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ORIGINAL PAPER

Assessment of health risks associated with the consumption of wastewater-irrigated vegetables in urban areas

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Abstract

Several health issues are related to toxic metals among which Pb, Cr, Cd, and Ni are categorized as human carcinogenic. We analyzed the health risks linked with food chain contamination due to vegetables irrigated with wastewater containing metals. Thirty-six samples of each vegetable, water, and soil (at two depths, 0–15 cm, and 15–30 cm) were collected individually from 12 different locations near Paharang drain, Faisalabad, and the contamination level of each metal (Cd, Cr, Mn, Ni, and Pb) was determined through atomic absorption spectroscopy. The results have shown that the highest concentration of Cd (0.23 ± 0.007 mg kg^{-1}), Cr (0.33 ± 0.11 mg kg^{-1}), Ni (0.15 ± 0.07 mg kg^{-1}), and Pb (0.35 ± 0.20 mg kg^{-1}) was found in the sewage water, which is used to irrigate soil and vegetables in the study area of Faisalabad, Pakistan. The concentration of all the considered metals in wastewater-irrigated vegetables exceeded the acceptable limits set by European Union and WHO, while the transfer factor (TF) was low for Cr, while for Mn, Ni, Cd, and Pb, it was more than the acceptable limits, respectively. Human risk index (HRI) was also found to be highest for *Coriandrum sativum* L. (7.36 mg kg^{-1}) for adults against Pb. The leafy vegetables cultivated by wastewater had potential health risks concerning Pb, Mn, and Cd. The hazard quotient of Pb, Mn, Ni, and Cd was more than 1, which revealed strict health risk from Cd, Ni, Cr, Mn and Pb, which showed severe health risk with the utilization of vegetables contaminated with wastewater containing these heavy metals.

Keywords Risk assessment · Hazard quotient (HQ) · Daily intake of metals (DIM) · Health risk index (HRI) · Transfer factor (TF)

Introduction

The increasing use of wastewater for irrigation warrants inspecting its influence on plants, which are keystones of the food chain (Hassn et al. 2021). Increased urbanization and industrialization lead to the massive release of wastewater containing toxic metals (Ghafoor et al. 2017; Sharif et al. 2019) that is being used for the irrigation of crops, particularly in urban and peri-urban areas due to the decreased accessibility of canal water/irrigation water (Iqbal et al. 2020). This unrestrained irrigation of crops and vegetables with wastewater for an extended period may alter the phytochemical properties and mineral content of plants and result in the uptake of heavy metals in food, which adversely affects plant growth and ultimately human health (Irfan et al. 2013; Bashir et al. 2014; Iqbal et al. 2022; Kanwal et al. 2021).

Heavy metals bioavailability in soil and vegetables is greatly affected by their form and oxidation state (Bashir

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et al. 2014; Mahmood and Malik 2014) contaminated soil, water, and air result in food chain contamination and ultimately affect environmental growth and human health (Bashir et al. 2014; Nolos et al. 2022). In developing countries, severe health and environmental risks are associated with such practices due to the lack of regulatory and policy frameworks. The metals are non-biodegradable and persistent, therefore, they generally accumulated in human body organs like the liver, bones, and kidneys (Mehdi et al. 2021). Toxic metals accumulation in the human body such as As, Hg, Zn, Cu, Al, and Pb may cause different types of diseases like diarrhea, gastrointestinal (GI) disorders, convulsion, tremor, stomatitis, ataxia, paralysis, vomiting, depression, and pneumonia (Muhmood et al. 2015).

The adverse effects of toxic metals can be lethal (acute, chronic, and subchronic), mutagenic, carcinogenic, or tetra genic and neurotoxin (European Union 2006). Pakistan is an agricultural country, where almost 32,500 ha of agricultural land is irrigated with 30% of the total wastewater approximately. Wastewater has been regularly (26%) used in municipal and peri-urban areas because of the easy availability with no cost; henceforth, it drops the value of crop production by equal to 60%, *i.e.*, in terms of pesticides and fertilizers (Mahfooz et al. 2020). Many studies have focused on and evaluated the potential risks posed because of toxic metal accumulation in plants and the environment (Chaoua et al. 2019; Aslam et al. 2021), there are numerous knowledge gaps where the targeted study was required. In the current paper, the trends and levels of toxic metal (Cd, Ni, Pb, Cr and Mn) concentrations in vegetables grown in soil which is irrigated with wastewater from the industrial city of Pakistan, the possible health risks allied with their daily consumption, and how the vegetables and soil are correlated are presented through the use of various indices, transfer factor (TF), daily intake of metals (DIM), hazard quotient (HQ) and health risk index (HRI), so to provide a more holistic analysis to fill the available data and gaps in information.

Materials and methods

Wastewater, vegetables, and soil sampling

Vegetables sample of coriander (*Coriandrum Sativum* L.), cauliflower (*Brassica oleracea* L), tomato (*Lycopersicon esculentum* L.), and spinach (*Spinacia oleracea* L.) samples were randomly collected from the experimental site which is in the vicinity of Paharng drain, Faisalabad, Pakistan (latitude 31.5347°′ N, longitude 73.1186°′ E) and presented in Fig. 1. The particulars of the studied plants sampled during the current experiment are specified in Table 1. In the laboratory, distilled water was used to wash the sample vegetables to eliminate soil particles, air-dried followed by oven drying of edible parts of vegetables until a constant weight was achieved and crushed into powder for easy plant digestion (Mustapha and Adeboye 2014; Hamid et al. 2016). The samples of soil were assembled from two diverse depths (0–15 and 15–30 cm) and labeled properly (Khan et al. 2013).

