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RESEARCH PAPER

Heavy Metal Pollution in Soils and Vegetables from Suburban Regions of Nairobi, Kenya and their Community Health Implications

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Abstract
This study aimed at quantifying the heavy metal levels in soils and vegetables sampled from five suburban regions of Nairobi, Kenya. Using inductively coupled plasma- mass spectrometry (ICP-MS) the metals were quantified from the samples. The assayed heavy metals including Cd, Cr, Co. Cu, Fe, Hg, Mn, Ni, Pb, Zn and the metalloid arsenic were elevated beyond the reference values in both soils and vegetables. High pollutant levels in soils were affiliated to use of industrial and domestic wastewater for irrigation, application of heavy metal containing agrochemicals and geogenic sources of the pollutants. In collard leaves, the uptake of contaminated water via the roots and subsequent accumulation in the leaves was attributable to the observed results. The total hazard quotient (THQ) and hazard index (HI) as a result of arsenic and Hg was >1 in all sampled sites and >10, respectively for both indices and heavy metals. Similarly, the cancer risk (CR) and target cancer risk (TCR) from consumption of collard was greater than the recommended levels of 10-6 and 10-4, respectively with exception of Pb. The indices were indicative of negative non-carcinogenic and carcinogenic effects of consuming the vegetables to the community of the study area. The results of the study, though preliminary, suggest the need to safeguard the health of communities in the study area to ensure that they do not consume heavy metal contaminated vegetables due to the established health effects of such pollutants.

Keywords: Heavy metals; Nairobi; Pollution; Soils; Vegetables

INTRODUCTION

Industrialization and the demand for food is a growing quest in developed and developing nations globally. These development advances induce new concerns on food safety and environmental pollution, which pose health risks to affected communities (Sultana et al., 2017; Manzoor et al., 2018; Nyika et al., 2020; Bayissa and Gebeyehu, 2021). Of the contaminant sources, heavy metals such as As, Cd, Co, Cr, Cu, Fe, Hg, Ni, Pb and Zn whose sources are either geogenic or anthropogenic have attracted the attention of researchers due to the negative health implications to humans once ingested in concentrations above the body requirements (Wang et al., 2018). The heavy metals induce kidney and gastrointestinal dysfunctions, skin lesions, immune system dysfunctions, vascular damage, nervous system disorders, cancers and birth defects (Balali-Mood et al., 2021). According to Nyika et al. (2020), heavy metals have a toxic, persistent, bio-accumulative and non-biodegradable nature and their entry to food chains during occupational operations or via contaminated water and food has negative implications to human health and other organisms. The demand for vegetables as part of food is growing owing to their nutritional

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value in human diet (Rai et al., 2019). However, most of the commercially available vegetables in developing and transiting economies are grown in the vicinity of suburban and urban areas of big towns (Manzoor et al., 2018; Sulaiman and Hamzah, 2018). Consequently, the vegetables are exposed to human-based pollution including exposure to municipal, mining, metallurgical and smelting wastes and industrial wastewater (Rai et al., 2019; Bayissa and Gebeyehu, 2021). Such exposure results to a public and community health concern for affected regions once vegetables are part of the diet. Sultana et al. (2017) noted that vegetables among other agricultural foods are adulterated with heavy metals through pesticide application, excessive metal-based fertilization, direct or indirect exposure automobile exhausts or industrial operations. The authors also noted that diet is the main exposure route to such heavy metal ingestion by humans and occupational exposure only plays a minor role.

Pollution of vegetables by heavy metals in most cases emanates from trace metal contaminated soils. Ahmad and Goni (2010) noted that polluted soils are the foremost route for entry of heavy metals in soils and a key route of human ingestion of the pollutants. It is for this reason that heavy metal pollution of vegetables has been established in urban and sub-urban regions of the world where soils are polluted (Antisari et al., 2015; Ahmad et al., 2021; Wang et al., 2021). In the reported studies, developing nations are more vulnerable to vegetation pollution by heavy metals compared to developed ones (Cai et al., 2015; Wang et al., 2018). Kenya is one of the fastest developing economies of sub-Saharan Africa based on the rise of small and medium scale industries working on tannery, manufacturing, floricultural, chemical, fabric and brewing processes particularly in or near urban and suburban regions (Jimenez et al., 2021). Most of the industries are found in the country's capital city, Nairobi, which contributes to more than 50 % of the country's gross domestic product. The wastewater released from such industries was reported to have toxic metals such as Thallium (Tl), nickel (Ni), Chromium (Cr), Cadmium (Cd), Lead (Pb) and Mercury (Hg) at elevated levels (Kinuthia et al., 2020). The heavy metals are noxious even in minute concentrations and result to negative health effects once they enter food chains (Gizaw, 2019).

