegetables to the oral reference dose (RfD). This index serves as an indicator of potential risks to human health. The calculation of this index was performed using previously defined specific equation (2).[30]

$$HRI = \frac{EDI}{RfD} \tag{2}$$

The oral reference dose (RfD) of As, Cd, Hg, Pb, Cr, Ni, Cu, Mn, and Zn were 0.0003,[31] 0.001,[31] 0.01, and 0.004,[31,32] 1.5, 0.02, 0.04, 0.033, and 0.3 mg/kg/day,[33] respectively.

The Hazard Index (HI) has been formulated to provide the potential risk of heavy metals to human health from exposure to multiple arrays of vegetables.[34] The calculation of the Hazard Index (HI) was performed using a specific equation (3)[28]:

$$\mathrm{HI} = \sum HQ = \sum HRI = \mathrm{HQ}_{\mathrm{As}} + \mathrm{HQ}_{\mathrm{Pb}} + \mathrm{HQ}_{\mathrm{Cr}} + \mathrm{HQ}_{\mathrm{Cd}} + \mathrm{HQ}_{\mathrm{Hg}} + \ldots\ldots \mathrm{HQ}_{\mathrm{n.}} \tag{3}$$

The presumption is that the severity of the negative impact is directly related to the total exposure to multiple metals. This also presupposes that the metals operate in similar ways that have a linear effect on the human organ in question. If the Hazard Index (HI) exceeds 1, it indicates an increased likelihood of experiencing non-carcinogenic health effects. The chance of these effects occurring escalates as the HI value increases.[35] Furthermore, HI greater than 10.0 indicates a severe long lasting health effect.[36] In this study, we have computed the hazard index for harmful elements such as Arsenic (As), Cadmium (Cd), Chromium (Cr), Mercury (Hg), and Lead (Pb).

Results

Study selection

Six hundred seventy four published articles and reports were identified from various electronic databases. Six hundred sixty seven articles were searched from electronic databases whereas seven articles were searched manually from Google. Among all searched articles, 237 were searched from PubMed, 175 from Hinari, 178 from AGORA, 71 from Google Scholar, and 13 articles were from Google through manual searching. Following the initial screening, 129 articles were screened, then 46 were sought for retrieval and 45 articles were assessed for eligibility. Finally, nineteen articles were included in this systematic review (Figure 1).

Characteristics of included articles

All (n = 19) articles were conducted in Ethiopia and primarily aimed to determine heavy metals concentration in vegetables grown with effluent-impacted river water. Of 19 studies included, 7 (36.85%) were conducted in Oromia region,[37-43] 4 (21.05%) in Amhara region,[44-47] 3 (15.80%) in Addis Ababa city,[48-50] 2 (10.52%) in Southern Nations and Nationalities People (SNNP),[51,52] 1 (5.26%) in Harari,[53] 1 (5.26%) in Sidama,[54] and 1 (5.26%) in Tigray[55] regional state.

Moreover, among included 19 articles,[37-55] 2 (10.52%) were published in 2024,[41,55] 3 (15.79%) in 2023,[37,46,49] 3 (15.79%) in 2022,[44,47,48] 4 (21.05%) in 2021,[43,45,52,54] 5 (26.32%) in 2020,[38-40,51,53] and 2 (10.52%) were published in 2019[42,50] (Table 1). All studies were, (laboratory based), cross-sectional. All studies included common heavy metals and about 94.74% of articles were graded as high quality (having ⩽2 score or low risk of bias).

Heavy metals concentration in vegetables

The mean concentration of Pb, Cr, Cd, As, Hg, Cu, Ni, Zn, Mn and Fe in tested common vegetables (ie, cabbage, lettuce, swiss chard, Ethiopian kale, spinach, tomato, onion, potato, carrot, beetroot, and khat) ranged from: 0.28-7.68, 0.75-33.01, 0.14-3.93, 0.05-3.13, ND-4.25, 0.92-15.33, 2.13-13.1, 18.27-62.83,