Samples were air-dried followed by oven drying, crushed, passed through a mesh sieve to get rid of any non-soil elements, and stored in plastic jars (Mahmood and Malik 2014; Hamid et al. 2016). The wastewater samples were taken from watercourses of the same fields from where the samples of selected vegetables and soil were collected to monitor the quality of water used for irrigation of the field rather than at outlets or drains of pumping stations. High-density polyethylene bottles were used to collect wastewater samples that were pre-cleaned. These bottles were washed earlier with a chemical-free soap and soaked overnight in 10% HNO_3 solution (Khan et al. 2013), and lastly washed with distilled water (Mahmood and Malik 2014). Plastic bottles in which samples were collected were filled with 2 mL of concentrated hydrochloric acid to diminish the chances of microbial activity throughout storage (Singh et al. 2010; Khan et al. 2013; Muhmood et al. 2015).

Soil, water, and plant analysis

In vegetable samples, the concentration level of toxic metals was projected by digestion with the di-acid mixture ($HNO_3 + HClO_4$) (Sidney 1984; Muhmood et al. 2015). The digested samples were cooled at room temperature and filtered through filter paper (Whatman No. 42), and distilled water was used to make volumes up to 100 ml (Muhmood et al. 2015). The procedure used for the calculation of the concentration of toxic metals in soil samples was followed by (Khan et al. 2013; Muhmood et al. 2015).

Heavy metal analysis

The metal (Cd, Cr, Mn, Ni, and Pb) concentrations in the collected samples were analyzed by atomic absorption spectrometry (Hamid et al. 2016). Standard solutions were prepared with deionized water as a matrix of each selected metal (Sidney 1984). To compare the level of concentration of selected heavy metals in vegetable samples, safe limits were used (FAO 2007).

Quality control analysis

The solution used in the experimental work was prepared with double deionized water, and the washing of glassware was done with 10% HNO_3. The stock solution was used to prepare standards which were used to calibrate the instrument. Blank and drift standards were run after every five

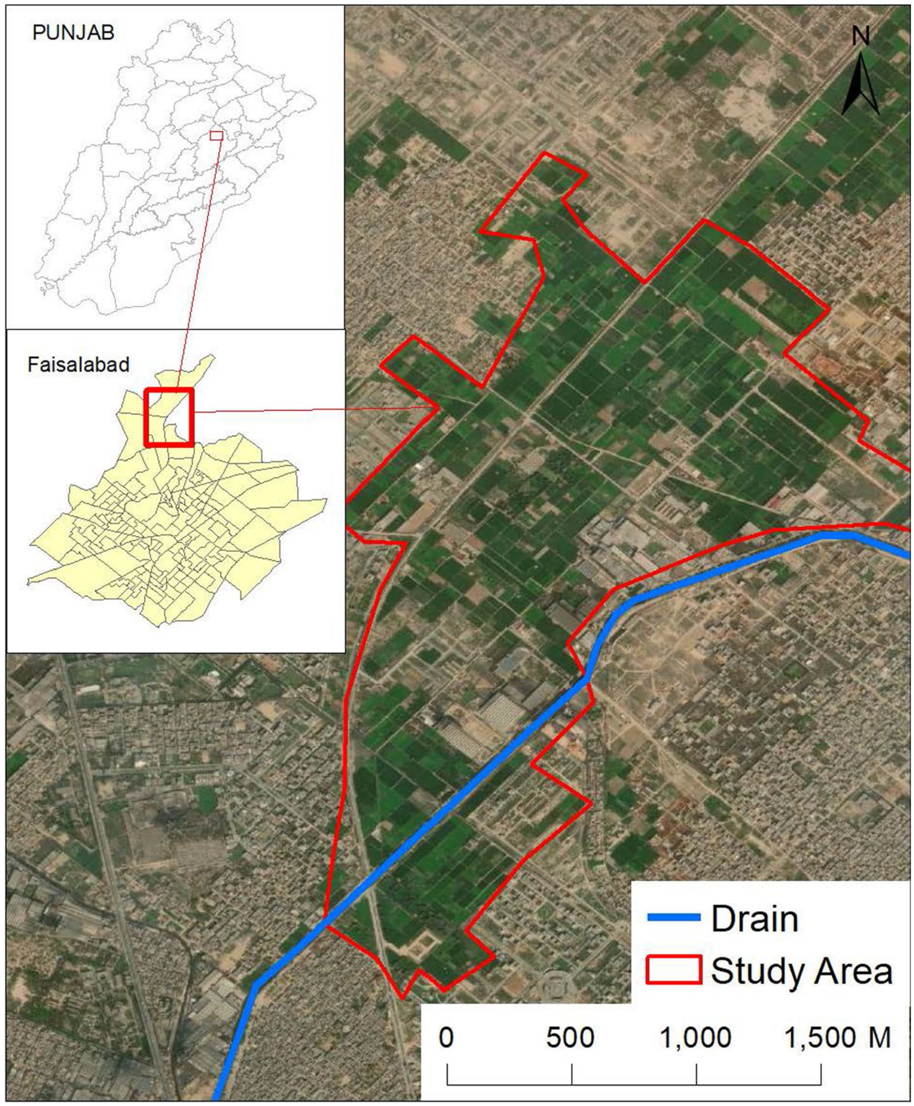

Fig. 1 Map showing the study area for present study

Table 1 Vegetables used in the study

English name	Common name	Plant specie	Family	Part used
Spinach	Paalak	*Spinacia oleracea* L.	Amaranthaceae	Leaves
Coriander	Dhania	*Coriandrum sativum* L.	Apiaceae	Leaves
Cauliflower	Phool Gobhi	*Brassica oleracea* L.	Brassicaceae	Fruiting flower
Carrot	Gajar	*Daucus carota* L.	Apiaceae	Underground stem

determinations for the calibration of the instrument. The measures of quality control were taken to assess the reliability and contamination of data.

