

Accumulation of phytotoxic metals and metalloids in vegetable continuum subjected to different irrigation streams: a threat towards nutritional security

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Abstract

The urban agro-ecosystem in developing countries plays a major role in uplifting the socioeconomic status of their inhabitants by confronting the challenges of improving food security and eradicating hunger. Food security and safety has become a serious global concern owing to accumulation of phytotoxic metals and metalloids in different food commodities subjected to different contaminated irrigation sources. The current study was undertaken to assess the concentrations of heavy metals and metalloid in ridge gourd (*Luffa cylindrica* L.), its planting soil medium and irrigation water sources used for crop production to determine the health risk. The results showed that the mean concentrations of different metals and metalloids in ground water samples i.e. Ni (0.14 mg L⁻¹), Fe (1.29 mg L⁻¹), Cu (0.10 mg L⁻¹), Pb (0.55 mg L⁻¹), As (0.10 mg L⁻¹), Cr (2.38 mg L⁻¹) and Cd (0.05 mg L⁻¹) were over the permissible limits. Soil samples irrigated with ground water showed that concentrations of Cd (23.67 mg kg⁻¹), Cr (26.66 mg kg⁻¹) and As (45.97 mg kg⁻¹) were above the permissible limits. Similarly, vegetable samples irrigated with ground water had a higher level of Cd (0.33 mg kg⁻¹) than their prescribed safe limits. The bio-concentration factor ranged from 0.00 to 8.21 for all irrigation sources. The target hazard quotients (THQ) for Zn, Fe, and Cr were higher than the threshold value when ridge gourd was consumed, indicating a health concern. Similarly, hazard index values were 5.05, 28, 27, and 1.01, from

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groundwater, canal water, and sewage water, respectively. Target Cancer Risk (TCR) exposed Ni, Cr, Cd and As in canal water were sources of high cancer risk and Pb showed moderate cancer risk for the local community. These findings suggest that human intake of ridge gourd vegetable from the studied area may pose health hazards. Hence, frequent monitoring of different irrigation streams used in urban and semi-urban agriculture is strongly recommended to manage higher concentrations of phytotoxic metals and metalloids in crop produce and their associated health risks for humans.

Keywords: hazard index; irrigation sources; pollution load index; target cancer risk; vegetable

Introduction

The quality of living beings and their environment are at constant risk of deterioration due to heavy metals and metalloid contamination, which is becoming a major ecological concern (Tóth *et al.*, 2016; Zia *et al.*, 2023). Elemental abundances such as metals and metalloids are ubiquitous components of the naturally occurring materials of the earth's crust, yet they cannot be degraded or removed due to their stable and persistent characters (Hussain *et al.*, 2017; Njagi *et al.*, 2017; Ahmed *et al.*, 2022). Heavy metals and metalloids pollute soil and also affects living beings around the globe (Nagajyoti *et al.*, 2010; Srivastava *et al.*, 2017). During mineral processing, some parts of these heavy metals and metalloids are left open which are transported to distant places through water and wind thus contaminating the earth's environment (Nagajyoti *et al.*, 2010; Woldetsadik *et al.*, 2017). Similarly, several anthropogenic and natural processes also augment the concentration of heavy metals in the environment (Dembitsky and Rezanka, 2003; Haque *et al.*, 2021). Modern agricultural practices including the increased application of chemical fertilizers and pesticides have caused global agricultural pollution that is responsible for the deterioration of the ecosystem (Malik *et al.*, 2017). Moreover, agro-ecosystem are also prone to heavy metals contamination due to wastewater irrigation, industrial by-products, and application of organic waste manure and sewage sludge (Khan *et al.*, 2013; Srivastava *et al.*, 2016; Sharma *et al.*, 2017; Adil *et al.*, 2023).

Heavy metals accumulated in soil are absorbed by plant root apoplast and later distributed to upper plant parts including fruit thus becoming an imminent threat to our food chain (Ahmad *et al.*, 2019; Alsafran *et al.*, 2021). Besides this, certain vegetables also uptake small amounts of heavy metals from atmospheric deposition (Prasad *et al.*, 2021). Vegetable heavy metal contamination is a major concern that cannot be avoided because of their regular intake in human diets and their importance in food quality assurance (Gupta *et al.*, 2019; Prasad *et al.*, 2021). Vegetables contain a wide variety of bioactive chemicals that strengthens their nutritional status all around the globe (Begum *et al.*, 2020).