With the buildup of noxious trace metals in water, soils and plants being on rise with advances such as urbanization and industrialization, the concern on their health implications will continue being a priority to researchers. The concern will be more pronounced in developing countries of Africa and Asia where economic growth, rising population and urbanization tendencies are priorities irrespective of their pollution effects (Cai et al., 2015; Wang et al., 2018; Bayissa and Gebeyehu, 2021). In Kenya for instance, the trends associated to economic growth are creators of environmental issues particularly the release of untreated wastes and wastewater to the environment where it causes soil and plant pollution (Kinuthia et al., 2020; Sayo et al., 2020; Tomno et al., 2020). In Kenya's Machakos (Tommo et al., 2020) and Embu (Sayo et al., 2020) towns, heavy metal pollution in vegetables has been reported. To exacerbate the problem is the little preparedness of Kenya like other developing countries to deal with pollution. This study sought to assay heavy metals from soils and vegetables collected from suburban regions of Nairobi County (Kenya). To the best of our knowledge, such a study has not been carried out in the region despite the fact that most vegetables consumed in the area are grown near sewage drains. The aim was to use the results to assess the community health hazard associated with vegetable consumption using various indices.

METHODOLOGY

Collection of Samples and Heavy Metal Analysis

Soils and vegetable samples for this study were collected in five suburban locations of Nairobi County namely, Saika, Kayole, Njiru, Chokaa and Ruai (Figure 1) whose georeferenced data is as shown in Table 1. The presence of small and medium-sized firms to manufacture soaps, textile, chemicals and plastics as well as domestic and industrial wastewater release in open

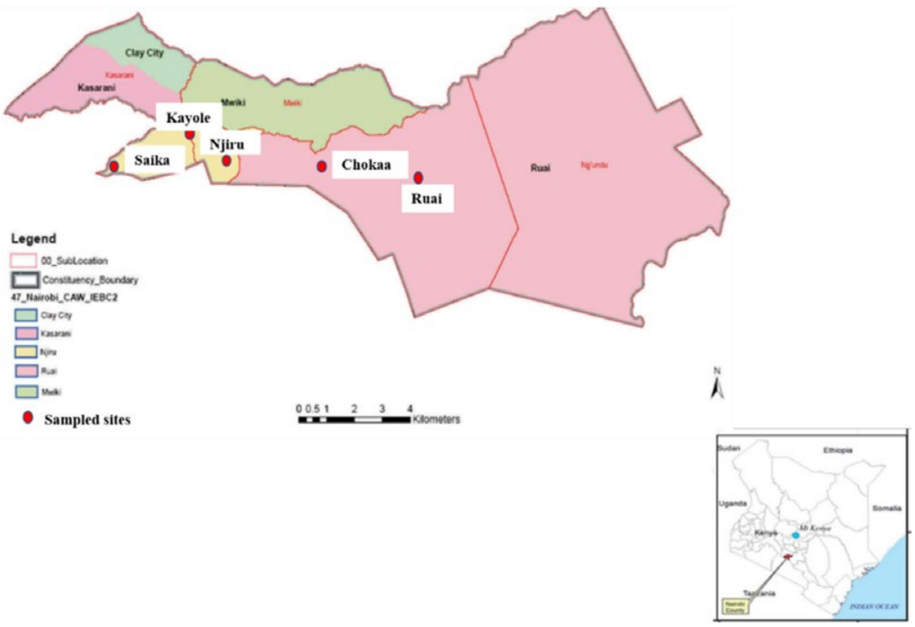

Fig. 1. Map of Nairobi County showing the sampled sites

Table 1. Name and location of sampling sites

Name of the Sampling Point	Georeferenced Data
Saika	-1.25863, 36.91451
Kayole	-1.26249, 36.91943
Njiru	-1.24686, 36.92547
Chokaa	-1.24910, 36.95144
Ruai	-1.26010, 36.97760

drains justified the selection of sampling points. Wastewater from the open drains was used to irrigate the vegetables as witnessed during sampling and as shown in Figure 2.