Pollution load index (PLI)

We calculated the soil contamination level of selected metals via the pollution load index (PLI) method liable for the concentration of metals in the soil. The level of PLI in soils was determined through the following modified equation (Khan et al. 2008).

$$PLI = \frac{C_{\text{soil samples}}}{C_{\text{reference}}} \ldots$$

where $C_{\text{soil samples}}$ and $C_{\text{reference}}$ symbolize the concentrations level of selected heavy metal in the wastewater-irrigated as well as reference soils, correspondingly. In soil, the reference values for Cr, Cd, Mn, Ni and Pb were 1.49, 9.07, 46.75, 9.06 and 8.15 (mg kg^{-1}) (Singh et al. 2010; Ashfaq et al. 2015; Khan et al. 2015).

Transfer factor (TF)

Metal transfer to plants from soil was calculated as a transfer factor by the method followed by Khan et al. (2008) and Mahmood and Malik (2014).

Daily metal intake (DMI)

Daily metal intake was estimated by the subsequent equation (Singh et al. 2010; Mahmood and Malik 2014).

$$\text{Daily metal intake} = \frac{C_{\text{metal}} \times C_{\text{factor}} \times D_{\text{food intake}}}{B_{\text{average weight}}} \ldots$$

Conversion factor (0.085) was used as documented by Rattan et al. (2005). The average child and adult body weights, and the average daily intake of vegetables for adults and kids were considered as documented by Wang et al. (2005) and Khan et al. (2008).

Health risk index (HRI)

Vegetables used by the receptor population are enriched with the highest level of toxic metals which arrives in the human body causing health risks. In current research work, HRI associated with vegetables grown with wastewater was estimated by the equation followed (Jan et al. 2010; Singh et al. 2010; Mahmood and Malik 2014). R_fd values for selected metals were adopted from (US-EPA and IRIS 2006; USEPA 2010; Khan et al. 2015).

Risk assessment

The risk of metal contamination to human health by eating filthy vegetables was described by Hazard Quotient (HQ). Less than 1 ratio of HQ will pose no danger to the population and if the ratio is greater than or equal to 1 then the population will suffer from health risks as measured by the procedure followed (Wang et al. 2005; Muhmood et al. 2015).

Results and discussion

The contamination of toxic metals in soil and water samples

In Table 2, the concentration level of selected toxic metals in the samples of soil and water used for irrigation collected in the vicinity of Paharang drain is presented. The highest concentration of Pb was observed in (0.59 ± 0.02 mg L^{-1}) in water samples followed by Cr (0.51 ± 0.01 mg L^{-1}), Cd (0.35 ± 0.01 mg L^{-1}), and Ni (0.27 ± 0.01 mg L^{-1}) when compared with the WHO and EU standards (Mahmood and Malik 2014; Muhmood et al. 2015). Heavy metals concentration in soil varied among the diverse sites around Paharang Drain, Faisalabad. However, the concentration of studied toxic metals in soil samples was under the permissible limits established by the EU and WHO (European Commission 2006; FAO 2007). The rationale behind using WHO and EU standards is that Pakistani standards are not well recognized across the globe because of its nature of national level, while aforementioned standards are well-reputed international standards that may be more useful for national and international scientific community.

In the present study results, the concentration of Cr, Cd, Mn, Ni, and Pb in wastewater was up to acceptable limits (European Commision 2006; FAO 2007). Mn concentration was highest in the soil irrigated with wastewater, tailed by the concentration of Pb and Cr. In Faisalabad city, the most important source of heavy metal buildup in wastewater is the sewage produced by the public and manufacturing industries of the city that is discharged into the drains (Muhmood et al. 2015). These results are under previous research studies in which water samples from different areas of Rawalpindi were taken and analyzed. The results have shown that the concentrations of toxic metals Zn, Fe, Cr, Cu,

Table 2 Concentration of metals in wastewater and wastewater-irrigated soils

Metals	Wastewater (mg L^{-1})	Permissible limit	Soil (0–15 cm) (mg kg^{-1})	Soil (15–30 cm)	Permissible limit
	Mean ± S.D.		Mean ± S.D	Mean ± S.D.	
Cd	0.23 ± 0.01	0.01*	1.3 ± 0.1	1.1 ± 0.1	3.0*
Cr	0.33 ± 0.11	0.05*	18.3 ± 7.0	15.1 ± 6.3	100**
Mn	0.87 ± 0.50	–	22.96 ± 9.2	19.21 ± 7.9	2000**
Ni	0.15 ± 0.07	.01*	1.2 ± 0.4	1.1 ± 0.4	50**
Pb	0.35 ± 0.20	0.2*	19.28 ± 8.7	13.8 ± 6.9	100**

*FAO (2007) and WHO (2007)

**European Commision (2006) and European Union Standards European Union (2006)

Ni, and Cd were above the acceptable limits (Mushtaq and Khan 2010). Another research study supports these results in which high concentrations levels of Cd, Cu, and Mn were found in wastewater samples of peri-urban areas of Lahore (Khan et al. 2013). It is also apparent from the results that the concentration level of Cd and Cr in soil samples was below acceptable limits as described by the European Union and WHO (European Commision 2006; FAO 2007). The leaching of toxic metals into inner deposits of soil and their uptake by vegetables could be grounds for low heavy metals concentration (Singh et al. 2010; Mahmood and Malik 2014).