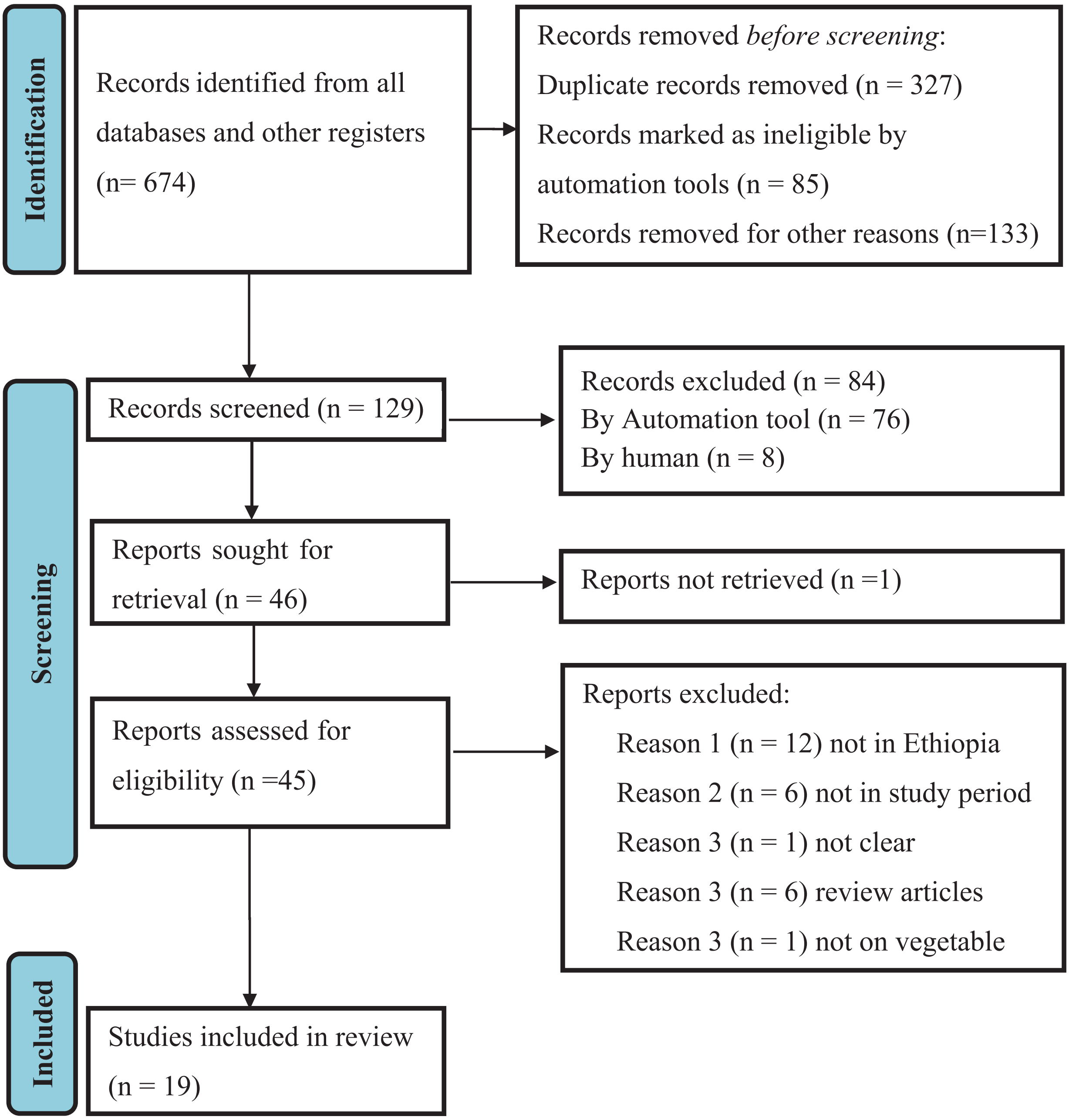

Figure 1. PRISMA flow diagram (2020) indicating the selection process of included articles.

8.83-331.8, and 177.8-1034.3 mg/kg dry weight, respectively. These evaluated vegetables are highly cultivated and commonly consumed in Ethiopia.

The concentration of the highly toxic heavy metals, including Pb, Cr, Cd, As, and Hg, detected in vegetables grown with wastewater impacted river water is shown in Figure 2. As can be seen in this figure, the highest mean concentration of chromium was found in onion. This might be due to the source of water for the irrigation (Awash River) which is impacted for long time by the wastewater discharge from Anmol Product Ethiopia PLC near Ginch town in Oromia region.[39] Beside this, chromium was also measured in high concentration in khat/*Catha edulis*. This can be explained by the presence of tannery industry in the vicinity of khat cultivated area, where the source of water for the irrigation impacted by the discharge of this industry.[47] On the other hand, higher concentration of Hg was detected in Cabbage and Tomato, 4.25 and 3.34 mg/kg respectively, grown with effluent affected water in Mojo[40] and Koka[43] of Oromia regional state. Lead was found almost in all studied vegetables in the included articles of this study. However, the heavy metal content of the vegetables analyzed shown a strong dependence on vegetable type; leafy and root vegetables had relatively higher metal concentrations.[56] Conversely, the current study found that onion, a bulb vegetable, contained the highest concentration of chromium (Cr), lead (Pb), and cadmium (Cd) compared to other evaluated vegetables.

Furthermore, the order of heavy metals based on overall mean concentration in total vegetables was found to be: Fe > Mn > Zn > Ni > Cu > Cr > Hg > Pb > Cd > As, while the order of toxic heavy metals in total vegetable was Cr > Hg > Pb > Cd > As (Table 2).

Table 1. Characteristics of studies included in the review (n = 19).