Urban regions in developing nations such as Pakistan have accumulated greater amounts of heavy metals in their soil and water because of fast industrialization and wastewater irrigation (Alam *et al.*, 2018). Although, agricultural sustainability can be achieved with the use of recycled wastewater but even recycled wastewater contains certain amount of heavy metals, which are toxic to plants and soil (Zwolak *et al.*, 2019). Petrochemical industries also contaminate soil and pose serious health concerns to humans and the environment due to their waste disposal in water bodies, multiple oil spill incidents, and chemical discharge into the environment (Sun *et al.*, 2019). Additionally, gasoline also played a significant part in increasing the concentration of heavy metals in roadside soils (Kumar *et al.*, 2019). Researchers have measured, documented, and reported significantly elevated levels of metals in vegetables grown near mining sites, solid waste dump sites, highways, and industrial sites as compared to those grown away from such sites (Zhou *et al.*, 2016; Gupta *et al.*, 2021). Therefore, the consumption of vegetables cultivated around such sites may pose serious health risks for humans (Anwar *et al.*, 2016).

Nowadays, public awareness regarding health risks associated with heavy metal contamination has gained much popularity. Prolonged intake of food items contaminated with heavy metals may cause nervous, bone, and cardiovascular abnormalities (Anwar *et al.*, 2016). Moreover, the low body weight of newly born babies, premature births, and congenital disabilities are also associated with prolonged heavy metal exposure (Taylor *et al.*, 2015). The minor concentration of certain elements such as Co, Cu, Ni, Mn, and Zn is essential for the normal functioning of the human body, however, they become lethal when reached higher limits (Simonsen *et al.*, 2011; Wuana and Okieimen, 2011; Ihedioha *et al.*, 2014; Mohammadi *et al.*, 2018). Conversely, Pb, As, Cd, and Cr may cause carcinogenic effects even at low concentrations (Gupta *et al.*, 2021).

Vegetable crops hold immense significance due to their dual benefits of nutritional value and economic impact. From a nutritional standpoint, vegetables are powerhouses of essential vitamins, minerals, and dietary fiber, promoting overall health and well-being of humans (Risku-Norja and Mäenpää, 2007; Manzoor *et al.*, 2018). Additionally, their rich array of antioxidants helps protect the body against oxidative stress and chronic diseases (Huber *et al.*, 2021). Moreover, the higher fiber content of vegetables aids in digestion and maintains a healthy gut. On the economic front, vegetable crops play a crucial role in the agricultural industry, providing income to farmers and supporting rural communities (Jaiswal *et al.*, 2022). They are a significant commodity in international trade, contributing to global food security and fostering economic exchange among nations. Altogether, vegetable crops are not only essential for a balanced diet but also hold great economic value for sustainable development and growth (IFOAM, 2022).

Ridge gourd (*Luffa cylindrica* L.) is a warm-season vegetable crop, and believed to have originated in India and the tropical regions of Asia. It's predominantly grown in countries like China, India, Turkey, Iran, and Southeast Asia. According to survey, ridge gourd was grown in the area of 2008 ha with 17301 tons of annual production in Pakistan (Anonymous, 2018-19). It is generally concentrated in the provinces of Sindh, Punjab, and Balochistan, where the climate and soil conditions are favorable for its growth (Naafe *et al.*, 2022). Ridge gourd cultivation in Pakistan provides an essential source of income for farmers, and the vegetable is in demand in both local markets and urban centers. It is widely used in traditional Pakistani cuisine and holds cultural significance as a popular ingredient in various dishes (Asad *et al.*, 2022). Farmers often employ traditional methods of cultivation, but modern techniques are also being adopted to improve its productivity. Depending upon the soil, varietal, and other climatic factors the average yield ranges between 70-90 quintal/hectare (Bajkani *et al.*, 2023).

Previously, many studies had reported the accumulation level of different organic and inorganic pollutants in edible vegetable species (Islam and Hoque, 2014; Lü *et al.*, 2014; Marzec *et al.*, 2014). However, the qualitative analysis of water sources used in urban agriculture in Pakistan along with accumulation of phytotoxic pollutants in fresh crop produce and planting soil medium were largely unexplored. As a result, the current research was aimed at determining metal and metalloid concentrations (Zn, Se, Pb, Ni, Mo, Fe, Cu, Cr, Cd, and As) in ridge gourd (*Luffa cylindrica* L.), its planting soil medium and irrigation water sources (municipal wastewater, groundwater, and canal water) used for crop production.

