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Original article

Human health risk hazards by heavy metals through consumption of vegetables cultivated by wastewater

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ABSTRACT

Need for irrigated agriculture is rising daily, but quality water for irrigation is on the decline, necessitating the use of urban wastewater as alternative source, particularly in low or middle income countries. This study assessed the effect of urban wastewater irrigation on the quality of groundwater, soil and vegetables in farms around Faisalabad, Pakistan. Human health risks of heavy metals were investigated through consumption of wastewater irrigated vegetables. Samples of soil, vegetables and water were obtained and analyzed for heavy metal concentrations (cadmium, Cd; lead, Pb; manganese, Mn; nickel, Ni; cobalt, Co; and zinc, Zn). The groundwater could be declared safe for consumption in the present state, as concentration of heavy metals standards. But wastewater-irrigated vegetables had higher Pb, Cd and Mn than the permissible limits. In wastewater-irrigated vegetables, highest HRI-Pb was recorded in mustard leaf and cabbage and was >1. EF for Zn and Mn in all vegetable plants, Ni in potato and cauliflower, Pb in mustard leaf and cabbage were >1.5, suggesting that the metals were generated by anthropogenic processes (such as wastewater irrigation). Long-term irrigation of farmlands with the wastewater will result to heavy metal contamination of groundwater, soil and vegetables in the study area. Therefore, strategies to save the groundwater from future contamination are necessary.

1. Introduction

Groundwater plays a significant role as a sustainable source of water for domestic and industrial purposes, particularly in the semi-arid and arid regions. It is estimated that over 4 million people in Faisalabad city, Pakistan rely on groundwater for consumption and other domestic purposes (Ahmed et al., 2019; Rani et al., 2021). However, the quality of groundwater may be altered due to unsustainable anthropogenic activities (Zwolak et al., 2019; Qayoom et al., 2021). For example, arsenic (As) contamination was found in groundwater in Hasilpur, Pakistan, with hazard quotient (HQ) and carcinogenic risk up to 58 and 2.3 × 10^{-3}, respectively (Mahmood et al., 2013; Tabassum et al., 2019; Alam et al., 2021). Higher As concentration to levels that pose health risk has also been found in groundwater-irrigated vegetables in the central region of Italy (Singh and Raj, 2018; Spognardi et al., 2019). Also, in the south of Setif Area of East Algeria, cadmium (Cd) and lead (Pb) concentrations in the groundwater had an HQ above recommended safe limits with likelihood of posing health risk. Irrigation of farmlands with urban wastewater is a known source of groundwater contamination (Rehman et al., 2019; Alam et al., 2022). Wastewater contains pollutants, resulting in contaminant transfer into irrigated soils leading to groundwater contamination as well as the contamination of irrigated vegetables (Hussain et al., 2019). Consumption of contaminated groundwater or plants could result in serious health problems, such as neurological, genotoxic, metagenomics, carcinogenic and respiratory effects (Mehmood et al., 2019; Mahmood et al., 2020).

In Faisalabad, vegetables sold in the supply market are produced by local farmers who irrigate their fields with groundwater, or largely with wastewater collected from different points along

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the sewer channels. Therefore, this study, carried out on farmers' fields in the region of Faisalabad, Pakistan, was conducted to assess the heavy metals contamination levels in the (1) groundwater compared to the wastewater and (2) in vegetables irrigated with groundwater compared to wastewater in this region, and (3) to determine the potential risks associated with consuming contaminated vegetables by using the daily intake (DIM) and transfer factor of metals (MTF) to compute health risk index (HRI) and Enrichment Factor (EF).

2. Materials and methods

2.1. Description of study site

Faisalabad is an industrial city in the district with the same name. It is the second largest city in Punjab province and the third biggest city in Pakistan (Fig. 1). The city is situated between the Chenab and Ravi rivers. Irrigation is based on water from these two rivers. To conduct the present study, two sites with different irrigation practices were identified based on a previous survey of Faisalabad. These sites have a long history of wastewater or groundwater irrigation. From each site, three sub-sites were selected, from where samples were collected for analyses. Soil, water, vegetable samples were collected from each selected site according to methods described by the American Public Health Association (APHA, 2005).