VEGETABLE	AUTHOR	YEAR	AREA	HEAVY METALS CONCENTRATION (MG/KG DRY WEIGHT)										RISK OF BIAS	REFERENCES
				PB	ZN	CU	CR	CD	NI	MN	FE	AS	HG		
Cabbage	Habte et al	2023	Addis Ababa	8.44	42.84	8.6	NS	NS	0.06	249.84	705.77	NS	NS	Low	[49]
	Lemessa et al	2022	Addis Ababa	0.169	4.96	NS	0.24	0.48	NS	NS	NS	NS	NS	M**	[48]
	Aschale et al	2019	Addis Ababa	NS	24.2	3.26	1.66	0.04	1.26	29.31	357.5	0.08	NS	Low	[50]
	Asrade et al	2023	Amhara	0.296	NS	2.806	0.758	ND	NS	NS	NS	NS	NS	Low	[46]
	Berihun et al	2021	Amhara	3.8	27.87	2.82	10	1.62	7.41	7.27	NS	NS	NS	Low	[45]
	Gebeyehu and Bayissa	2020	Oromia	7.56	23.53	9.42	4.63	1.56	4.13	302.23	490.46	5.73	4.23	Low	[40]
	Bayissa and Gebeyehu	2021	Oromia	6.98	35.33	15.06	4.8	1.015	2.96	92.23	396	6.56	4.26	Low	[43]
	Dagne et al	2019	Oromia	5.47	NS	NS	2.9	3.2	NS	NS	NS	NS	NS	Low	[42]
	Ejigu et al	2020	Oromia	ND	ND	ND	ND	ND	NS	NS	NS	NS	NS	Low	[39]
	Getnet et al	2020	Oromia	0.28	10.44	0.32	ND	ND	NS	NS	NS	NS	NS	Low	[38]
	Guadie et al	2020	SNNP	23.1	31	ND	ND	2.2	NS	35	190	NS	NS	Low	[51]
	Feseha et al	2021	SNNP	0.37	15.67	17.56	2.46	0.35	17.11	NS	NS	NS	NS	Low	[52]
	Bekele et al	2021	Sidama	0.26	118.5	4.16	0.51	0.315	0.61	NS	NS	0.13	NS	Low	[54]
	Alamnie et al	2020	Harar	0.17	NS	NS	1.53	0.93	NS	NS	NS	NS	NS	Low	[53]
Lettuce	Ketema et al	2023	Oromia	0.21	7	9.19	0.29	0.15	NS	NS	NS	NS	NS	Low	[37]
	Dagne et al	2019	Oromia	5.5	NS	NS	3.77	3.68	NS	NS	NS	NS	NS	Low	[42]
	Habte et al	2023	Addis Ababa	8.43	45.63	7.84	NS	NS	0.17	312.02	694.6	ns	NS	Low	[49]
	Lemessa et al	2022	Addis Ababa	0.2	4.6	NS	0.25	0.042	NS	NS	NS	ns	NS	M**	[48]
	Aschale et al	2019	Addis Ababa	NS	49.26	11.25	2.57	0.1	1.82	42.53	484.5	0.1	NS	Low	[50]
	Welde Amanuel and Kassegne	2022	Amhara	0.673	0.325	0.1	0.24	0.135	0.293	0.323	2.133	NS	NS	Low	[44]
	Asrade et al	2023	Amhara	0.297	NS	0.152	0.779	ND	NS	NS	NS	NS	NS	Low	[46]
	Berihun et al	2021	Amhara	2.38	64.55	1.61	6.66	0.23	48.14	41.52	NS	NS	NS	Low	[45]
	Guadie et al	2020	SNNP	17.2	40.1	ND	ND	2.1	NS	50	180		NS	Low	[51]
	Feseha et al	2021	SNNP	0.24	23.21	16.58	1.61	0.21	15.06	NS	NS	NS	NS	Low	[52]
	Tadesse et al	2024	Tigray	0.66	119	0.8	3.49	0.58	NS	18.8	450	0.03	ND	Low	[55]
	Alamnie et al	2020	Harari	0.27	NS	NS	2.6	0.5	NS	NS	NS	NS	NS	Low	[53]

(Continued)

Table 1. (Continued)