Materials and Methods

Study area

This research work was carried out in a semi-urban location of Kasur, Punjab, Pakistan during 2021-2022. River Sutlej flows near the city and its geographical location is 31.1179° N, 74.4408° E. In recent observations, the average temperature has ranged between 25 °C to 40 °C, indicating warm to hot conditions. Humidity levels varied from 30% to 70%, reflecting fluctuating moisture in the air. Precipitation data indicates sporadic rainfall, with an average of 20-30 mm over the past month. Wind patterns have predominantly shown easterly to southeasterly directions, averaging 5-10 km/h. Atmospheric pressure has ranged around 1010 hPa

(hecto Pascals), suggesting relatively stable conditions. Three locations were selected for sampling: Bahadar Pura, Shamas Pura, and Kalio Khurd, which were irrigated with municipal wastewater, groundwater, and canal water, respectively. Each location hosted six replicates of soil, water, and vegetable samples (Figure 1).

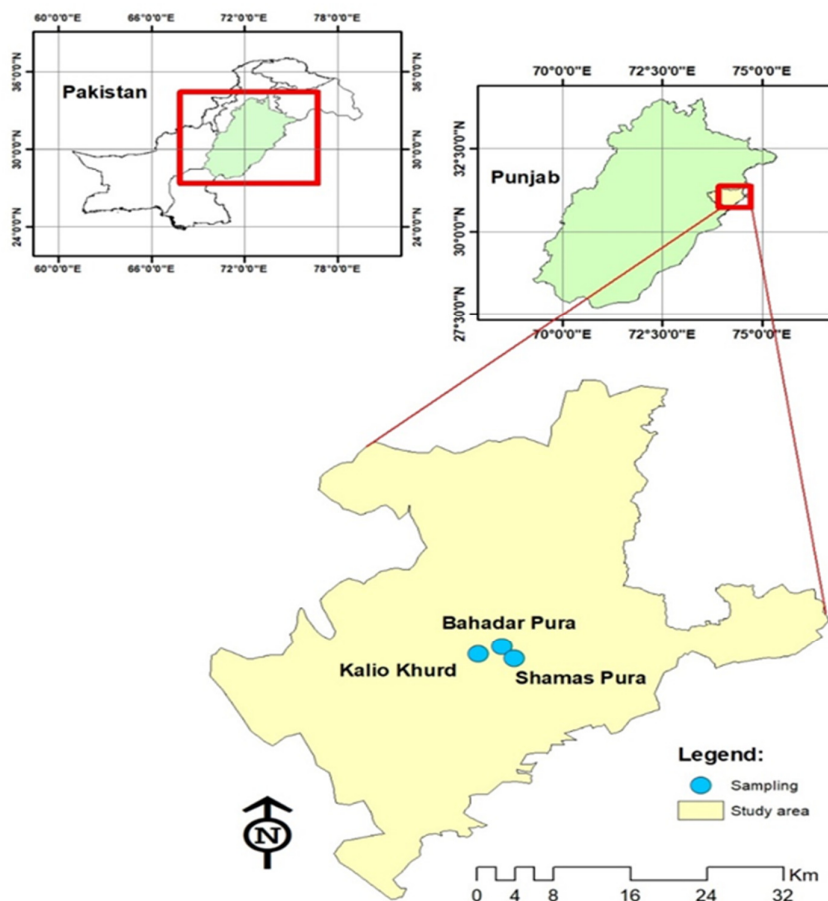


Figure 1. Location map of the study area

Sample collection

Ridge gourd fruit and soil samples were collected at various locations around the research region. Ridge gourd fruit samples were picked by hand while wearing gloves and placed in plastic bags. To eradicate soil contaminants, the plant samples were washed at least two times with pure distilled water before being placed in clean polythene bags. However, soil samples (Approximately 1.0 kg) from each locality were collected at 10-20 cm depth using a steel crab (Tariq *et al.*, 2021). Air-dried samples were homogenized, sieved (2 mm), and kept in polythene bags for subsequent analysis (Ryan *et al.*, 1996). The same number of groundwater, canal, and waste water samples were taken from various locations around the studied area, including tube wells, canals, and waste water. Pre-cleaned plastic bottles were utilized to collect the water samples. All collected samples were labelled in the field according to their origins, location characteristics, and time of collection. Following the methods indicated by Estefan *et al.* (2013). Collected samples were kept under appropriate conditions (temperature ~ 15 °C) until they were brought to the research lab facility for detailed investigation.

Digestion of vegetable sample

The ridge gourd fruit sample was chopped into small pieces using a knife and later dried in a heating oven (70-80 °C) for 24 hours to eradicate moisture. With a pestle and mortar, the dry samples were ground into powder. The samples were sieved and dried again in a desiccator. The dried ridge gourd fruit samples (1 g) were then subjected to a 1:2 combination of H₂SO₄ and H₂O₂ in a glass flask. The sample was digested until the solution became colourless. The final sample volume of 50 ml was prepared with distilled water and stored in pre-washed bottles.