2.2. Collection of soil, water and plant samples

A quantity of 500 g soil sample was collected in triplicate from a monolith of $10 \times 10 \times 15$ cm^3 from each sub-site. Before collecting in plastic bags, materials like rocks, gravels and organic debris were removed manually from the soil.

Water (groundwater and wastewater) samples were filtered before storing in labelled 1 L plastic bottles that had earlier been soaked in 10% HNO_3 for 24 h and afterwards washed with deionized water to remove free soap and contaminants. The water samples were stored on ice before transporting to the laboratory where they were preserved at 4 °C for further analyses (APHA, 2005).

List of vegetable crops collected from the sub-sites of each zone is given in Table 1. Five replicates of each vegetable crop were collected per sampling zone. The vegetables were washed and oven dried (65 °C) in the laboratory and preserved for further analyses.

2.3. Sample digestion

One gram (1 g) of each oven dried and ground vegetable parts or soil samples was digested at 80 °C in a 15 ml of tri-acid mixture containing HNO_3, H_2SO_4, and $HClO_4$ in 4.5:1:1 ratio, to obtain a clear solution (APHA, 2005). The solution was further filtered and the filtrate was made up to 50 ml by adding distilled water.

Water (groundwater and wastewater) samples (50 ml) were digested at 80 °C in a 10 ml conc. HNO_3 to obtain a clear solution (APHA, 2005), that was further filtered and the filtrate made up to 50 ml by adding distilled water