VEGETABLE	AUTHOR	YEAR	AREA	HEAVY METALS CONCENTRATION (MG/KG DRY WEIGHT)										RISK OF BIAS	REFERENCES
				PB	ZN	CU	CR	CD	NI	MN	FE	AS	HG		
Swiss chard	Ketema et al	2023	Oromia	0.25	7.1	8.58	0.33	0.18	NS	NS	NS	NS	NS	Low	[37]
	Habte et al	2023	Addis Ababa	8.06	45.49	9.57	NS	NS	0.24	531	860.01	NS	NS	Low	[49]
	Lemessa et al	2022	Addis Ababa	0.414	6.23	NS	0.725	0.0435	NS	NS	NS	NS	NS	M**	[48]
	Aschale et al	2019	Addis Ababa	NS	57.77	11.59	1.96	0.1	1.47	147.07	362.5	0.12	NS	Low	[50]
	Welde Amanuel and Kassegne	2022	Amhara	0.674	0.224	0.067	0.257	0.127	0.284	0.58	1.73	NS	NS	Low	[44]
	Berihun et al	2021	Amhara	9.52	48.65	1.88	11.66	1.38	51.85	76.66	NS	NS	NS	Low	[45]
	Feseha et al	2021	SNNP	0.328	25.36	10.42	1.265	0.392	11.62	NS	NS	NS	NS	Low	[52]
Ethiopian kale	Aschale et al	2019	Addis Ababa	NS	37.35	4.8	1.6	0.08	0.63	28.19	177.8	0.07	NS	Low	[50]
	Berihun et al	2021	Amhara	7.14	88.3	2.4	13.33	6.25	11.11	30.61	NS	NS	NS	Low	[45]
	Alamnie et al	2020	Harar	0.13	NS	NS	0.77	0.67	NS	NS	NS	NS	NS	Low	[53]
Spinach	Tadesse et al	2024	Tigray	0.61	ND	0.92	2.31	0.15	NS	17.2	503.4	0.01	ND	Low	[55]
	Alamnie et al	2020	Harar	0.06	NS	NS	2.23	0.37	NS	NS	NS	NS	NS	Low	[53]
Tomato	Lemessa et al	2022	Addis Ababa	0.061	4.12	NS	0.33	0.422	NS	NS	NS	NS	NS	M**	[48]
	Guadie et al	2020	SNNP	15	28.5	ND	ND	2	NS	70	285	NS	NS	Low	[51]
	Feseha et al	2021	SNNP	0.21	14.64	25.66	1.63	0.36	23.15	NS	NS	NS	NS	Low	[52]
	Asrade et al	2023	Amhara	0.274	NS	2.522	0.809	0.178	NS	NS	NS	NS	NS	Low	[46]
	Berihun et al	2021	Amhara	5.95	24.61	2	5.8	2.43	13.88	2.42	NS	NS	NS	Low	[45]
	Gebeyehu and Bayissa	2020	Oromia	3.63	24.5	16.27	1.49	0.56	1.86	27.2	85.1	1.93	3.43	Low	[40]
	Bayissa and Gebeyehu	2021	Oromia	2.215	18.01	10.8	0.88	0.415	1.115	17.98	63.36	0.98	3.245	Low	[43]
	Dagne et al	2019	Oromia	4.6	NS	NS	2.97	2.2	NS	NS	NS	NS	NS	Low	[42]
Onion	Habte et al	2023	Addis Ababa	7.68	44.23	9.23	NS	NS	0.18	659.59	1034.3	NS	NS	Low	[49]
	Berihun et al	2021	Amhara	ND	19.15	2.15	6.66	3.93	9.25	3.94	NS	NS	NS	Low	[45]
	Ejigu et al	2020	Oromia	ND	ND	ND	59.35	ND	NS	NS	NS	NS	NS	Low	[39]

(Continued)

Table 1. (Continued)

VEGETABLE	AUTHOR	YEAR	AREA	HEAVY METALS CONCENTRATION (MG/KG DRY WEIGHT)										RISK OF BIAS	REFERENCES
				PB	ZN	CU	CR	CD	NI	MN	FE	AS	HG		
Potato	Habte et al	2023	Addis Ababa	8.58	50.17	9.73	NS	NS	0.45	250	458.59	NS	NS	Low	[49]
	Aschale et al	2019	Addis Ababa	NS	14.63	5.24	1.43	0.04	0.55	5.4	101.75	0.03	NS	Low	[50]
	Asrade et al	2023	Amhara	0.507	NS	2.233	0.764	0.134	NS	NS	NS	NS	NS	Low	[46]
	Berihun et al	2021	Amhara	9.52	56.7	11.29	6.66	6.01	20.37	0.91	NS	NS	NS	Low	[45]
	Bekele et al	2021	Sidama	0.385	26.4	4.3	0.82	0.06	0.875	NS	NS	0.295	NS	Low	[54]
Carrot	Aschale et al	2019	Addis Ababa	NS	23.03	7.33	2.23	0.05	1	14.05	214.5	0.05	NS	Low	[50]
	Feseha et al	2021	SNNP	0.34	13.51	25.82	1.83	0.32	21.72	NS	NS	NS	NS	Low	[52]
	Asrade et al	2023	Amhara	0.507	NS	2.235	0.777	1.767	NS	NS	NS	NS	NS	Low	[46]
Beetroot	Habte et al	2023	Addis Ababa	10	47.75	9.75	NS	NS	ND	257.88	538.5	NS	NS	Low	[49]
	Asrade et al	2023	Amhara	0.301	NS	0.206	0.752	0.138	NS	NS	NS	NS	NS	Low	[46]
Khat	Ketema et al	2023	Oromia	0.28	10.6	12.1	0.28	0.2	NS	NS	NS	NS	NS	Low	[37]
	Damana et el	2024	Oromia	ND	26.43	18.55	1.44	ND	2.13	8.83	NS	NS	NS	Low	[41]
	Alemu and Tegegne	2022	Amhara	NS	NS	NS	35.7	NS	NS	NS	NS	NS	NS	Low	[47]

Abbreviations: **M, moderate; ND, not detected; NS, not studied.