Digestion of water sample

After taking water samples to the laboratory, firstly it was filtered using (Whatman No. 42 filter paper) and later acidified to bring a pH level of 2 or less. The water sample at this stage was clear and ready for further analytical analysis. A 50 mL of water sample was taken in a beaker; subsequently, 10 mL of pure HNO₃ was added. The beaker's contents were heated in a water bath until the final volume reached 40 ml. Whatman No. 42 filter paper was used to filter the solution. Using a volumetric flask, the filtrate was diluted to 50 mL with distilled water. The same procedure was used to prepare all remaining samples. With the exception of the sample, a blank solution was made in the same manner.

Digestion of soil samples

After pre-drying the soil samples, 1 g of sample was taken into the digestion tube with 10 ml of aqua regia (HNO₃: HCl) which contain three parts concentrated hydrochloric acid and one part concentrated nitric acid. After cooling the digested samples, 10 mL of distilled water was added. Fine filters were used to filter the samples, and distilled water was added to get the total volume up to 50 ml.

Estimation of metals and metalloids

The metal concentrations (Ni, Fe, Cu, Pb, Se, Zn, As, Cr, Cd, and Mo) were measured using a Perkin-Elmer AAS-5000 atomic absorption spectrometer (Perkin-Elmer Corp., 1980). Nevertheless, Se was evaluated using a fluorometric technique in soil, water, and vegetable samples, and total As was assessed using a flow injection hydride generation AAS (Perkin Elmer Analyst 400) using arsenate as a standard (Olsen *et al.*, 1954; Welz and Sperling, 1999).

Quality control analysis and assurance

Merck-Germany analytical grade chemicals were utilized for metal analysis. Using a calibration curve, the atomic absorption spectroscopy (AAS) instrument was calibrated using a series of standard solutions from the elemental stock solution. The stock solution was made using double deionized water. The atomic absorption spectrometer employed for the quantification of Ni, Fe, Cu, Pb, Se, Zn, As, Cr, Cd, and Mo had a detection limit exceeding 0.01 parts per million (ppm). In contrast, the detection limit for arsenic, determined using flow injection hydride generation AAS, was greater than 0.1 parts per billion (ppb). However, it's important to note that the method detection limit for each individual metal and metalloid was established at 0.001 ppm, highlighting the heightened sensitivity of the analytical method employed for this study. To avoid contamination, high-quality glassware (Merck-Germany) was used after washing with diluted HNO₃. To improve the accuracy of the data, the analysis was performed three times for each sample using the usual reference approach.

Bioconcentration factor

The bioconcentration factor (BCF) was calculated using the procedure reported by Cui *et al.* (2004).
BCF= (Element concentration in vegetable sample)/(Element concentration in experimental soil).

Pollution load index

The pollution load index (PLI) was calculated by employing the techniques outlined by Liu *et al.* (2005) and is shown below.

$$PLI = (\text{Element concentration in experimental soil}) / (\text{Element concentration in reference soil})$$

Assessment of health risk index (HRI)

The health risk index was calculated using the following formula:

$$HRI = DIM / RfD$$

The RfD here represents the reference oral dose and according to EPA, its values are 1.50, 0.005, 0.02, 0.70, 0.0035, 0.30, 0.04, 0.001, 0.005, 0.0003 mg kg⁻¹ day⁻¹ for Cr, Se, Ni, Fe, Pb, Zn, Cu, Cd, Mo and As, respectively, as per the lists of United States Environmental Protection Agency (USEPA) and the Agency for Toxic Substances and Disease Registry (ATSDR) (US-EPA, 1992, 2000, ATSDR, 2004; US-EPA, 2005). DIM is a daily intake of metals (mg person⁻¹ day⁻¹) and it was determined by the formula given below;

$$DIM = \text{metal conc.} \times Cf \times \text{daily vegetable intake} / \text{average body weight}$$

where, Cf is conversion factor (0.085), daily vegetable intake, respectively. The respondents have an average 65 kg body weight, and were inquired about their daily food intake of vegetables was found 0.600 kg day⁻¹ approximately (Chary *et al.*, 2008; US-EPA, 2010).