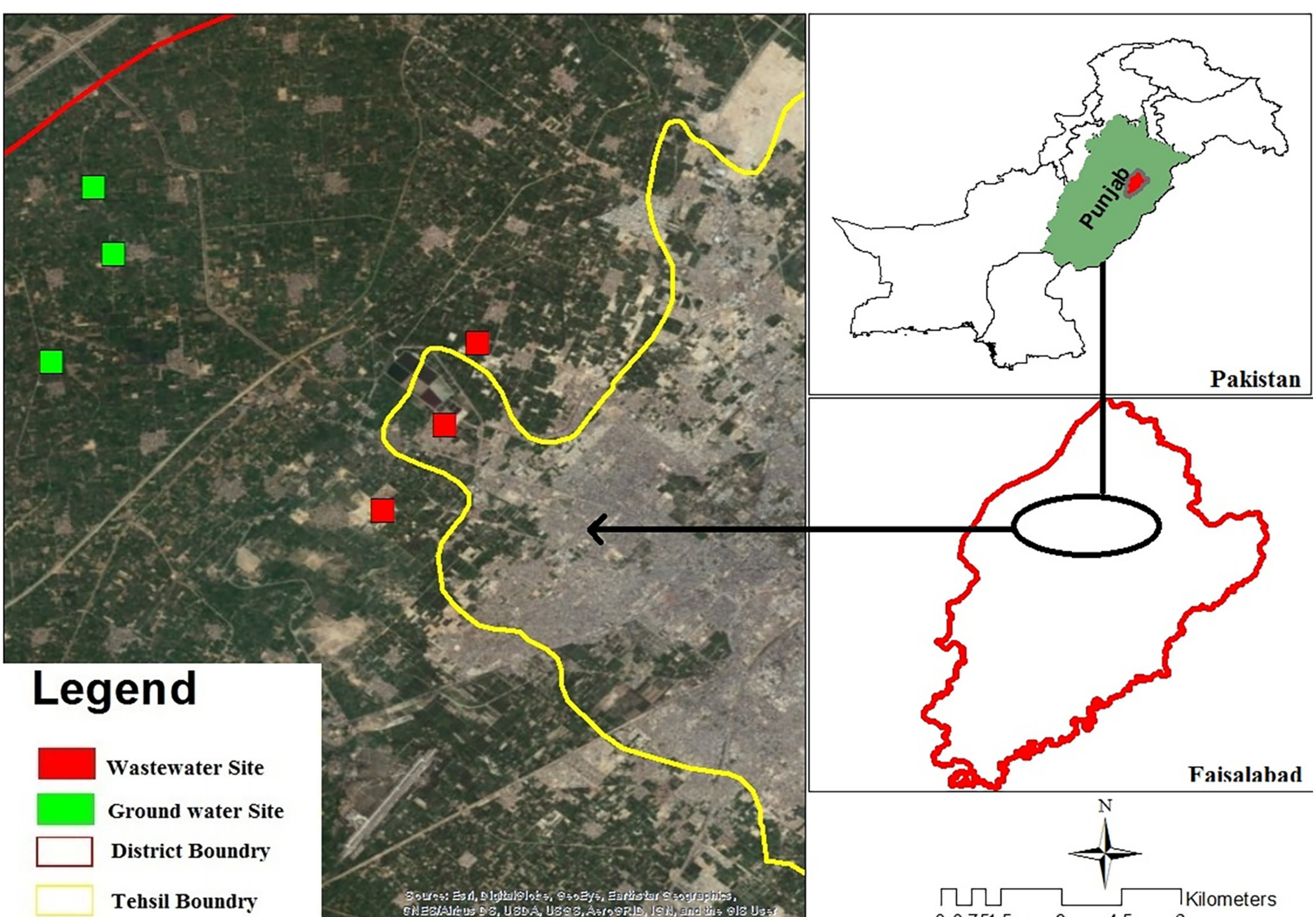

Fig. 1. Sampling site map, Faisalabad, Pakistan.

Table 1
Vegetables collected for this study.

English name	Local name	Family	Plant species	Part sampled
Potato	Aloo	Solanaceae	*Solanum tuberosum L.*	Tubers
Mustard Leaf	Saag	Amaranthaceae	*Spinacia oleracea L.*	Leaves
Cabbage	Band Gobi	Brassicaceae	*Brassica oleracea*	Leaves
Carrot	Gajr	Apiaceae	*Daucus carota L.*	Underground stem
Cauliflower	Phool Gobi	Brassicaceae	*Brassica oleracea*	Fruiting flower

2.4. Analysis of heavy metals

Heavy metal concentrations in the soil, plant and water filtrates obtained above were detected through atomic absorption spectrophotometer (UVAS, Lahore). The machine was manually calibrated using standard solutions and a drift blank.

2.5. Data analyses

Data analyses were carried out as previously described in Rehman et al. (2019). Metal transfer factor (MTF) from soil to plants was calculated as the concentration of heavy metals in dry plant parts divided by that in the soil. Daily Intake of Metal (DIM) was calculated according to Chary et al. (2008). The mean daily vegetable intake (320 mg person^{-1} day^{-1}) from 200 people with a regular body weight of 52.50 kg was used in the final computation. A dose of oral reference was used to compare with the test crops to calculate the health risk index (HRI) (Cui et al., 2004). Approximated exposure was measured by dividing heavy metals daily intake with their safe limits. HRI < 1 is considered safe for consumption, but may raise health concerns when HRI > 1 (USEPA, 2006). Heavy metal translocation from soil to edible vegetables was determined by calculating the Metal Enrichment Factor (EF) according to Chopra and Pathak (2012).

2.6. Statistical analysis

Data was analyzed using SPSS v. 12. Results were compared with permissible limits by applying descriptive statistics.

3. Results

3.1. Concentration of heavy metals in (ground and waste) water and soil samples

Heavy metal concentrations were greater in wastewater samples than the groundwater samples (Table 2). Metal concentrations in the groundwater samples varied from <0.01 to 1.50 mg/L. Zn had the highest (1.10 ± 0.23 mg/L) and Cd (0.002 ± 0.001 mg/L) the lowest mean concentration. All metals sampled in the groundwater were below the permissible limits. In the wastewater samples, heavy metal concentrations varied from 0.01 to 25.50 mg/L. Mn had the highest (19.10 ± 5.10 mg/L) and Ni (0.02 ± 0.01 mg/L) the lowest mean concentration. Mn concentration in wastewater samples was about 125-fold greater than the WHO limit of 0.2 mg/L, whereas other metals were well below the permissible limits.