Health risk implications of heavy metal concentrations in vegetables

EDI of heavy metals in vegetables. The Estimated Daily Intake (EDI) of ten heavy metals, namely As, Cd, Pb, Cr, Hg, Mn, Ni, Cu, Fe, and Zn, was determined based on the average concentration of each metal in different foods and their corresponding consumption rates. The EDI and the Maximum Tolerable Daily Intake (MTDI) of these metals, derived from the consumption of vegetables, are presented in (Table 3). Accordingly, the EDI of Pb, Cr, Cd, As, Hg, Cu, Ni, Zn, Mn, and Fe in vegetables was range from: 1.04×10^{-3}-2.86×10^{-2}, 2.79×10^{-3}-1.23×10^{-1}, 5.2×10^{-4}-1.46×10^{-2}, 3.72×10^{-5}-1.16×10^{-2}, 1.24×10^{-2}-1.58×10^{-2}, 3.42×10^{-3}-4.39×10^{-2}, 7.90×10^{-3}-4.87×10^{-2}, 0.068-0.23, 0.03-1.23, and 0.53-3.84 mg/kg/day, respectively.

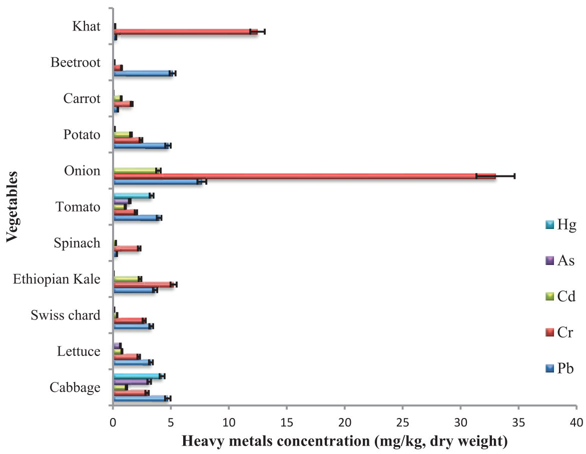

Figure 2. Concentration of highly toxic heavy metals in vegetables grown with wastewater impacted rivers.

Health Risk Index (HRI) and Hazard Index (HI). The HRI of more toxic heavy metals for all vegetable types ranged as; Pb (0.26-7.15), Cr (1.86×10^{-3}-8.20×10^{-2}), Cd (0.52-14.6), As (0.12-38.7), and Hg (1.24-1.58). The HRI for total vegetables was 35, 0.168, 46.6, 70, and 2.82 for Pb, Cr, Cd, As, and Hg, respectively (Table 4). The Hazard Index (HI) of more toxic heavy metals in vegetables also ranges from 1.03 to 49 which were much higher than 1. The HI value for consumption of cabbage, tomato, onion, lettuce, Ethiopian kale, and potato exceeds 10 showing severe health impacts (Table 4).

Discussion

Heavy metals are viewed as contaminants due to their harmful impacts and their tendency to bioaccumulate in living organisms.[61] When consumed by humans, they can lead to long-term poisoning. Among the routes of exposure, consuming vegetables

Table 2. Overall mean concentration of heavy metals in total vegetables.

VEGETABLES	HEAVY METALS CONCENTRATION (MG/KG DRY WEIGHT)										N*
	PB	CR	CD	AS	HG	CU	NI	ZN	MN	FE	
Cabbage	4.74	2.95	1.17	3.13	4.25	7.12	4.79	33.43	119.32	427.95	14
Lettuce	3.28	2.23	0.78	0.65		5.94	13.09	39.3	77.54	362.25	12
Swiss chard	3.31	2.7	0.37	0.12		7.02	13.10	27.26	188.8	408.08	7
Ethiopian kale	3.64	5.24	2.34	0.07		3.60	5.87	62.83	29.4	177.8	3
Spinach	0.34	2.27	0.26	0.01		0.92			17.2	503.4	2
Tomato	3.99	1.99	1.07	1.46	3.34	11.45	10	19.07	29.4	144.49	8
Onion	7.68	33.01	3.93			5.69	4.72	31.69	331.8	1034.3	3
Potato	4.75	2.42	1.56	0.16		6.56	5.56	36.98	85.44	280.17	5
Carrot	0.43	1.62	0.72	0.05		11.8	11.36	18.27	14.05	214.5	3
Beetroot	5.15	0.75	0.14			4.98		47.75	257.9	538.5	2
Khat	0.28	12.48	0.2			15.33	2.13	18.52	8.83		3
Median concentration	3.64	2.42	0.78	0.14	3.8	6.56	5.87	32.56	77.54	385.16	
Overall mean	3.42	6.15	1.14	0.71	3.8	7.31	7.85	33.51	105.4	409.14	
Safe limit	0.1-0.3[a,b]	1-2.3[a,c]	0.05-0.2[a,b]	0.1[a]	0.01-0.3[b,d]	10-40[a,b]	10[a]	50[c]	500[c]	425[e]	