Target hazard quotient (THQ)

The target hazard quotient (THQ) of each trace metal was calculated using the following protocols described by Zhuang *et al.* (2009).

$$THQ = (EFr \times ED \times FI \times MC) / (RfD \times BW \times AT) \times 10^{-3}$$

Here, EFr stands for exposure frequency (365 days/per year), ED is for exposure duration which is primarily the life expectancy of the local population (~66.5 years for Pakistan as reported by the World Health Organization), FI is for food ingestion rate (kg person⁻¹ day⁻¹), MC is for metal concentration in mg kg⁻¹, RfD is for reference dose, BW is body weight (~65 kg), and AT is for average exposure time (365 days year⁻¹ × number of exposure years, assuming 66.5 years). THQ > 1 is an indication that intake of a particular metal through a vegetable diet is of potential health risk (Chauhan and Chauhan, 2014; Zhou *et al.*, 2016).

Hazard index (HI)

It is calculated by the given formula $HI = \sum THQ$, where $THQ = (\text{daily intake of metals} \times \text{conc. of metals in sample} / RfD)$. If HI is greater than one, then there is a health significance resulting from exposure to a particular element.

Cancer risk

It is calculated by following the formula,

$$CR = DIM / CPS^{\circ}$$

where CPS^o is the oral cancer slope factor. Some CPS^o values of 1.50, 0.38, 0.50, 0.0085, 1.70 (mg kg⁻¹ day⁻¹) for As, Cd, Cr, Pb, and Ni respectively (Ashraf *et al.*, 2021).

Statistical analysis

The descriptive statistics approach was used to process the data acquired in this study. All data processing and statistical calculations were performed with statistical software (Statistix, Version 10), and regression, correlation coefficients, and principal component analysis (PCA) were performed with XLSTAT software (Version 2021). The data was used to develop biplots created to compare the correlations among the observed data.

Results

Metal and metalloids concentrations in water samples

The results of the experiment showed that the mean concentration of Se (0.1 mgL^{-1}), Pb (0.6 mgL^{-1}), Ni (0.3 mgL^{-1}), Fe (1.7 mgL^{-1}), Cd (0.1 mgL^{-1}), Cr (8.7 mgL^{-1}) and As (0.2 mgL^{-1}) were above the permissible limits in sewage water samples. However, the concentrations of Zn (1.5 mgL^{-1}) and Mo (0.2 mgL^{-1}) were within the safe limits. The results further showed that the mean concentration of Cr and Cd in sewage water samples were 8.7 and 0.1 mgL^{-1} (Table 1). Similarly, in canal water the mean concentration of Se (0.1 mgL^{-1}), Pb (0.3 mgL^{-1}), Ni (0.3 mgL^{-1}), Cu (0.1 mgL^{-1}), As (0.1 mgL^{-1}), Fe (1.6 mgL^{-1}), and Cr (6.2 mgL^{-1}) surpassed the permissible limits. However, the concentration of Zn (1.1 mgL^{-1}) and Mo (0.1 mgL^{-1}) were within the prescribed limits. The results further revealed that the mean concentration of Cr and Cd in canal water samples was 6.6 and 0.05 mgL^{-1} (Table 1). The mean concentration of various metals and metalloids in ground water samples was Pb, Fe, Cu, Ni, As, Cr and Cd were above the prescribed safe limits while Zn (0.8 mgL^{-1}) and Mo (0.1 mgL^{-1}) were within the range of safe limits. The results further showed that mean concentrations of Cr and Cd in ground water samples were 2.38 and 0.05 mgL^{-1} (Table 1).

Table 1. Metals and metalloids contents (mgL^{-1}) in water samples of various irrigation sources (Mean \pm SE)

Metals	Ground Water	Canal Water	Sewage Water	Permissible limits *
Ni	0.1 ± 0.03	0.3 ± 0.00	0.3 ± 0.01	0.02
Fe	1.3 ± 0.17	1.3 ± 0.02	1.6 ± 0.05	0.30
Cu	0.10 ± 0.03	0.1 ± 0.00	0.1 ± 0.00	0.02
Pb	0.6 ± 0.05	0.3 ± 0.02	0.6 ± 0.07	0.01
Zn	0.7 ± 0.10	1.1 ± 0.02	1.4 ± 0.04	3.00
Se	0.1 ± 0.01	0.1 ± 0.00	0.1 ± 0.02	0.02
Mo	0.1 ± 0.00	0.1 ± 0.00	0.2 ± 0.00	40.0
As	0.1 ± 0.01	0.1 ± 0.00	0.2 ± 0.03	0.01
Cr	2.4 ± 0.28	6.6 ± 0.06	8.7 ± 0.27	0.003
Cd	0.1 ± 0.01	0.1 ± 0.00	0.1 ± 0.00	0.05

(*US-EPA, 2000)