Heavy metals concentration in vegetables

The concentration level of Cr in vegetables was higher than the permissible limits (European Union 2002). According to the results, few vegetable samples were found within a safe limit for the concentration of Cd. 84%, 61%, and 80% of spinach, coriander, cauliflower, and carrot samples surpassed the EU safe limits (European Commision 2006) for Cd, respectively (Table 3). Cr concentration among the vegetables grown in the vicinity of Paharang Drain was maximum in *Spinacia oleracea* L*., i.e.*, 4.35 ± 0.02 mg kg^{-1} followed by *Coriandrum sativum* L. (4.34 ± 0.02 mg kg^{-1}), *Brassica oleracea* (4.0 ± 0.06 mg kg^{-1}), *Daucus carota* L. (3.02 ± 0.01 mg kg^{-1}), etc. The concentration of manganese was observed highest in *Spinacia oleracea* L. (111.6 ± 33.5 mg kg^{-1}), followed by *Coriandrum sativum* L. (107.6 ± 32.1 mg kg^{-1}), which are leafy vegetables.

Similarly, a high concentration of Pb and Ni was observed in leafy *Spinacia oleracea* L. (62.5 ± 18.5 mg kg^{-1}; 31.3 ± 3.3 mg kg^{-1}) and *Coriandrum sativum* L. (56.1 ± 15.2 mg kg^{-1}; 29.7 ± 2.9 mg kg^{-1}), respectively. Results have proved that 100% of vegetable samples for selected metals were exceeding the critical limits (WHO 2007). Vegetables' morphology and composition for the uptake of heavy metals, segregation, buildup, and maintenance are diverse, which ultimately results in deviations in heavy metals absorption in various vegetables (Khan et al. 2015). The variants among vegetables against the concentration of toxic metals may also be owing to the various reasons like the concentration of heavy metals in water consumption for irrigation as well as atmospheric deposition along with the ability of the plant to accept and accumulate the toxic metals (Muhmood et al. 2015). Toxic metals are transported from roots to other parts of vegetables and crops. In the body of a human, Cd produced noxious effects on different parts of the body such as the testes, ovaries, hepatic system, renal system, nervous system, cardiovascular system, and also induced gastrointestinal problems (Cooke 2011). Carcinogenic effects are associated with the ingestion of a few toxic metals, specifically Cd and Pb (Trichopoulos 1997) which may lead to hypertension, dysfunction of the kidney, malformation and bone fractures, cardiovascular problems, and other serious ailments of the immune and nervous system (El-Kady and Abdel-Wahhab 2018). Cr has carcinogenic effects on the cardiovascular and urogenital system (Costa and Klein 2006). The results of the current research study are also per the findings of other researchers (Jan et al. 2010). One previous study has proved that leafy vegetables like *Spinacia oleracea* and *Coriandrum sativum* have a higher concentration level of toxic metals than tuber and bulb-type vegetables (Mahmood and Malik 2014). The present research study has also proved that the Cd and Cr concentration in 89% of the vegetable sample irrigated with wastewater was higher than the permissible limits established by the EU standard (European Commission 2006). Further, in the vicinity of the study area, open-air discharge of several automobiles and industrial operation is common becoming the reason for air deterioration of the area with smoke, which contains numerous toxic metals that may originate from atmospheric deposition of toxic metals on the vegetable leaves thus causing an increased buildup of toxic metals in leafy vegetables (Mahmood and Malik 2014; Muhmood et al. 2015). Various studies conducted in Pakistan documented that the vegetables irrigated with groundwater are less contaminated as compared to the vegetables irrigated with wastewater (Ahmad et al. 2010; Jan et al. 2010).

Table 3 Heavy metals concentration in vegetables (mg kg^{-1}) irrigated with wastewater

Vegetables	Cd Mean ± SD	Cr Mean ± SD	Mn Mean ± SD	Ni Mean ± SD	Pb Mean ± SD
Spinacia oleracea L	2.1 ± 0.7	2.7 ± 1.1	111.6 ± 33.5	31.3 ± 3.3	62.5 ± 18.5
Coriandrum sativum L	0.4 ± 0.2	2.6 ± 1.1	107.6 ± 32.1	29.7 ± 2.9	56.1 ± 15.2
Brassica oleracea L	0.2 ± 0.1	2.5 ± 1.0	56.8 ± 13.1	24.1 ± 8.5	48.5 ± 13.4
Daucus carota L	0.3 ± 0.1	1.9 ± 0.8	56.9 ± 20.8	19.3 ± 6.7	42.8 ± 12.5
Permissible Limit	0.2**	1**	500**	NA	0.43**