Source: [a]Azadeh et al[57], [b]Ametepey et al[58], [c]Broadhurst and Domenico[59], [d]Codex Alimentarius Commission[60], [e]Latif et al[33].
*N = Sample size.

Table 3. Estimated daily intake (EDI) of heavy metals in vegetables.

VEGETABLES	ESTIMATED DAILY INTAKES (MG/KG/DAY)									
	PB	CR	CD	AS	HG	CU	NI	ZN	MN	FE
Cabbage	1.76×10^{-2}	1.10×10^{-2}	4.35×10^{-3}	1.16×10^{-2}	1.58×10^{-2}	2.65×10^{-2}	1.78×10^{-2}	0.12	0.44	1.59
Lettuce	1.22×10^{-2}	8.30×10^{-3}	2.90×10^{-3}	2.42×10^{-3}		2.21×10^{-2}	4.87×10^{-2}	0.15	0.28	1.34
Swiss chard	1.23×10^{-2}	1.00×10^{-2}	1.38×10^{-3}	4.47×10^{-4}		2.61×10^{-2}	4.87×10^{-2}	0.10	0.70	1.51
Ethiopian Kale	1.35×10^{-2}	1.95×10^{-2}	8.71×10^{-3}	2.6×10^{-4}		1.34×10^{-2}	2.18×10^{-2}	0.23	0.10	0.66
Spinach	1.27×10^{-3}	8.45×10^{-3}	9.70×10^{-4}	3.72×10^{-5}		3.42×10^{-3}			0.06	1.87
Tomato	1.48×10^{-2}	7.40×10^{-3}	3.98×10^{-3}	5.41×10^{-3}	1.24×10^{-2}	4.26×10^{-2}	3.72×10^{-2}	0.07	0.10	0.53
Onion	2.86×10^{-2}	1.23×10^{-1}	1.46×10^{-2}			2.12×10^{-2}	1.76×10^{-2}	0.12	1.23	3.84
Potato	1.77×10^{-2}	9.01×10^{-3}	5.8×10^{-3}	6.07×10^{-4}		2.44×10^{-2}	2.07×10^{-2}	0.14	0.31	1.04
Carrot	1.60×10^{-3}	6.03×10^{-3}	2.68×10^{-3}	1.86×10^{-4}		4.39×10^{-2}	4.23×10^{-2}	0.07	0.05	0.79
Beetroot	1.92×10^{-2}	2.79×10^{-3}	5.2×10^{-4}			1.85×10^{-2}		0.17	0.95	2.00
Khat	1.04×10^{-3}	4.64×10^{-2}	7.40×10^{-4}			5.70×10^{-2}	7.90×10^{-3}	0.068	0.03	
Total	1.40×10^{-1}	2.52×10^{-1}	4.66×10^{-2}	2.10×10^{-2}	2.82×10^{-2}	2.99×10^{-1}	2.63×10^{-1}	1.25	4.32	15.22
MTDI*	0.21	0.2	0.021	0.13	—	30	0.3	60	2-5	

Abbreviation: *MTDI, Maximum tolerable daily intake.

Table 4. Health Risk Index (HRI) and Hazard Index (HI) for the highly toxic heavy metals.

VEGETABLES	HEALTH RISK INDEX (HRI) FOR MORE TOXIC HEAVY METALS					HAZARD INDEX (HI)
	PB	CR	CD	AS	HG	
Cabbage	4.40	7.33×10^{-3}	4.35	38.7	1.58	49.0
Lettuce	3.05	5.53×10^{-3}	2.90	8.07		14.0
Swiss chard	3.08	6.67×10^{-3}	1.38	1.49		5.96
Ethiopian kale	3.38	1.30×10^{-2}	8.71	0.867		13.0
Spinach	0.318	5.63×10^{-3}	0.97	0.124		1.42
Tomato	3.70	4.93×10^{-3}	3.98	18.0	1.24	26.9
Onion	7.15	8.20×10^{-2}	14.6			21.8
Potato	4.43	6.01×10^{-3}	5.80	2.02		12.3
Carrot	0.4	4.02×10^{-3}	2.68	0.620		3.70
Beetroot	4.80	1.86×10^{-3}	0.52			5.32
Khat	0.26	3.09×10^{-2}	0.74			1.03
Total	35.0	0.168	46.6	70.0	2.82	

contaminated with heavy metals is a key means for humans to encounter these substances.[62] In this systematic review, the mean concentration of heavy metals was determined based on the data obtained from the incorporated studies,[37-55] with the variety of vegetables playing a significant role. Some heavy metals play a great role as micronutrients at recommended levels.