Metal and metalloids concentration in soil samples

The results of soil samples irrigated with sewage water showed that mean concentrations of Cr (67.6 mg/kg), Cd (39.4 mg/kg), and As (60.7 mg/kg) were above the permissible limits while the concentrations of the rest of the metals and metalloids were within the prescribed safe limits (Table 2). The results further showed mean concentrations of Cd (30.5 mg/kg), Cr (52.4 mg/kg), and As (55.26 mg/kg) in soil samples irrigated with canal water were above the permissible limits. However, the concentrations of the rest of the metals and metalloids were within the prescribed safe limits in soil samples irrigated with canal water (Table 2). Similarly, soil samples irrigated with ground water showed that concentrations of Cd (23.7 mg/kg), Cr (26.7 mg/kg), and As (45.9 mg/kg) were above the permissible limits while concentrations of the rest of the metals and metalloids were below the safer limit (Table 2).

Table 2. Metals and metalloids contents (mg/kg) in soil samples irrigated with various water sources (Mean \pm SE)

Metals	Ground Water	Canal Water	Sewage Water	Permissible limits*
Ni	7.2 \pm 0.47	8.2 \pm 0.09	11.6 \pm 0.01	50
Fe	52.7 \pm 8.41	94.8 \pm 0.09	101.4 \pm 0.05	50000
Cu	4.0 \pm 0.53	6.3 \pm 0.27	8.9 \pm 0.00	100
Pb	34.4 \pm 1.31	44.2 \pm 0.07	54.8 \pm 0.07	100
Zn	2.4 \pm 0.43	4.6 \pm 0.59	8.7 \pm 0.04	300
Se	2.0 \pm 0.28	3.5 \pm 0.06	5.8 \pm 0.02	10
Mo	5.6 \pm 1.05	8.2 \pm 0.06	10.7 \pm 0.00	40
As	45.9 \pm 2.58	55.2 \pm 0.61	60.7 \pm 0.03	20
Cr	26.6 \pm 3.51	52.3 \pm 2.03	67.6 \pm 0.27	8
Cd	23.6 \pm 2.71	30.5 \pm 0.23	39.4 \pm 0.00	0.3

(*WHO, 1996, US-EPA, 2002; EU, 2006)

Metal and metalloids concentration in vegetable samples

Vegetable samples irrigated with sewage water showed higher concentrations (mg/kg) of Zn (38.1), Pb (0.5), Ni (0.5), Cr (1.1) and Cd (0.7) were under the safe limits while concentrations of Fe (25.9), Cu (0.6) and As (0.08) were below the permissible limits. The results further revealed that the concentrations of Se and Mo in vegetable samples irrigated with sewage water were 0.1 and 0.2 mgkg⁻¹ respectively (Table 3). The results showed that the concentrations of Zn (37.6 mgkg⁻¹), Pb (0.4 mg/kg), Cr (0.9 mgkg⁻¹) and Cd (0.5 mgkg⁻¹) in vegetable samples irrigated with canal water were higher than allowable limits. However, the levels of Ni, Fe, Cu, and As in the same vegetable samples were below their permissible limits. The results further showed that the concentrations of Se and Mo in vegetable samples irrigated with canal water were 0.1 and 0.1 mgkg⁻¹ respectively (Table 3). Vegetable samples irrigated with groundwater had a higher level of Cd (0.3 mgkg⁻¹) than their prescribed safe limits. However, the concentrations of the rest of the metals and metalloids in the ridge gourd were below their permissible limits. The results further showed that the concentrations of Mo in vegetable samples irrigated with canal water were 0.1 mgkg⁻¹, respectively (Table 3).

Table 3. Metals and metalloids contents (mg/kg) in vegetable samples grown by various irrigation sources (Mean \pm SE)

Metals	Ground Water	Canal Water	Sewage Water	Permissible limits*
Ni	0.2 \pm 0.04	0.4 \pm 0.01	0.5 \pm 0.00	67
Fe	11. \pm 0.26	24.2 \pm 0.20	25.9 \pm 0.12	425
Cu	0.1 \pm 0.03	0.4 \pm 0.02	0.6 \pm 0.05	73
Pb	0.1 \pm 0.04	0.4 \pm 0.01	0.5 \pm 0.02	0.30
Zn	16.2 \pm 0.72	37.6 \pm 0.53	38.1 \pm 0.11	100
Se	0.1 \pm 0.00	0.1 \pm 0.00	0.1 \pm 0.00	2
Mo	0.1 \pm 0.00	0.1 \pm 0.00	0.16 \pm 0.00	-
As	0.1 \pm 0.00	0.1 \pm 0.00	0.08 \pm 0.00	14
Cr	0.6 \pm 0.01	0.8 \pm 0.04	1.02 \pm 0.01	2.30
Cd	0.3 \pm 0.05	0.5 \pm 0.04	0.72 \pm 0.01	0.10