**European Commision (2006) and European Union Standards European Union (2006)

Pollution load index (PLI) and transfer factor (TF) for vegetable, soil system

The pollution load index is summarized in Table 4, which was used to analyze the contamination status along the two depths of soil considered in the study. The contamination level was greater in the upper soil layer (0–15 cm) than in the deep layer (15–30 cm). In soil, the reference values for Cd, Cr, Mn, Ni, and Pb were 1.49, 9.07, 46.75, 9.06, and 8.15 mg kg^{-1}, respectively (Singh et al. 2010). Anyhow, the values observed for the investigated metals were lower than reference soil values. Transfer factor for vegetables grown in the studied area ranges from (0.15–1.61 and 0.18–1.91), (0.1–0.15 and 0.13–0.18), (2.47–4.86 and 2.96–5.81), (16.04–26.11 and 17.50–28.48) and (2.22–3.24 and 3.1–4.53) for Cd, Cr, Mn, Ni and Pb concerning the two soil depths understudy, respectively (Table 5). Cd TF was the highest for *Spinacia oleracea* L. (1.61), followed by the *Coriandrum sativum* L. (0.31), *Daucus carota* L. (0.23), *Brassica oleracea* (0.15). Transfer factor for Cr was lowest for the selected vegetables when compared with Cd which ranges from 0.1 to 0.15. The trend of Cr concentration in vegetables was *Spinacia oleracea* L.> *Coriandrum sativum* L. ≥ *Brassica oleracea*> *Daucus carota* L., while a slight change in the Cd TF was observed in vegetables as compared to the other metal, which is *Spinacia oleracea* L.> *Coriandrum sativum* L. > *Daucus carota* L. > *Brassica oleracea*.

The transfer factor of metal from soil to plants is an essential module for the exposure of humans to toxic metals through the food chain as well as to evaluate the risk index of human health (Muhmood et al. 2015; Woldetsadik et al. 2017). In the current study, the transfer factor for Ni was found to be maximum but it may vary considerably in various vegetables. Higher uptake of metals was observed for leafy vegetables as compared to the other vegetables. Leafy vegetables have a greater rate of transpiration to tolerate the moisture content and plant growth; a reason for the high metal uptake (Laţo et al. 2012; Mahmood and Malik 2014).

Table 4 Pollution Load Index (PLI) for toxic metals in soil irrigated with wastewater

Metals	PLI in soil (0–15 cm)	PLI in soil (15–30 cm)
Cd	0.87	0.73
Cr	2.01	1.66
Mn	0.49	0.41
Ni	0.13	0.12
Pb	2.37	1.69

DIM (daily intake of metals) and HRI (health risk index) of heavy metals

Calculated DIM values for children and adults are presented in Table 6. The presented data exposed that the DIM values were high for vegetables irrigated with wastewater. DIM was found to be the highest for Mn ranges from 0.033 to 0.67, and 0.03–0.059 followed by Ni ranges from 0.012 to 0.019 and 0.01–0.016, Pb ranges from 0.008 to 0.011 and 0.022–0.033 and Cr that ranges from 0.0011 to 0.0016 and 0.0009–0.0014 for children and adults, correspondingly. In contrast, DIM for Cd was recorded as 0.0001–0.0012 and 0.0001–0.0011 for children and adults, respectively. The Health risk index (HRI) for toxic metals by consuming vegetables irrigated with sewage water for children and adults was intended (Table 6). The highest HRI was found for *Spinacia oleracea* L. (8.198) against Pb in adults.

HRI of Cd and Cr ranges from 0.12 to 1.2 for children and 0.1–1.1 for adults and 0.001–0.0007 for children, and 0.0007–0.0009 for adults, while HRI for Mn ranges (1.039–2.04 and 0.904–1.774), Ni ranges (0.580–0.945 and 0.505–0.822), and Pb ranges (1.886–2.790 and 5.610–8.198) for children and adults, respectively (Table 6). DIM for adults and children becomes a source of severe health hazards through the ingestion of toxic metals contaminated vegetables grown with wastewater. Measures of human risk associated with the consumption of vegetables irrigated with wastewater are of prime importance in states like Pakistan, where the practice of wastewater irrigation is still abandoned. Abundant exposure pathways primarily depend on contaminated sources of soil, water, air, food, and the consuming population (Muhmood et al. 2015; Irshad et al.

Table 5 Transfer factor (TF) for vegetables/soil system

Metals	*Spinacia oleracea* L.		*Coriandrum sativum* L.		*Brassica oleracea* L.		*Daucus carota* L.	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Cd	1.61	1.91	0.31	0.36	0.15	0.18	0.23	0.27
Cr	0.15	0.18	0.14	0.17	0.14	0.17	0.1	0.13
Mn	4.86	5.81	4.69	5.60	2.48	2.96	2.47	2.96
Ni	26.11	28.48	24.77	27.03	20.11	21.93	16.04	17.50
Pb	3.24	4.53	2.91	4.07	2.51	3.51	2.22	3.1

Table 6 Daily intake of metals (DIM) (mg person^{-1} day^{-1}) and health risk index (HRI) for heavy metals in vegetables grown at Paharang Drain

Metals	*Spinacia oleracea* L.		*Coriandrum sativum* L.		*Brassica oleracea* L.		*Daucus carota* L.	
	Child	Adult	Child	Adult	Child	Adult	Child	Adult
Cd								
DIM	0.0012	0.0011	0.00024	0.00021	0.00012	0.0001	0.00018	0.0002
HRI	1.2	1.1	0.24	0.21	0.12	0.1	0.18	0.16
Cr								
DIM	0.0016	0.0014	0.0015	0.0013	0.0015	0.0013	0.001[1]	0.0001
HRI	0.001	0.00093	0.001	0.00087	0.001	0.00087	0.00073	0.0007
Mn								
DIM	0.067	0.059	0.065	0.056	0.034	0.030	0.033	0.03
HRI	2.04	1.774	1.967	1.711	1.039	0.904	1.04	0.905
Ni								
DIM	0.019	0.016	0.018	0.016	0.015	0.013	0.012	0.01
HRI	0.945	0.822	0.896	0.780	0.728	0.633	0.580	0.505
Pb								
DIM	0.011	0.033	0.009	0.029	0.008	0.025	0.008	0.022
HRI	2.790	8.198	2.299	7.362	2.017	6.356	1.886	5.610