In each of the five locations, a sample of collard leaves (*Brassica oleracea*) and soil sample was collected at the same location with the permission of farmers. Collard vegetable was selected for the study because the leaves were grown in all the sampled sites and its consumption was common among the locals. Lans et al. (2012) noted that collard locally known as 'Sukuma wiki' is one of the most consumed vegetables in Nairobi County. Using a procedure described by Gebeyehu and Bayissa (2020), the vegetable leaves were pre-treated prior to heavy metal analysis. A soil sample of about 500 g each was collected in a polyethylene bag at a 0-20 cm depth using an auger sampler. The collected samples were labelled and taken to the laboratory for physicochemical analysis using the protocol by Gebeyehu and Bayissa (2020).

At the laboratory, microwave acid digestion of both vegetable leaves and soil samples was conducted. Using a 0.5 g of powder vegetable sample, 3 ml 10 M HCl and 9 ml 10M HNO_3 were added to microwave digestion vessels. The vessels were tightly capped and microwave digested for 45 mins at 180°C before filtering the digestate with a Whatman No. 42 filter paper to a volumetric flask and the volume filled to the 50 ml mark using 2% HNO_3. The same procedure was repeated using homogenized dry soil samples. Concentrations of As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn for both vegetable leaves and soils were determined using inductively coupled plasma mass spectrometry (ICP-MS) in triplicates and via the EPA method 6020B

Fig. 2. Vegetables growing using wastewater from open drains in a) Chokaa and b) Njiru areas of Nairobi, Kenya

(US-EPA, 2014). Analysis was preceded by instrument calibration using blanks and calibration standards of the metal being assayed. Other parameters including the nebulizer flow, coolant flow, pump seed and plasma power were also optimized before analysis to enhance the accuracy of analyzed concentrations.

Health Hazard Assessment Following the Consumption of Vegetables

In this study five indices were used to assess the health implications of consuming contaminated vegetables. They include the bioconcentration factor (BCF), target cancer risk (TCR), hazard index (HI), target hazard quotient (THQ) and estimated daily intake (EDI). The BCF was used to assess if collard leaves were heavy metal accumulators as has been done in previous studies (Huang et al., 2008; Sharma et al., 2018; Bayissa and Gebeyehu, 2021). It is a ratio of the heavy metal concentration in a given edible plant part to the heavy metal concentration in a specified soil sample and computed as shown in Equation [1]. BCF levels greater than 1 suggest that a plant is a potential accumulator.

$$BCF = \frac{C_{plant}}{C_{soil}} \quad [1]$$

Where: C_{plant} and C_{soil} are the heavy metal concentrations of a vegetable and soil sample, respectively.

The EDI in this study was computed using the average heavy metal concentration in collard leaves and the estimated daily consumption levels in grams. In this case, the formula described by Alghobar and Suresha (2017) summarized in Equation [2] was used.

Table 2. The oral reference doses in mg/kg/day for some heavy metals (USEPA, 2004)

Heavy Metal	**Oral Reference Dose (Rfd)**
As	0.0003
Cd	0.001
Cr (VI)	0.003
Co	0.0003
Cu	0.037
Fe	0.7
Hg	0.0003
Mn	0.14
Ni	0.02
Pb	0.0035
Zn	0.3

$$\mathrm{EDI} = \frac{E_{f\times}\, E_D \times F_{IR} \times C_M \times C_F}{B_w \times T_A} \times 0.001 \qquad [2]$$

In the equation, E_f is the exposure rate per year (365 days), the E_D is the exposure period (65 years) equivalent to the life expectancy (Bayissa and Gebeyehu, 2021) while F_{IR} is the mean vegetable consumption estimated at 240 g per individual (World Health Organization, 2002). The 0.001 is a unit conversion factor, T_A is exposure time (65 years x 365 days), B_w is the reference body weight for an adult at 70 kg while C_f is the concentration conversion factor for dry weight from wet vegetable weight (0.085) while C_M is the metal concentration in mg/kg (Bayissa and Gebeyehu, 2021).

The THQ estimated the non-cancer health hazard associated with ingesting vegetables with elevated heavy metals as previously done by Chen et al. (2011). It was calculated as shown in Equation [3].

$$\mathrm{THQ} = \frac{\mathrm{EDI}}{\mathrm{RfD}} \qquad [3]$$

Where; RfD is the oral reference dose in mg/kg/day of metals as shown in Table 2 while EDI is the approximated daily metal intake per individual in mg/day/kg body weight. THQ levels <1 are considered safe from non-cancerous effects while levels >1 infer to increased etiology to such effects (Chen et al., 2011; Antoine et al., 2017).