In soil irrigated with wastewater, heavy metal concentration ranged from 0.30 to 39.50 mg kg^{-1}. Pb had the highest (26.80 ± 8.00 mg kg^{-1}) and Cd (0.80 ± 0.30 mg kg^{-1}) the lowest mean concentration (Table 2). In groundwater-irrigated soil, heavy metals were in the range 0.01–1.20 mg kg^{-1}, with Mn having the highest (1.00 ± 0.15 mg kg^{-1}) mean concentration and lowest mean concentration was found in Cd (0.01 ± 0.01 mg kg^{-1}) (Table 2). In soil irrigated with both water sources, mean metal concentrations were lower than the WHO limits.

3.2. Determination of metal concentrations in vegetable parts

The mean metal concentrations were greater in plants grown with wastewater compared to groundwater (Table 3). In plants grown with groundwater, metal concentration was found highest for Mn in mustard leaf (14.2 ± 4.10 mg kg^{-1}) and cabbage (10.6 ± 1.50 mg kg^{-1}). Among the vegetables, Pb (0.060 ± 0.20 mg kg^{-1}), Cd (0.003 ± 0.001 mg kg^{-1}), Zn (0.200 ± 0.07 mg kg^{-1}), Mn (14.2 ± 4.10 mg kg^{-1}) and Ni (0.080 ± 0.01 mg kg^{-1}) were highest in mustard leaf, but were lower than the WHO standards. Cobalt was highest in cabbage (0.520 ± 0.28 mg kg^{-1}) and mustard leaf (0.414 ± 0.30 mg kg^{-1}), but was much lower than the WHO standard (40.00 mg kg^{-1}). In the wastewater-irrigated vegetables, metal concentration was found highest for Mn in mustard leaf (32.80 ± 5.03 mg kg^{-1}) and cabbage (20.60 ± 3.40 mg kg^{-1}). Among the vegetables, Pb (24.20 ± 4.30 mg kg^{-1}), Cd (0.10 ± 0.05 mg kg^{-1}), Co (1.70 ± 0.40 mg kg^{-1}), Zn (12.80 ± 1.00 mg kg^{-1}), Mn (32.80 ± 5.03 mg kg^{-1}) and Ni (3.20 ± 0.40 mg kg^{-1}) were highest in mustard leaf. In all vegetables, Pb concentration (2.60 ± 0.58 mg kg^{-1} to 24.20 ± 4.30 mg kg^{-1}) was about 52 to 480 folds greater than the WHO standard (0.05 mg kg^{-1}). In mustard leaf and cabbage, Cd and Mn concentrations were about 5- and 2-fold higher than the standard.

Table 2
Heavy metals concentrations in water (mg/L) and soil (mg kg^{-1}) irrigated with different water sources.

Sample	Value	Pb	Mn	Cd	Ni	Zn	Cu
Water							
Wastewater	Mean ± S.D	2.30 ± 0.84.00	19.10 ± 5.10	0.11 ± 0.02	0.02 ± 0.01	0.06 ± 0.02	0.09 ± 0.01
	Range	1.30–3.50	12.70–25.50	0.09–0.15	0.01–0.04	0.03–0.08	0.07–0.10
Groundwater	Mean ± S.D	0.04 ± 0.03	0.09 ± 0.01	0.002 ± 0.001	0.004 ± 0.002	1.10 ± 0.23	0.02 ± 0.01
	Range	0.02-	0.07–0.10	<0.01	<0.01	0.90–1.50	0.01–0.03
WHO Standard		*5*	*0.2*	*0.1*	*0.2*	*2*	*Not Listed*
Soil							
Wastewater	Mean ± S.D	26.80 ± 8.00	25.40 ± 4.60	0.80 ± 0.30	1.70 ± 0.50	5.14 ± 0.38	2.30 ± 0.60
	Range	19.00–39.50	19.00–31.00	0.30–1.10	1.10–2.10	4.70–5.70	1.75–3.35
Groundwater	Mean ± S.D	0.11 ± 0.04	1.00 ± 0.15	0.01 ± 0.01	0.20 ± 0.08	0.74 ± 0.12	0.70 ± 0.20
	Range	0.08–0.09	0.80–1.20	0.01–0.03	0.10–0.30	0.60–0.92	0.30–0.90
WHO standard		*84*	*80*	*3*	*75*	*300*	*Not Listed*