However, some of them, like Pb, Cd, As, and Hg, are highly toxic even at lower concentration levels.[5]

For instance, chromium significantly contributes to keeping blood sugar levels within the recommended range. However, when present in excess, it becomes harmful and poses a risk to human health.[63] In the present review study (Table 2), the mean concentration of chromium in cabbage, Swiss chard, Ethiopian kale, onion, potato, and khat found to be 2.95, 2.7, 5.24, 33.01, 2.42, and 12.48 mg/kg, respectively; which was higher than the maximum acceptable limits of Cr in vegetables (2.3 mg/kg) set by different organizations.[27,59,64] This is a result of cultivating vegetables with untreated or partially treated industrial wastewater discharged to the adjacent environment particularly river water.[27,65,66]

Alternatively, exposure to high level cadmium can damage the kidney. The mean concentration of Cd in common vegetables range from 0.26 to 3.93 mg/kg that was higher than the maximum safe limit 0.2 mg/kg.[57,58] Similarly, As, Hg, and Pb are non-essential elements which are toxic and not needed by organisms.[67] Overexposure to lead can cause detrimental health outcomes, including high blood pressure, digestive issues, stunted growth, malfunctions in the nervous system, cognitive impairments, hearing deficits, and reproductive complications.[33] The present review found higher mean concentration lead ranging from 0.34 to 7.68 mg/kg in all vegetables, which was greater than the safe limit (0.3 mg/kg) set for vegetables.[57,58] Anthropogenic activities like using lead-based paints, washing cars, and utilizing lead-acid batteries may have led to the contamination of vegetables with lead through the untreated discharge of municipal and industrial wastewater.[68]

Arsenic (As) mean concentration in potato, tomato, cabbage, lettuce, and Swiss chard was in the range of 0.12 to 3.13 mg/kg that was higher than the maximum tolerable limit (0.1 mg/kg). Arsenic maximum mean concentration was recorded in cabbage (3.13 mg/kg) and tomato (1.46 mg/kg). The elevated levels of arsenic detected can be attributed to the release of the metal and its compounds from the industries situated in the local area. This was mostly resulted from the individual studies conducted in Modjo[40] and Koka[43] area of Oromia region. Moreover, this systematic review study found that the overall mean concentration of mercury (Hg) in vegetables range from 3.34 mg/kg (in tomato) to 4.25 mg/kg (in cabbage), which was much higher than maximum tolerable concentration range (0.01-0.3 mg/kg) in vegetable.[58,60] The higher mean concentration of toxic heavy metals in vegetables in Ethiopia may be due to the rise of anthropogenic activities and the use of untreated or partially treated wastewater for agricultural purposes.

Additionally, this review study reported the mean concentration of Nickel (Ni) in vegetables to be in the range of safe limit (10 mg/kg)[57] except in lettuce and Swiss chard (13.1 mg/kg in both). This high concentration was primary recorded by Berihun et al[45] in lettuce (48.14 mg/kg) and Swiss chard (51.85 mg/kg) cultivated in Amhara region with effluent-impacted water. The contamination of the vegetables by nickel can often be traced back to human activities, particularly the utilization of liquid waste from municipal and industrial sources for the cultivation of vegetables. Exposure to nickel can lead to a range of health complications in humans, including allergies, diseases of the heart and kidneys, fibrosis of the lungs, and even cancers of the lung and nose.[69]

What's more, this study found that the overall mean concentration of copper (Cu) in vegetables range from 0.92 to 15.33 mg/kg, which was lower than the maximum standard safe limit range from 10 to 40 mg/kg in vegetables. Similarly, the study found the mean concentration of manganese (Mn) in vegetables ranged from 14.05 to 257.9 mg/kg that was lower than the standard guideline (500 mg/kg).[59] The sources of such metals can be attributed to the e-waste processing and utilization of products containing the metals.[68,70]

On the other hand, Iron (Fe) is a vital element for nearly all life forms, especially for human health, due to its involvement in numerous metabolic activities, such as the transportation of oxygen, the synthesis of deoxyribonucleic acid (DNA), and electron transport. Nevertheless, an overabundance of iron can result in damage to body tissues.[71] The current review study found the overall mean concentration of iron in vegetables ranged from 144.49 to 1034.3 mg/kg. The higher mean concentration was recorded in cabbage (427.95 mg/kg), spinach (503.4 mg/kg), beetroot (538.5 mg/kg), and the highest in onion (1034.3 mg/kg), which were higher than the standard guideline in vegetables (425 mg/kg) by FAO/WHO.[33]

Zinc is another essential metal that is crucial to the metabolic and physiological functions of numerous organisms, playing a significant role in growth and the development of bones. Moreover, Zinc is the most significant mineral in our bodies, acting as a micronutrient in biological entities and activating enzymes for the creation of nucleic acids, proteins, and metabolism.[72] However, it's important to note that elevated levels of zinc can lead to toxicity in humans.[73] The present study found the mean concentration of Zn in vegetables studied lower than the standard guideline limit (50 mg/kg)[59] except in Ethiopian kale (62.83 mg/kg) which was higher than safe limit.