The HI estimated the cumulative health risk associated with consumption of heavy metal contaminated vegetables. Previously, Gebeyehu and Bayissa (2020) used the index to compute the health risk associated with consumption of tomatoes and cabbages grown in heavy metal polluted soils of Mojo area of Ethiopia. HI was computed using Equation [4].

$$\mathrm{HI} = \sum_{n=1}^{i} THQ_n ; i = 1,2,3 \ldots\ldots\ldots, n \qquad [4]$$

Where; HI represents the hazard index and THQ is the target hazard quotient of each individual heavy metal consumed from contaminated vegetables. HI values <1 and >10 represent probable and chronic health impact, respectively.

The cancer risk (CR) associated with consumption of polluted vegetables was computed as shown in equation [5]. The TCR affiliated with the cancer risk of As, Cd, Cr, Ni and Pb ingestion was computed using Equation [6] and based on availability of the oral cancer slope factor (CPSo). Both CR and TCR have been used to previously assess the cancer risk associated with consumption of heavy metal polluted vegetables (Bayissa and Gebeyehu, 2021; Gebeyehu and Bayissa, 2020; Kamunda et al., 2016).

$$CR = EDI \times CPSo \qquad [5]$$

$$TCR = \sum_{n=1}^{i} CR; i = 1, 2, 3, \ldots.., n \qquad [6]$$

Where CR represents the cancer risk due to heavy metal intake, CPSo is the oral cancer slope factor in mg/kg/day, n is the number of heavy metals considered and EDI was as previously described. In this study, CPSo for As, Cd, Cr, Ni and Pb was 1.5, 0.38, 0.5, 1.7 and 0.0085 mg/kg/day, respectively (Gebeyehu and Bayissa, 2020). For a single cancer-causing metal, the permissible limit was 10^{-6} while for multi-cancerous metals, the allowable limit was 10^{-4} (Tepanosyan et al., 2017)

RESULTS AND DISCUSSION

Physicochemical characteristics of Soils

The soils, used for collard cultivation were assayed for physicochemical characteristics as shown in Table 3. The average soil pH was 7.74 showing that areal soils were slightly alkaline. The obtained levels were within the range of pH levels obtained in a study by Alghobar and Suresha (2017) who evaluated the accumulation of heavy metals in vegetables grown using sewage water. All soil samples had a clayey texture but at varying composition of silt, sand and clay. The electrical conductivity (EC) of the soil samples assayed at an average of 763.36 µS/cm. The levels are higher compared to those of a study by Alghobar and Suresha (2017) and lower compared to those of a study by Mekki and Sayadi (2017) who both evaluated heavy metal accumulation in soils and vegetables exposed to contaminated wastewater. The EC levels were related to the clayey texture of soils since such soils are able to accumulate mineral contents from the wastewater as Bayissa and Gebeyehu (2021) noted.

Table 3. Physicochemical characteristics of sampled soils

Sampling Point	pH	EC (µS/cm)	% OM	% MC	CEC (cmol (+)/ kg)	Clay (%)	Silt (%)	Sand (%)	Soil Class
Saika	7.9	828.4	2.31	25.27	38.44	47.41	26.66	25.93	Clayey
Kayole	7.62	687.5	2.28	25.53	37.98	49.01	17.11	33.88	Clayey
Njiru	7.71	830.1	2.06	23.24	41.44	44.76	21.60	33.64	Clayey
Chokaa	7.83	775.2	2.09	19.92	43.21	50.01	19.23	30.76	Clayey
Ruai	7.62	695.6	2.04	19.66	42.10	39.49	23.41	37.1	Clayey
Mean	7.74	763.36	2.16	22.72	40.63	46.14	21.60	32.26	-
SD	0.13	69.23	0.02	2.82	2.31	4.21	3.70	4.19	-

Percentage organic matter (%OM) of the soils ranged between 2.04 and 2.31% and an average of 2.31 %. The levels were comparable to those obtained in a study by Sharma et al. (2018) evaluating the heavy metal contamination in Indian soils and crops but considerably lower to minimum levels reported by Plunkett (2010) at 44.9%. Lower levels of OM could be associated with vulnerability of the soils to erosion and their overcultivation leading to soil organic carbon losses as Gebeyehu and Bayissa (2020) highlighted. The percentage moisture content (%MC) of sampled soils was at an average of 22.72 % while the cation exchange capacity (CEC) was 40.63 cmol (+)/ kg. Soil CEC levels are related to its capacity to retain nutrients and fertility and increases along with pH increases (Mukhopadhyay et al. (2019). In this case, CEC levels are associated with the clayey texture and organic matter of the soils, which enabled their electrically charged portions to hold onto and attract unlike ions.