(*EU, 2006; US-EPA, 2002; WHO, 1996; WHO/FAO permissible limits (Aderinola *et al.*, 2012; Atta *et al.*, 2023)

Pollution load index and bioconcentration factor

The results revealed that a maximum bioconcentration factor (4.40) for Zn and a pollution load index of Cd (76.4) for Cd were observed. However, Se, Fe, Pb, and As showed minimum bioconcentration factor while Fe and Zn depicted minimum pollution load index in wastewater samples. Furthermore, it was observed that the maximum pollution load index of Cd (98.4) was followed by Cr (6.5) and As (2.7) for canal water samples. However, Zn (8.2) had the maximum bioconcentration factor in canal water samples followed by Fe

(0.3). Similarly, the pollution load index of heavy metals and metalloids also varied within ground water samples. Cadmium (127.1) had the maximum pollution load index in ground water samples followed by Cr and As. However, Zn (6.8) had the maximum bioconcentration factor in ground water samples (Table 4).

Table 4. Bioconcentration factor and pollution load index in vegetable samples grown by various irrigation sources

Metals	Bioconcentration Factor			Pollution Load Index		
	GW	CW	SW	GW	CW	SW
Ni	3.0×10^{-2}	5.0×10^{-2}	4.0×10^{-2}	2.3×10^{-1}	1.6×10^{-1}	1.4×10^{-1}
Fe	2.1×10^{-1}	2.6×10^{-1}	2.6×10^{-1}	0	0	0
Cu	6.0×10^{-2}	6.0×10^{-2}	6.0×10^{-2}	9.0×10^{-2}	6.0×10^{-2}	4.0×10^{-2}
Pb	0	1.0×10^{-2}	1.0×10^{-2}	5.5×10^{-1}	4.4×10^{-1}	3.4×10^{-1}
Zn	6.8	8.2	4.4	3×10^{-2}	2.0×10^{-2}	1.0×10^{-2}
Se	1.0×10^{-2}	2.0×10^{-2}	1.0×10^{-2}	5.8×10^{-1}	3.5×10^{-1}	2.0×10^{-1}
Mo	2.0×10^{-2}	1.0×10^{-2}	1.0×10^{-2}	2.7×10^{-1}	2.1×10^{-1}	1.4×10^{-1}
As	0	0	0	3.0	2.7	2.3
Cr	2.0×10^{-2}	2.0×10^{-2}	2.0×10^{-2}	8.4	6.5	3.3
Cd	1.0×10^{-2}	2.0×10^{-2}	2.0×10^{-2}	127.0	98.4	76.3

GW = Ground water; CW = Canal water; SW = Sewage water

Health risk index

The HRI values showed the level of risk arising from the intake of metals and metalloids in contaminated ridge gourd vegetable. The HRI values of metals-metalloid-polluted ridge gourd vegetable grown from different irrigation sources at experimental areas ranged from (0.0005 to 0.5639) for sewage water (0.0002 to 1.2716) for canal water and (0.0004 to 0.3876) for ground water. This observation points to the fact that the health risk index value was low, as no value exceeded the canal irrigation sampling locations. The HRI value of Cd was above one where canal water irrigation was used; however, other metals and metalloids showed HRI values below one, which represents a relatively minor risk (Table 5).

Table 5. Health risk index of vegetable samples grown by various irrigation sources

Metals	DIM			HRI		
	GW	CW	SW	GW	CW	SW
Ni	2×10^{-4}	3×10^{-4}	4×10^{-4}	1×10^{-2}	1.6×10^{-2}	1.9×10^{-2}
Fe	8.7×10^{-3}	1.9×10^{-2}	2×10^{-2}	1.3×10^{-2}	6.5×10^{-1}	2.9×10^{-2}
Cu	2×10^{-4}	3×10^{-4}	4×10^{-4}	7.5×10^{-3}	2.6×10^{-2}	1.1×10^{-2}
Pb	1×10^{-4}	4×10^{-4}	4×10^{-4}	3.9×10^{-2}	2.6×10^{-3}	1.2×10^{-1}
Zn	1.3×10^{-2}	2.9×10^{-2}	2×10^{-2}	4.4×10^{-2}	2.9×10^{-1}	9.9×10^{-2}
Se	0	0	1×10^{-4}	5.3×10^{-3}	4×10^{-3}	1.2×10^{-2}
Mo	1×10^{-4}	1×10^{-4}	1×10^{-4}	2×10^{-2}	3.3×10^{-3}	2.5×10^{-2}
As	0	0	1×10^{-4}	1.2×10^{-1}	2×10^{-4}	2×10^{-1}
Cr	5×10^{-4}	7×10^{-4}	8×10^{-4}	4×10^{-4}	1.3	5×10^{-4}
Cd	3×10^{-4}	4×10^{-4}	6×10^{-4}	3.9×10^{-1}	7×10^{-4}	5.6×10^{-1}