2020), but the exposure routes through the food chain are one of the crucial ways of human exposure to toxic metals (Muchuweti et al. 2006). The heavy metal pollution index was calculated to identify the unfavorable effects on human health induced (Ahmad et al. 2011). The vegetable contamination with detrimental metals could directly impact the nearby inhabitant's health because vegetables grown from peri-urban areas are generally consumed in the vicinity. In the present study, the daily intake of metals was greater in Spinach. (Khan et al. 2008) found maximum intakes of Cu, Cd, Cr, Pb, Zn, and Ni from *Lactuca sativa* L., *Raphanus sativus* L., *Lactuca sativa* L., *Brassica napus* L., and *Spinacia oleracea* L. consumption for adults and children. Likewise, (Zhuang et al. 2009) have also obtained HRI for Pb and Cd more than the acceptable limits in cereals and vegetables.

Hazard quotient (HQ)

Estimation of the exposure level is very important to observe the risk to health associated with any pollutant. The food chain is considered the most significant trail among numerous potential ways of human exposure. The data regarding the hazard quotient are given in Table 7. The highest HQ was obtained in the case of Pb (16.35, 18.527, 21.458, and 23.894 for children and 9.564, 10.838, 12.552, and 13.977 for adults) from the consumption of wastewater-irrigated spinach, coriander, carrot, and cauliflower, respectively. Hazard quotient one (1) is considered unacceptable, so *Spinacia oleracea* L. (Spinach) consumption would adversely affect human health. The highest hazard quotient was obtained for Cd from the intake of Spinach for both children and adults. The results regarding hazard quotient are agreed with those reported in a study that the health risk index of Cd, Cu, Pb, Ni, and Zn from *Lactuca sativa* L, *Raphanus sativus* L., *Lactuca sativa* L., *Brassica napus* L., and *Spinacia oleracea* L. and found that HQ was less than 1 (Khan et al. 2008). It was identified by various researchers that vegetable farming in soil contaminated with metals can pose a serious health risk for users (Li et al. 2016; Bi et al. 2018), but (Zhou et al. 2016) proposed that the metal concentrations increased in the order: melon vegetables/legume vegetables < stalk vegetables/solanaceous vegetables/ root vegetables < leafy vegetables.

Table 7 Hazard quotient (HQ) of different metals

Metals	*Spinacia oleracea* L.		*Coriandrum sativum* L.		*Brassica oleracea* L.		*Daucus carota* L.	
	Child	Adult	Child	Adult	Child	Adult	Child	Adult
Cd	1.20	1.1	0.24	0.21	0.12	0.1	0.18	0.16
Cr	2.975	5.09	2.818	4.82	2.760	4.72	2.080	3.56
Mn	5.172	3.025	4.987	2.918	2.634	1.541	2.637	1.543
Ni	2.396	1.401	2.273	1.330	1.845	1.079	1.472	0.861
Pb	23.894	13.977	21.458	12.552	18.527	10.838	16.35	9.564

Environmental measures to potentially eliminate the risks induced by toxic metals

Human health is of prime concern of the globe which is vulnerable to the contamination of the food chain through anthropogenic sources of toxic metals like wastewater irrigation, industrial effluents, and sludge application. Thus, remediation of toxic metals from soil can reduce the transference of toxic metals in the soil–crop system. Lessening the toxic metal sources is an operative approach for improving human health safety. Accumulation of toxic metals in food crops can be significantly reduced by avoiding the use of sewage sludge and ineffectively treated effluent. In soil, less particulate matter deposition could result from the management of air quality which ultimately reduces the pollution of foodstuff. The application of biochar is considered an eco-remediation approach to lessen the contamination of toxic metals in soil and confer multilayered benefits (Peng et al. 2018).

Nanoparticle technologies are an amazing investigation hot spot for guaranteeing the security of soil as an essential constituent of agro-nanotechnology and for dropping the bioavailability of toxic metals. Biological remediation is a solar-based, eco-friendly, and cost-effective approach in contrast to physicochemical methods which are effective and quick for extremely polluted sites but may cause secondary pollution by altering the biological, physical, and chemical features of soil (Mahar et al. 2016), while biological remediation maintains the natural attributes of soil through bio/phytoremediation, biostimulation, composting, bioaugmentation, bioleaching, land aeration, bioremediation and bioventing (Rai 2018).

Conclusion

In the current study, the concentration of toxic metals in vegetables and soil irrigated with sewage water was investigated. Collected samples of vegetables, soil, and wastewater were analyzed for the occurrence of Pb, Ni, Cr, Mn, and Cd and evaluated for possible environmental and human health hazards. Almost all the metals exceeding the threshold limits, especially the leafy vegetables, had accumulated the maximum metals among the selected vegetables. Furthermore, all HQ values below 1 mean a potentially low non-carcinogenic risk to human health to the inhabitants from the vegetable consumption. The concentrations of Pb, Ni, Cr, and Ni in target vegetables have a probable carcinogenic health risk to the population. However, more researches are essential to detect more vegetables and from which zone they should be grown to endure the vegetable and dietary preference requirements of the inhabitants. Henceforth, intensifying the current study to contain which vegetable part stores metals, analysis of pollutant transport, biomonitoring of metals of concern, various ways of metal acquaintance like drinking water, eating other foods (cereals, root crops and fruits), air contact, and variability and uncertainty analyses, is vital for further understanding of the risks allied with the raised metal concentrations in the soil irrigated with wastewater and its produced health risks, specifically pointing carcinogenic risk. Additionally, the findings of this research are valuable for the expansion of more intensive studies against specific toxins and eatable agricultural harvests that are used by the people. Furthermore, epidemiological studies precise to carcinogenic risks are beneficial to support health establishments and pertinent government agencies to generate required agendas to protect public health.