Table 3
Heavy metals concentrations (mg kg^{-1}) in vegetables grown with groundwater and wastewater.

Vegetables	Value	Pb	Cd	Cu	Zn	Mn	Ni
Groundwater							
Potato	Mean ± S.D	0.010 ± 0.002	0.003 ± 0.003	0.046 ± 0.033	0.010 ± 0.003	2 ± 0.8	0.020 ± 0.005
	Range	0.007–0.013	0.001–0.009	0.010–0.090	0.009–0.016	0.96–3	0.016–0.027
Mustard Leaf	Mean ± S.D	0.060 ± 0.200	0.003 ± 0.001	0.414 ± 0.300	0.200 ± 0.070	14.2 ± 4.1	0.080 ± 0.010
	Range	0.034–0.083	0.002–0.005	0.170–0.800	0.120–0.290	9–19	0.059–0.090
Cabbage	Mean ± S.D	0.010 ± 0.004	0.001 ± 0.000	0.520 ± 0.280	0.020 ± 0.010	10.6 ± 1.5	0.020 ± 0.010
	Range	0.009–0.019	< 0.001	0.200–0.900	0.010–0.031	9–13	0.015–0.031
Carrot	Mean ± S.D	0.010 ± 0.002	0.001 ± 0.000	0.032 ± 0.010	0.020 ± 0.010	2.1 ± 0.8	0.020 ± 0.002
	Range	0.010–0.017	0.001–0.002	0.010–0.050	0.011–0.029	1.1–3	0.012–0.019
Cauliflower	Mean ± S.D	0.030 ± 0.020	0.002 ± 0.005	0.031 ± 0.020	0.150 ± 0.030	2.4 ± 1	0.050 ± 0.010
	Range	0.010–0.053	0.002–0.003	0.012–0.070	0.110–0.190	1.5–4	0.039–0.070
Wastewater							
Potato	Mean ± S.D	2.60 ± 0.58	0.002 ± 0.001	0.25 ± 0.05	2.20 ± 1.30	7.26 ± 1.62	0.70 ± 0.40
	Range	1.90–3.20	0.001–0.003	0.19–0.30	1.00–4.00	5.20–9.20	0.29–1.15
Mustard Leaf	Mean ± S.D	24.20 ± 4.30	0.10 ± 0.05	1.70 ± 0.40	12.80 ± 1.00	32.80 ± 5.03	3.20 ± 0.40
	Range	19.00–30.00	0.10–0.20	1.10–2.30	11.50–14.00	28.50–41.2	2.70–3.80
Cabbage	Mean ± S.D	24.00 ± 2.80	0.05 ± 0.02	1.60 ± 0.30	2.60 ± 0.70	20.60 ± 3.40	2.60 ± 0.50
	Range	21.00–27.00	0.03–0.09	1.10–1.90	1.75–3.50	17.00–25.20	2.10–3.40
Carrot	Mean ± S.D	3.20 ± 1.00	0.002 ± 0.001	0.09 ± 0.01	1.90 ± 0.70	7.00 ± 2.70	1.20 ± 0.40
	Range	2.10–4.70	0.001–0.003	0.09–0.12	1.00–2.90	3.50–10.50	0.70–1.70
Cauliflower	Mean ± S.D	4.50 ± 1.50	0.004 ± 0.002	0.50 ± 0.20	7.70 ± 1.90	5.50 ± 1.70	0.90 ± 0.30
	Range	2.70–6.50	0.002–0.009	0.20–0.80	5.50–10.30	3.50–7.70	0.50–1.30
Standard	WHO	0.05	0.02	40	50	16.61	10