The current systematic review revealed that the concentration of majority of toxic heavy metals in vegetables grown with wastewater-impacted water was higher than the maximum allowable safe limit that would be a public health risk associated with the consumption of these vegetables. A comparative study by Hussain et al[66] shown that consumption of plants even cultivated with treated wastewater has demonstrated a higher daily intake of metals (DIM) value compared to those grown using tap water (effluent free water).

To reduce the health risks posed by heavy metals, industries should implement advanced treatment technologies to effectively remove these harmful substances from wastewater before it is discharged into the environment. For example, using modified biochar which is a powerful adsorbent for heavy metal removal from contaminated water.[74,75] Moreover, use of green synthesized carbon nanomaterials, such as carbon nanotubes, are highly effective in removing heavy metals from water due to their superior physicochemical properties, large surface area, and diverse functionalities.[18] Additionally, farmers and agricultural workers need to be aware of the importance of using safe irrigation water to prevent contamination of vegetables.

In the current study, the estimated daily intakes (EDIs) of each heavy metal via consumption of studied vegetables were lower than the Maximum Tolerable Daily Intake (MTDI) of these metals. It's important to note that consuming all vegetables cultivated with water affected by effluents may not necessarily be safe. This is because, based on the current review study, the Estimated Daily Intake (EDI) of Chromium (Cr) at 0.252 mg/kg/day and Cadmium (Cd) at 0.0466 mg/kg/day exceed the Maximum Tolerable Daily Intake (MTDI) of 0.2 and 0.021 mg/kg/day, respectively.

The HRI due to consumption of all vegetables for Pb, Cd, As, and Hg was far greater than 1 (HRI > 1) except for Cr (HRI < 1) causing a cumulative effects. The HRI < 1 means the exposed population is safe of metals health risk; however, (HRI > 1) indicates that greater health risk of heavy metals. Therefore, wastewater irrigated vegetable consumers are at greater risk of heavy metals like Pb, Cd, As, and Hg. On the other hand, the HI of harmful elements considerably exceeds 1, it points to an increased chance of experiencing non-carcinogenic health effects from these elements due to wastewater-impacted river water irrigated vegetable consumption. Moreover, the HI of targeted heavy metals due to consumption of cabbage, tomato, onion, lettuce, Ethiopian kale and potato exceeds 10.0. This suggested a long lasting severe health impacts among consumers. As a result, this systematic review study revealed that the health risks faced by the consumers were more severe than initially anticipated.

Conclusion

This systematic review highlights the health risks associated with consuming vegetables grown with untreated wastewater, particularly in certain regions of Ethiopia. It revealed that the overall mean concentration of toxic heavy metals in vegetables grown with wastewater-affected river water was higher than the maximum allowable safe limit that would be a public health risk. Therefore, vegetable irrigation with wastewater-impacted river may not result in safe produces unless the wastewater is completely treated. Furthermore, it emphasizes that inspecting and monitoring the quality of irrigation wastewater is significantly important to minimize risks. Also implementing measures to reduce harmful heavy metals to acceptable levels is crucial for mitigating potential health hazards. Government and regulatory bodies should implement and enforce policies to ensure the quality of irrigation water. Farmers and agricultural workers need to be aware of the importance of using safe irrigation water.

Limitations

Unpublished articles as well as conference proceedings and dissertations were not included in this systematic review due to the type of search strategies adopted. This review was based on previous findings that were conducted in time periods from 2019 to 2024.

Abbreviations

EDIs, Estimated Daily Intakes; FAO, Food and Agricultural Organization; HI, Hazard Index; HQ, Hazard Quotient; HRI, Health Risk Index; MeSH, Medical Subject Headings; PRISMA, Preferred Reporting Items for Systematic Review and Meta-Analysis; SNNP, Southern Nations and Nationalities People; WHO, World Health Organization

Author Contributions

The first draft proposal of this study was developed by BN. By critically reviewing, providing all relevant inputs, and contributing to intellectual substance of the study, all authors (BN, SF, DD and NES) significantly contributed to the conception, conceptualization, and manuscript preparation of this systematic review. All authors read and approved the final manuscript.

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Availability of Data and Materials

All relevant data are included in the manuscript.

Supplemental Material

Supplemental material for this article is available online.

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