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Availability of data and materials All data generated or analyzed during this research experiment are part of this manuscript.

Declarations

Ethical approval and consent to participate The authors declare that all ethical standards were met during the conduct of this experiment and proper consent was sought from all individuals wherever involved.

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

References

Ahmad K, Khan ZI, Ibrahim M, Ashraf M, Hussain M (2010) Evaluation of nutritional composition of plant species of Soone valley in Punjab, Pakistan. J Plant Nutr 33:496–517

Ahmad K, Ibrahim M, Khan ZI, Rizwan Y, Ejaz A, Fardsous A, Gondal S, Lee DJ, Al-Yemeni M (2011) Effect of sewage water on mineral nutritive potential of six fodder species grown under semiarid conditions. Saudi J Biol Sci 18:317–321

Ashfaq A, Khan ZI, Bibi Z, Ahmad K, Ashraf M, Mustafa I, Akram NA, Perveen R, Yasmeen S (2015) Heavy metals uptake by cucurbita maxima grown in soil contaminated with sewage water and its human health implications in peri-urban areas of Sargodha City. Pak J Zool 47:1051–1058

Aslam A, Ibrahim M, Mahmood A, Mubashir M, Sipra HFK, Shahid I, Ramzan S, Latif MT, Tahir MY, Show PL (2021) Mitigation of particulate matters and integrated approach for carbon monoxide remediation in an urban environment. J Environ Chem Eng 9:105546

Bashir M, Khalid S, Rashid U, Adrees M, Ibrahim M, Islam MS (2014) Assessment of selected heavy metals uptake from soil by vegetation of two areas of district Attock, Pakistan. Asian J Chem 26:1063–1068

Bi C, Zhou Y, Chen Z, Jia J, Bao X (2018) Heavy metals and lead isotopes in soils, road dust and leafy vegetables and health risks via vegetable consumption in the industrial areas of Shanghai, China. Sci Total Environ 619:1349–1357

Chaoua S, Boussaa S, El Gharmali A, Boumezzough A (2019) Impact of irrigation with wastewater on accumulation of heavy metals in soil and crops in the region of Marrakech in Morocco. J Saudi Soc Agric Sci 18:429–436

Cooke JA (2011) Cadmium in small mammals, environmental contaminants in Biota. CRC Press, pp 627–644

Costa M, Klein CB (2006) Toxicity and carcinogenicity of chromium compounds in humans. Crit Rev Toxicol 36:155–163

El-Kady AA, Abdel-Wahhab MA (2018) Occurrence of trace metals in foodstuffs and their health health Impactr. Trends Food Sci Technol 75:36–45

European Union (2002) Heavy metals in wastes, European Commission on Environment. http://ec.europa.eu/environment/waste/studies/pdf/heavymetalsreport.pdf

European Union (2006) Commission regulation (EC) No. 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. Off J Eur Union L 364:5–24

FAO (2007) WHO, expert standards program codex alimentation commission. Geneva, Switzerland

Ghafoor S, Ata S, Mahmood N, Arshad SN (2017) Photosensitization of TiO_2 nanofibers by Ag_2S with the synergistic effect of excess surface Ti3+ states for enhanced photocatalytic activity under simulated sunlight. Sci Rep 7:255

Hamid A, Riaz H, Akhtar S, Ahmad SR (2016) Heavy metal contamination in vegetables, soil and water and potential health risk assessment. Am Eurasian J Agric Environ Sci 16:786–794

Hasan M, Mehmood K, Mustafa G, Zafar A, Tariq T, Hassan SG, Loomba S, Zia M, Mazher A, Mahmood N, Shu X (2021) phytotoxic evaluation of phytosynthesized silver nanoparticles on lettuce. Coatings 11(2):225

Iqbal Z, Abbas F, Ibrahim M, Qureshi TI, Gul M, Mahmood A (2020) Human health risk assessment of heavy metals in raw milk of buffalo feeding at wastewater-irrigated agricultural farms in Pakistan. Environ Sci Pollut Res 27:29567–29579

Iqbal Z, Abbas F, Ibrahim M, Mahmood A, Gul M, Qureshi TI (2022) Ecological risk assessment of soils under different wastewater irrigation farming system in Punjab, Pakistan. Int J Environ Sci Technol 19:1925–1936

Irfan M, Rashid U, Ibrahim M, Nisa ZU, Ala'a H, Ali S (2013) Optimization of Cr (III) removal from wastewater using *Thespesia populnea* particles by response surface methodology. Asian J Chem 25:9315

Irshad MK, Chen C, Noman A, Ibrahim M, Adeel M, Shang J (2020) Goethite-modified biochar restricts the mobility and transfer of cadmium in soil-rice system. Chemosphere 242:125152

Jan FA, Ishaq M, Khan S, Ihsanullah I, Ahmad I, Shakirullah M (2010) A comparative study of human health risks via consumption of food crops grown on wastewater irrigated soil (Peshawar) and relatively clean water irrigated soil (lower Dir). J Hazard Mater 179:612–621

Kanwal U, Ibrahim M, Abbas F, Yamin M, Jabeen F, Shahzadi A, Farooque AA, Imtiaz M, Ditta A, Ali S (2021) Phytoextraction of lead using a hedge plant [*Alternanthera bettzickiana* (Regel) G. Nicholson]: physiological and biochemical alterations through bioresource management. Sustainability 13:5074