3.3. Heavy metals transfer factor (MTF) from irrigated soil to vegetable parts

MTF for Pb, Zn, Mn and Ni was greater in wastewater than groundwater-irrigated vegetables (Table 4). In the groundwater-irrigated vegetables, MTF-Cd was greatest in mustard leaf (14.20) and cabbage (10.60). Among the vegetables, MTF for Pb (0.540), Cd (14.200), Co (0.169), Zn (0.418) and Mn (0.281) were highest in mustard leaf. MTF-Ni was highest in cabbage (0.743) and mustard leaf (0.591). Among the wastewater-irrigated vegetables, highest MTF was observed for Mn (2.482) and Zn in mustard leaf (1.928). Among the vegetables, MTF for Pb (0.903), Cd (1.294), Co (0.167), Zn (1.928), Mn (2.482) and Ni (0.744) were highest in mustard leaf.

3.4. Daily intake metal (DIM) and health risk index (HRI)

Among groundwater-irrigated vegetables, DIM for Pb (3.00E-05), Cd (7.40E-03), Co (2.00E-06), Zn (4.00E-05) and Mn (1.00E-04) were highest in mustard leaf (Table 5). DIM for Ni was highest in cabbage (3.00E-04) and mustard leaf (2.00E-04). Among wastewater-irrigated vegetables, DIM for Pb (3.00E-05), Cd (7.40E-03), Co (2.00E-06), Zn (4.00E-05), Mn (1.00E-04) and Ni (9.00E-04) were greatest in mustard leaf.

Mustard (2.23E-01) and cabbage (1.66E-01) grown with groundwater showed the greatest HRI-Cd, but was lower than 1 (Table S1). Among the vegetables, HRI for Pb (8.00E-03), Cd (2.23E-01), Co (1.00E-04), Zn (2.00E-03) and Mn (4.00E-04) were highest in mustard leaf. HRI-Ni was highest in cabbage (6.30E-03) and mustard leaf (5.00E-03). In wastewater-irrigated vegetables, the highest HRI was observed for Pb in mustard leaf (3.14E+00) and cabbage (3.11E+00), and were >1. Among the vegetables, HRI for Pb, Cd, Co, Zn, Mn and Ni were greatest in mustard leaf (3.14E+00, 5.16E−01, 2.00E-03, 8.29E-02, 2.20E-02 and 2.10E-03, respectively) followed by in cabbage (3.11E + 00, 3.23E-01, 8.00E-04, 6.84E-02, 4.50E-03 and 2.00E-03, respectively).

3.5. Heavy metals enrichment factor

EF for Pb was greatest in mustard leaf (1.672) and cabbage (1.658), but was lowest in cauliflower (0.565) (Table S2). EF for Cd and Ni was highest in cauliflower (0.333, 5.145) but lowest in cabbage (0.021, 0.932). EF for Co and Zn was highest in cabbage (1.243, 12.446), but Co was lowest in potato (0.018) and Zn in cauliflower (1.702). EF for Mn was highest in potato (25.962) and cabbage (17.589) but lowest in cauliflower (7.228).

Table 4
Heavy metal transfer factor (MTF) in vegetables grown with groundwater and wastewater.

Vegetables	Pb	Cd	Cu	Zn	Mn	Ni
Groundwater						
Potato	0.091	1.950	0.135	0.119	0.016	0.066
Mustard Leaf	0.540	14.200	0.169	0.418	0.281	0.591
Cabbage	0.120	10.600	0.048	0.128	0.029	0.743
Carrot	0.113	2.100	0.056	0.092	0.028	0.046
Cauliflower	0.295	2.430	0.116	0.304	0.208	0.045
Wastewater						
Potato	0.096	0.286	0.002	0.439	0.428	0.109
Mustard Leaf	0.903	1.294	0.167	1.928	2.482	0.744
Cabbage	0.896	0.809	0.060	1.590	0.504	0.692
Carrot	0.121	0.276	0.002	0.699	0.377	0.043
Cauliflower	0.166	0.217	0.006	0.518	1.504	0.231

Table 5
Daily intake of metals (DIM, mg person^{-1} day^{-1}) for vegetables grown with groundwater and wastewater.