Heavy Metal Concentration in Soils and Vegetables

Assayed heavy metals in the soil samples were quantified and their levels recorded as shown in Table 4. In all the samples, the assayed heavy metals were present and their average levels were indicative of pollution. Further, the levels were compared to European Union reference values from various sources (Brown, 1987; Chang et al., 2014; Mahmood and Malik, 2014; Sharma et al., 2018). The levels of arsenic surpassed the reference value of 14 mg/kg in all the sampled soils. The trend could be attributable to release of the pollutant or arsenic-based compounds along with effluents from industries of the sampled sites' vicinities. Arsenic sources in the soils could also be geogenic in addition to being released from pesticides applied on the vegetables by the farmers. According to Shrivastava et al. (2017), elevated levels of arsenic in agricultural soils of West Bengal (India) could be associated with natural or anthropogenic sources. The use of herbicides such as Agent Blue was associated with arsenic pollution of soils and subsequent transfer to crops (Bencko and Foong, 2017).

The average levels of Cd, Co Cu and Zn exceeded the reference values of 0.3, 8, 20 and 50 mg/kg, respectively while the levels of Cr and Ni were within the reference value of 100 and 50 mg/kg in all sampled soils with some exceptions. Although these heavy metals have natural sources, their elevation could be due to anthropogenic sources. According to Mahey et al. (2020), anthropogenic sources of the metals could be wastes and wastewaters with cosmetic chemical wastes, electronic wastes such as computer monitors, televisions and mobile batteries, mining waste and paint residues. These could enter wastewaters used in study areas and eventually be

Table 4. Heavy metal concentrations in sampled soils (mg/kg)

Heavy Metal Concentration (mg/kg)	Saika	Kayole	Njiru	Chokaa	Ruai	Mean	Standard Deviation	Reference value (mg/kg)
As	29.81	20.92	31.37	27.67	26.49	27.25	4.01	14
Cd	6.03	4.32	6.45	6.04	4.81	5.53	0.91	≤ 0.3
Cr (vi)	60.73	49.21	50.0	48.15	53.24	52.27	5.10	100
Co	21.7	18.94	15.9	13.52	15.11	17.03	3.27	8
Cu	24.03	19.85	28.66	26.34	27.88	25.35	3.55	20
Fe	28,108	26,939	36,505	27,349	33,286	30,437	4246.57	-
Hg	6.7	6.13	7.73	8.23	7.31	7.22	0.83	≤ 0.3
Mn	3,666	3,203	6,893	2,756	3,300	3,963	1669.37	2000
Ni	50.73	44.32	42.57	35.02	41.29	42.79	5.66	50
Pb	29.76	20.9	31.42	27.67	28.52	27.65	4.03	10
Zn	126.67	97.64	135.91	108.26	99.43	113.58	16.97	50

absorbed by the soils. The levels of the four heavy metals (Cd, Co, Cu and Zn) were in higher concentrations than levels reported by Sharma et al. (2018). The levels of Fe ranged between 26,939 to 36,505 mg/kg while those of Mn were between 2,756- 6,893 mg/kg. The elevated nature of the metals could be associated with their lithological rather than anthropogenic sources as noted by Nyika et al. (2019), in a heavy metal evaluation of South African soils.

The mean levels of Hg and Pb surpassed the reference values of ≤0.3 and 10 mg/kg, respectively. The two heavy metals are toxic if ingested by humans and cause negative health effects as noted by Kinuthia et al. (2020). Overall, sampled soils exhibited pollution with assayed heavy metal levels exceeding the allowable limits. This could be a result of contamination by industrial effluents and agrochemicals used by farmers. Apart from parental materials sourced heavy metals, human activities such as discharge of effluents and wastes from industries as well as application of agrochemicals results to pollution of soils (Zhong et al., 2016). Sharma et al. (2018) also agreed that soils accumulate heavy metals due to the discharge of effluents and wastes containing such pollutants to the environment in a study evaluating heavy metal levels in soils and crops. The clayey nature of the soils could also be an enhancer of metal accumulation in sampled soils. According to Pikula and Stepien (2021), clay soils retain higher metal amounts compared to sandy soils because their particles act as binding or adsorption surfaces for the pollutants.