Khan S, Cao Q, Zheng Y, Huang Y, Zhu Y (2008) Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environ Pollut 152:686–692

Khan A, Javid S, Muhmood A, Mjeed T, Niaz A, Majeed A (2013) Heavy metal status of soil and vegetables grown on peri-urban area of Lahore district. Soil Environ 32:49–54

Khan ZI, Ahmad K, Ashraf M, Parveen R, Mustafa I, Khan A, Bibi Z, Akram NA (2015) Bioaccumulation of heavy metals and metalloids in luffa (*Luffa cylindrica* L.) irrigated with domestic wastewater in Jhang, Pakistan: a prospect for human nutrition. Pak J Bot 47:217–224

Laţo A, Radulov I, Berbecea A, Laţo K, Crista F (2012) The transfer factor of metals in soil–plant system. Res J Agric Sci 44:67–72

Li B, Wang Y, Jiang Y, Li G, Cui J, Wang Y, Zhang H, Wang S, Xu S, Wang R (2016) The accumulation and health risk of heavy metals in vegetables around a zinc smelter in northeastern China. Environ Sci Pollut Res 23:25114–25126

Mahar A, Wang P, Ali A, Awasthi MK, Lahori AH, Wang Q, Li R, Zhang Z (2016) Challenges and opportunities in the phytoremediation on heavy metal contaminated soils: a review. Ecotoxicol Environ Saf 126:111–121

Mahfooz Y, Yasar A, Guijian L, Islam QU, Akhtar ABT, Rasheed R, Irshad S, Naeem U (2020) Critical risk analysis of metals toxicity in wastewater irrigated soil and crops: a study of a semi-arid developing region. Sci Rep 10:1–10

Mahmood A, Malik RN (2014) Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan. Arab J Chem 7:91–99

Mehdi SEH, Amen R, Ali A, Anjum H, Mahmood A, Mubashir M, Mukhtar A, Ullah S, Al-Sehemi AG, Ibrahim M (2021) Sources, chemistry, bioremediation and social aspects of arsenic-contaminated waters: a review. Environ Chem Lett. https://doi.org/10.1007/s10311-021-01254-3

Muchuweti M, Birkett J, Chinyanga E, Zvauya R, Scrimshaw MD, Lester J (2006) Heavy metal content of vegetables irrigated with mixtures of wastewater and sewage sludge in Zimbabwe: implications for human health. Agric Ecosyst Environ 112:41–48

Muhmood A, Majeed A, Javid S, Niaz A, Majeed T, Shah SSH (2015) Health risk assessment from wastewater irrigated vegetables. Am Eurasian J Agric Environ Sci 15:1424–1434

Mushtaq N, Khan KS (2010) Heavy metals contamination of soils in response to wastewater irrigation in Rawalpindi region. Pak J Agric Sci 47:215-224

Mustapha HI, Adeboye OB (2014) Heavy metals accumulation in edible part of vegetables irrigated with untreated municipal wastewater in tropical savannah zone, Nigeria. Afr J Environ Sci Technol 8:460–463

Nolos RC, Agarin CJM, Domino MYR, Bonifacio PB, Chan EB, Mascareñas DR, Senoro DB (2022) Health risks due to metal concentrations in soil and vegetables from the six municipalities of the Island Province in the Philippines. Int J Environ Res Public Health 19:1587

Peng X, Deng Y, Peng Y, Yue K (2018) Effects of biochar addition on toxic element concentration in plants: a meta-analysis. Sci Total Environ 616–617:970–977

Rai PK (2018) Phytoremediation of emerging contaminants in wetlands. CRC Press, Boca Raton, p 248

Rattan R, Datta S, Chhonkar P, Suribabu K, Singh A (2005) Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. Agric Ecosyst Environ 109:310–322

Sharif HMA, Mahmood A, Cheng HY, Djellabi R, Ali J, Jiang WL, Wang SS, Haider MR, Mahmmod N, Wang AJ (2019) Fe_3O_4 Nanoparticles coated with EDTA and Ag nanoparticles for the catalytic reduction of organic dyes from wastewater. ACS Appl Nano Mater 2(8):5310–5319

Sidney W (1984) Official methods of analysis of the association of official analytical chemists. 0935584242

Singh A, Sharma RK, Agrawal M, Marshall FM (2010) Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. Food Chem Toxicol 48:611–619

Trichopoulos D (1997) Epidimology of cancer. In: DeVita VT (ed) Cancer: principals and practice of oncology. Lippincott Company, Philadelphia, pp 231–258

US-EPA, IRIS (2006) United States, Environmental Protection Agency, Integrated Risk Information System

US EPA (2010) Integrated risk information system: pentachlorophenol. US Environmental Protection Agency, Washington

Wang X, Sato T, Xing B, Tao S (2005) Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. Sci Total Environ 350:28–37

Woldetsadik D, Drechsel P, Keraita B, Itanna F, Gebrekidan H (2017) Heavy metal accumulation and health risk assessment in wastewater-irrigated urban vegetable farming sites of Addis Ababa, Ethopia. Int J Food Contam 4:9

Zhou H, Yang W-T, Zhou X, Liu L, Gu J-F, Wang W-L, Zou J-L, Tian T, Peng P-Q, Liao B-H (2016) Accumulation of heavy metals in vegetable species planted in contaminated soils and the health risk assessment. Int J Environ Res 13:289

Zhuang P, Zou B, Li N, Li Z (2009) Heavy metal contamination in soils and food crops around Dabaoshan mine in Guangdong, China: implication for human health. Environ Geochem Health 31:707–715

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