Vegetables	Pb	Cd	Cu	Zn	Mn	Ni
Groundwater						
Potato	1.00E-05	1.00E-03	1.00E-06	1.00E-05	1.00E-05	2.00E-05
Mustard Leaf	3.00E-05	7.40E-03	2.00E-06	4.00E-05	1.00E-04	2.00E-04
Cabbage	1.00E-05	5.50E-03	0.00E + 00	1.00E-05	1.00E-05	3.00E-04
Carrot	1.00E-05	1.10E-03	1.00E-06	1.00E-05	1.00E-05	2.00E-05
Cauliflower	2.00E-05	1.30E-03	1.00E-06	3.00E-05	8.00E-05	2.00E-05
Wastewater						
Potato	1.00E-03	3.80E-03	1.00E-06	4.00E-04	1.10E-03	1.00E-04
Mustard Leaf	1.30E-02	1.70E-02	1.00E-04	1.70E-03	6.60E-03	9.00E-04
Cabbage	1.20E-02	1.07E-02	3.00E-05	1.40E-03	1.30E-03	8.00E-04
Carrot	2.00E-03	3.60E-03	1.00E-06	6.00E-04	1.00E-03	1.00E-04
Cauliflower	2.00E-03	2.90E-03	2.00E-06	4.00E-04	4.00E-03	3.00E-04

4. Discussion

4.1. Metal concentrations in different water sources and irrigated soil

In this study, and as expected, metal concentrations in the wastewater samples were multiple folds greater than in the groundwater samples. This is because wastewater is generally from diverse sources of industrial and domestic origin and are well known sources of pollutants. In the wastewater samples, heavy metals were in the order Mn > Pb > Cd > Co > Zn > Ni, but in the groundwater samples, were in the order Zn > Mn > Pb > Co > Ni > Cd. Our results also showed that Cd and Mn concentrations were greater in the wastewater samples than the WHO limits, whereas all metals sampled in the groundwater were below the limits. Results also attributed greater soil heavy metals content to wastewater irrigation, compared to groundwater irrigation; but the soil heavy metal contents were below the WHO standards. Type of soil (amount of clay content), soil depth, length of time of wastewater irrigation are among factors that contribute to heavy metals contamination of groundwater (Abdelwaheb et al., 2019). Abdelwaheb et al. (2019) noted greater groundwater contamination in soils with low clay content, but high clay content minimized contaminant leaching.

Wastewater, if untreated before applying to agricultural fields, could be a potential source of various organic and inorganic contaminants (Rehman et al., 2019), leading to the contamination of groundwater. Faisalabad generates well above 6.45 m^3/s wastewater effluents (WWF, 2007), bulk of which is disposed into rivers Ravi and Chenab through the Madhuana and Paharang drains and channels. Seepage from these drains and channels, coupled with the utilization of wastewater for watering agricultural lands, are major routes of soil and groundwater contamination in this region.

According to the WB-SCEA (2006), only about 8% of urban wastewater generated in Pakistan was treated before disposing into rivers. The most important strategy to preserve the quality of the groundwater is by reducing the contaminant concentrations in the wastewater before releasing into the environment. Sun et al. (2019) described the use of a self-sustained photo-bio electrochemical fuel cell for the removal of oxytetracycline in wastewater. Also, low-cost adsorbents of agricultural sources, such as sawdust, animal manures, eggshell waste and plant residues have been effectively used to reduce metal contaminants and to improve aerobic conditions in wastewater (Zajda and Aleksander-Kwaterczak, 2019). Azadi et al. (2018) used extracts from *Persicaria bistoria* plants to synthesis Fe_3O_4 nanoparticles that were used for wastewater treatment. Bacteria isolated from wastewater have also been utilized for heavy metal decontamination of wastewater. Cai et al. (2019) isolated Ni^{2+} resistant strains and Mn^{2+} tolerant strains for removal of respective metals in wastewater. If well treated, wastewater could provide a dependable source of water for irrigation in water-scarce regions.