The heavy metal levels in sampled collard were evaluated and results were as shown in Table 5. Using European Union standards documented from various studies (Brown, 1987; Chang et al., 2014; Mahmood and Malik, 2014; Sharma et al., 2018), pollution due to As, Cd, Cr, Hg and Pb was evident and the average levels of the heavy metals exceeded the allowable reference values. The accumulation of these heavy metals is attributable to the use of wastewater to irrigate and fertilize collard plants. According to Chang et al. (2014), sewage fertilization and irrigation of leafy vegetables is the main cause of their heavy metal uptake and accumulation. The heavy metals can be taken up via leaf absorption of polluted air or from root uptake from already contaminated soil-water according to Souri et al. (2019). The mean levels of Co, Cu, Mn, Ni and Zn in the collard were within the allowable limits.

Bioconcentration Factor

The BCF was used in this study to assess the ability of collard to uptake heavy metals from the soils. Obtained results showed that collard leaves accumulated heavy metals but not in large quantities since all BCF values and the average levels of each metal were < 1 with exception of

Table 5. Heavy metal concentrations in sampled collard leaves

Heavy Metal Concentration (mg/kg)	Saika	Kayole	Njiru	Chokaa	Ruai	Mean	Standard Deviation	Reference value (mg/kg)
As	6.75	1.32	6.48	0.93	1.12	3.32	3.01	0.1
Cd	5.17	0.9	4.51	0.91	0.87	2.47	2.17	0.05-0.2
Cr (vi)	5.22	1.01	4.56	0.93	2.23	2.79	2.00	1-2.3
Co	1.36	0.50	1.38	0.39	1.24	0.97	0.49	50
Cu	14.16	10.9	102.5	16.9	10.3	30.95	40.08	10-40
Fe	403.0	352.1	431.6	336.4	455.4	395.7	50.8	-
Hg	4.16	3.26	4.36	3.23	3.56	3.71	0.52	0.01-0.3
Mn	81.68	19.06	102.5	16.9	25.06	49.04	40.09	500
Ni	2.92	1.38	3.22	0.9	4.27	2.54	1.38	10
Pb	7.26	2.63	6.72	1.81	4.53	4.59	2.41	0.1-0.3
Zn	36.24	17.05	18.16	34.4	17.86	24.74	9.69	50

Table 6. Bioconcentration factors of heavy metals for sampled collard

Heavy Metal BCF	Saika	Kayole	Njiru	Chokaa	Ruai	Mean	Standard Deviation
As	0.22	0.06	0.21	0.03	0.04	0.11	0.09
Cd	0.86	0.21	0.7	0.15	0.18	0.42	0.33
Cr (vi)	0.09	0.02	0.09	0.02	0.04	0.05	0.04
Co	0.06	0.03	0.09	0.03	0.08	0.06	0.03
Cu	0.59	0.55	3.58	0.64	0.37	1.15	1.36
Fe	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Hg	0.02	0.53	0.56	0.39	0.49	0.40	0.22
Mn	0.02	0.01	0.01	0.006	0.008	0.01	0.01
Ni	0.06	0.03	0.08	0.03	0.1	0.06	0.03
Pb	0.24	0.13	0.21	0.07	0.16	0.16	0.07
Zn	0.28	0.17	0.13	0.32	0.18	0.22	0.08

Table 7. EDI of heavy metals in mg/day/kg body weight following consumption of collard leaves

Heavy Metal/ EDI (mg/day/kg body weight)	Saika	Kayole	Njiru	Chokaa	Ruai	Maximum acceptable daily intake (mg/day)
As	1.9E-3	3.8E-4	1.9E-3	2.7E-4	3.3E-4	0.13
Cd	1.5E-3	2.6E-4	1.3E-3	2.6E-4	2.5E-4	0.02-0.07
Cr (vi)	1.5E-3	2.9E-4	1.3E-3	2.7E-4	6.5E-4	0.035-0.2
Co	4.0E-4	1.4E-4	4.0E-4	1.1E-4	3.6E-4	0.05
Cu	4.1E-3	3.2E-3	0.03	4.9E-3	3.0E-3	2.5-3
Fe	0.12	0.1	0.13	0.1	0.13	15
Hg	1.2E-3	9.5E-4	1.3E-3	9.4E-4	1.0E-3	0.04
Mn	0.02	5.6E-3	0.03	4.9E-3	7.3E-3	2-5
Ni	8.5E-4	4.0E-4	9.3E-4	2.6E-4	1.2E-3	0.1-0.3
Pb	2.1E-3	7.7E-4	1.9E-3	5.2E-4	1.3E-3	0.21
Zn	0.02	5.0E-3	5.3E-3	0.1	5.2E-3	60-65

Cu. In the cases where the BCF was < 0.1, it was suggested that collard plants could eliminate the pollutants through their roots, stem and leaves while levels ≥ 0.5 alluded to the vegetable being contaminated by heavy metals as suggested by Gupta et al. (2022). The ability of a vegetable to accumulate a given heavy metal is influenced by factors such as the soil physicochemical characteristics, the concentrations and specificity of the given heavy metals and the plant type (Sharma et al., 2018). In this case, collard accumulated heavy metals at specific sampling sites differently but Cd, Cu, Pb and Zn accumulation was better compared to other metals based on the computed BCF values.

Health Risks Associated with Heavy Metals

The EDI of heavy metals for adult population in this study was determined using consumption rate of collard leaves and the assayed concentration of the pollutants. The obtained results were as shown in Table 7. In all the sampling sites the EDI of metals did not surpass the allowable daily intake levels. The results were similar to studies evaluating the daily intake levels of vegetables

Table 8. The target hazard quotient (THQ) and hazard index (HI) from ingesting heavy metal contaminated collard leaves

Heavy Metal/ THQ	Saika	Kayole	Njiru	Chokaa	Ruai	HI
As	6.3	1.3	6.3	0.9	1.1	15.9
Cd	1.5	0.26	1.3	0.26	0.25	3.57
Cr (vi)	0.5	0.1	0.43	0.09	0.22	1.34
Co	1.33	0.47	1.33	0.37	1.2	4.7
Cu	0.11	0.09	0.81	0.13	0.08	1.22
Fe	0.17	0.14	0.18	0.14	0.18	0.81
Hg	4	3.2	4.3	3.1	3.3	17.9
Mn	0.15	0.04	0.21	0.035	0.05	0.49
Ni	0.04	0.02	0.05	0.01	0.06	0.18
Pb	0.6	0.22	0.54	0.15	0.37	1.88
Zn	0.07	0.02	0.02	0.1	0.02	0.23

such as cabbage, coriander, onion and tomato that reported low EDI levels compared to the permissible limits (Gebeyehu and Bayissa, 2020; Bayissa and Gebeyehu, 2021; Gupta et al., 2022). EDI levels of Fe, Mn and Zn were considerably higher compared to the other heavy metals. This trend was also analogous in studies by Gebeyehu and Bayissa (2020) who determined EDI levels of metals following consumption of tomatoes and cabbages as well as Gupta et al. (2022) following consumption of coriander and tomatoes. In the studies, higher levels of EDI were related to higher concentrations of the heavy metals in the vegetables.

The non-cancerous risk to humans following ingestion of toxic metals in collard leaves was assayed using the THQ and HI and obtained results were as shown in Table 8. THQ values of As, Co and Hg were >1 with a few exceptions, which suggested that the consumption of collard from the five sampling sites was likely to cause health risks associated with the heavy metals. Levels of Cd in two of the five sampling sites also had THQ values >1. The heavy metals cause chronic and acute effects to body organs where birth defects, immune system dysfunctions and damage of skin, nervous system, kidney and gastrointestinal organs have been associated with their ingestion by humans (Balali-Mood et al., 2021).

The cumulative effect of consuming heavy metal contaminated collard was determined using the HI (Figure 3). From consuming the vegetables, there was probable risk of chronic effects from all heavy metals as HI values were >0 though the risk was pronounced in increasing order of Ni > Zn > Mn > Fe > Cu > Cr> Pb > Cd > Co > As > Hg. Hazard index levels of As and Hg were the highest at 15.9 and 17.9, respectively and showed chronic effects from consuming vegetables containing them. The results were similar to two studies in Ethiopia evaluating the HI of heavy metals polluted vegetables where As and Hg had the greatest contribution to the index (Gebeyehu and Bayissa, 2020; Bayissa and Gebeyehu, 2021). Elevated levels of the metals in this case could be a result of sources of wastewater used to irrigate the vegetables.