4.2. Heavy metal concentration in vegetable plants

Heavy metals (Pb, Zn, Mn, Cd, Co, and Ni) were highest in leaves of mustard and cabbage than other vegetables irrigated with wastewater; concentrations of Pb, Mn and Cd were higher than the WHO permissible standards. Bioaccumulation of heavy metal in vegetable plants is an important concern to public health. Here, we found that irrigation with groundwater did not result in high metal concentrations in the plants, because the water quality is still considered good. However, vegetable irrigation with wastewater could lead to increased metal uptake into plant parts. Mahmood and Malik (2014) reported Pb and Cd above the European Union limits in vegetables grown with wastewater. Khan et al. (2019) also found Cr in grains of wheat irrigated with wastewater exceeded the permissible limit. Bashir et al. (2009) found metals concentrations in edible parts of vegetables irrigated with wastewater exceeded the permissible limit.

For all heavy metals in groundwater-irrigated vegetables, Cd had the highest metal transfer factors (MTF) and was found in mustard leaf and cabbage; but in wastewater-irrigated vegetables, Mn and Zn had the highest MTF and were found in mustard leaf. The MTF-Cd in the groundwater-irrigated vegetables in this study are well above those in vegetables grown with groundwater in Lahore, Pakistan (Rehman et al., 2019), in vegetables grown with surface water in the vicinity of river Padma, Bangladesh and in food crops grown near Dabaoshan mine, South China. Although our results indicate that the groundwater did not contribute to increased metal contents in the vegetables beyond permissible limits, a high MTF-Cd in the vegetables could suggest the need to employ rapid remediation strategies so as to save the groundwater from contamination.

4.3. Daily intake of metals (DIM), health risk index (HRI) and Enrichment factors (EF)

In both groundwater and wastewater-irrigated vegetables, highest DIM was observed for Cd and Pb in mustard leaf and cabbage; but, were below those observed in mustard leaf and cabbage grown in open fields in the vicinity of Chinese industrial zones. Compared to the dietary reference intake limits of the Food and Drug Administration, DIM-Pd and Cd were higher in wastewater, but not groundwater, irrigated mustard leaf and cabbage, suggesting the potential health risk to consumers of such vegetables. In this study, HRI values for groundwater-irrigated vegetables were generally lower than 1, suggesting that consumers are not likely to be exposed to any health problems. Though HRI values for wastewater-irrigated vegetables were mostly lower than 1, mustard leaf and cabbage had HRI < 1 for Pb, suggesting a possibility of potential health risk due to Pb toxicity. Cd showed the potential to increase in HRI, though still lower than 1. The EF values in metals are used to assess the presence and intensity of anthropogenic contaminant deposition on surface soil. According to research, EF values between 0.5 and 1.5 suggest the metal could be wholly due to materials from the Earth's crust or natural processes, but EF > 1.5 suggests metals could be from anthropogenic sources. Therefore, our results suggest that Mn, Zn, Pb and Ni were generated by man-made processes (e.g. irrigation with wastewater).

5. Conclusion

Results revealed that wastewater irrigation is a major source of heavy metal contamination in soil and crops of vegetable gardens in Faisalabad. Heavy metal concentrations in the groundwater and irrigated crops in this region have not exceeded the WHO allowable limit, this could be termed safe for consumption. Health risk index in groundwater-irrigated vegetables was lower than 1; but in wastewater-irrigated mustard leaf and cabbage, HRI was >1. Although the groundwater and irrigated vegetables cultivated in the regions of Faisalabad could be termed safe for consumption, there is a potential of heavy metal contamination over time. Therefore, there is the need to urgently embark on mitigation strategies that will both save the groundwater from being contaminated, while also providing adequate treatment plans for the large volume of wastewater generated in Faisalabad, Pakistan.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.jksus.2022.102467.

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