Using the CR and TCR, the cancer risk of ingesting heavy metal polluted collard was assayed and obtained results were as shown in Table 9. In most sampling sites, the risk of a single or multiple heavy metal/s causing cancer was evident with most computed values being greater than 10^{-6} and TCR being greater than 10^{-4} with exception of Pb. The highest risk was associated with consumption of As and Ni based on the TCR values. Results of no cancer risk for Pb ingestion were similar to those by Gebeyehu and Bayissa (2020) while the carcinogenic nature associated with arsenic was similar to studies by Antoine et al. (2017) and Shaheen et al. (2016)

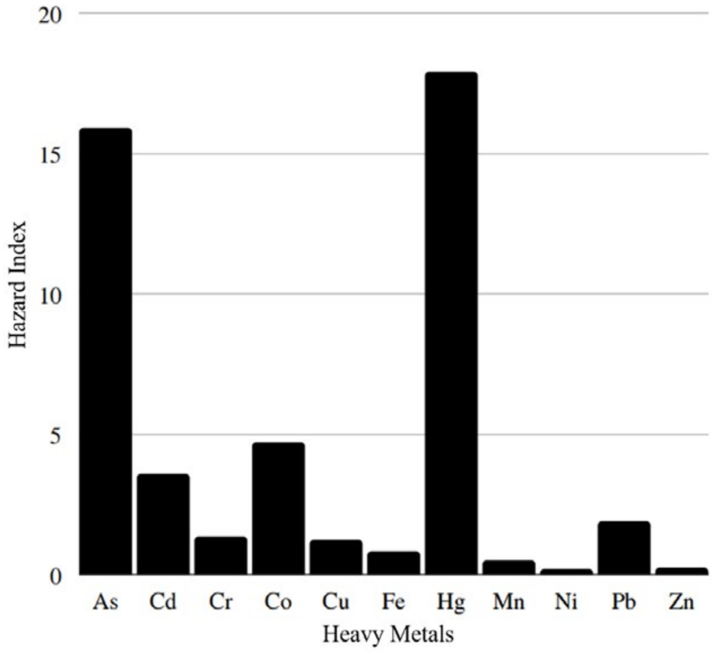

Fig. 3. Hazard index of ingesting different metals after consumption of polluted collard leaves

Table 9. The target cancer risk (TCR) associated with ingestion of heavy metal contaminated collard leaves

Heavy Metal/ CR	Saika	Kayole	Njiru	Chokaa	Ruai	TCR
As	0.003	0.00057	0.0029	0.0041	0.0005	0.01557
Cd	0.00057	0.00011	0.00049	0.0001	0.00024	0.00152
Cr (vi)	0.00075	0.00145	0.00065	0.00014	0.000325	0.00332
Ni	0.00145	0.00068	0.00158	0.00044	0.00204	0.01015
Pb	1.7E-5	6.5E-6	1.6E-5	4.4E-6	1.1E-5	4.5E-5

who evaluated the risk of consuming heavy metal contaminated vegetables in Jamaica and Bangladesh, respectively. The cancer and non-cancerous risk in the study was estimated based on projections of daily collard ingestion and as such, results should be treated as preliminary to allow validation studies. In addition, only collard consumption was considered in the study although farmers grew other vegetables such as spinach, tomato, coriander and onions in the polluted soils (Figure 2). Therefore, only a portion of the hazard to the community of the study area was investigated. This observation calls for holistic investigation of the health hazard associated with using heavy metal polluted wastewater and soils to grow vegetables in the study area to obtain more accurate results.

CONCLUSION

This study quantified the levels of heavy metals in soil and collard vegetable samples collected near open wastewater drains from suburban regions of Nairobi County. Results obtained established the presence of As, Cd, Co, Cu, Hg, Mn, Pb and Zn beyond the allowable limits in sampled soils. Noxious heavy metals such as Cd, Cr, Hg and Pb as well as metalloids such as As were found in elevated levels in the collard leaves, which alluded to higher health risks to the communities consuming the vegetable leaves. Although the bioconcentration factor showed low accumulation levels of metals at <1 in collard, there were suggestions that the pollutants were present in leaves of the vegetable. EDI levels showed lower intake of the heavy metals compared to reference values, although the computed THQ and HI of Hg and As were >1 and >10, respectively. The indices suggested the possibility of chronic non-carcinogenic effects on consumption of the vegetables by the community. Similarly, the cancer risk and TCR were found to be high in Hg and arsenic surpassing the 10^{-6} and 10^{-4} allowable levels. The findings of this study though preliminary by the fact that they considered one vegetable of the many cultivated using polluted wastewater in the sampled sites, suggested the need for intensified research to ensure that communities of the study area are not consuming polluted vegetables and that wastewater used for irrigation must undergo prior-to treatment. Irrigation of vegetables with polluted water and their subsequent consumption has negative non-cancerous and cancerous health effects as established from this study.

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CONFLICT OF INTEREST

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

LIFE SCIENCE REPORTING

No life science threat was practices in the research.

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