DIM = Daily intake of metals; HRI = Health risk index; GW = Ground water; CW = Canal water; SW = Sewage water

Target hazard quotients and hazard index

The noncarcinogenic health risk is related to THQ, and its permissible limit value is ≤ 1 , above that this value represents the associated health risks. Results obtained in this study revealed that the THQ values for the measured metals and metalloids polluted ridge gourd vegetable are below 1 in vegetable samples irrigated from various sources. However, the target health quotients of specific metals and metalloids showed values greater

than one Zn for canal and swage irrigation, and Fe and Cr for canal irrigation. From these values, we observed that the canal water is a major accumulator of metals and metalloid buildup in vegetable samples (Table 6). The HI represents the cumulative effect of toxic metals and metalloid ingestion from the consumption of contaminated foods, results of HI shown in Table 6 depicted that HI values are above the allowable limit (1) in vegetable samples grown from various irrigation sources. Maximum hazard index was noted from the canal water as compared to the rest of the irrigation sources.

Table 6. Target hazard quotients of vegetable samples grown by various irrigation sources

Metals	THQ			THQm		
	GW	CW	SW	GW	CW	SW
Ni	1.2×10^{-4}	1.9×10^{-4}	2.31×10^{-4}	2.20×10^{-3}	6.70×10^{-3}	9.90×10^{-3}
Fe	1.5×10^{-4}	7.7×10^{-3}	3.41×10^{-4}	1.45×10^{-1}	1.61×10^1	7.53×10^{-1}
Cu	8.9×10^{-5}	3.0×10^{-5}	1.31×10^{-4}	1.90×10^{-3}	9.60×10^{-3}	6.40×10^{-3}
Pb	4.6×10^{-5}	3.1×10^{-5}	1.35×10^{-3}	5.00×10^{-3}	1.00×10^{-3}	5.91×10^{-2}
Zn	5.1×10^{-4}	3.5×10^{-3}	1.17×10^{-3}	7.20×10^{-1}	1.11×10^1	3.80×100
Se	6.2×10^{-5}	4.7×10^{-5}	1.4×10^{-4}	1.00×10^{-4}	2.00×10^{-4}	8.00×10^{-4}
Mo	2.4×10^{-4}	3.9×10^{-5}	2.9×10^{-4}	1.80×10^{-3}	3.00×10^{-4}	4.00×10^{-3}
As	1.5×10^{-3}	2.9×10^{-6}	2.4×10^{-3}	4.80×10^{-3}	0.00×100	1.55×10^{-2}
Cr	4.5×10^{-6}	1.5×10^{-2}	6.3×10^{-6}	2.00×10^{-4}	1.09×100	5.00×10^{-4}
Cd	4.5×10^{-3}	7.7×10^{-6}	6.6×10^{-3}	1.20×10^{-1}	3.00×10^{-4}	4.15×10^{-1}
Hazard Index (HI)				5.05	28.27	1.01

THQ = Target hazard quotient; THQm = Target hazard quotient of specific metal; HI = Hazard index; GW = Ground water; CW = Canal water; SW = Sewage water

Cancer risk

In general, it is considered that when humans are exposed to potentially toxic elements, it may pose a significant negative impact on their health and that sustained exposure (oral, dermal, and inhalation) with a specific carcinogenic metal may cause cancer. The risk of having cancer rises with time. TCR represents the approximation of possible future cancers. Then, it also represents the potential for an individual to develop cancer-causing risks. If TCR values are in the range of 10 to 6, it represents a low cancer risk, if it is between 10 and 5 and 10 to 4, then it is a moderate cancer risk, and if between 10 and 3 and from 10 to 1, then it points to high risks. TCR values for ground water samples As and Ni is at lower risks Cr and Cd are at moderate cancer risk while the Pb is at high risk. Similarly, Ni, Cr, Cd, and As in canal water are sources of high cancer risk and Pb showed moderate cancer risk for the local community. However, for the sewage water Ni and As are at low cancer risk while Cr and Cd are at moderate cancer risk and Pb was at the highest cancer risk for the people consuming this contaminated vegetable (Table 7).

Table 7. Cancer risk of vegetable samples grown by various irrigation sources

Metals	Cancer Risk		
	GW	CW	SW
Ni	1.2×10^{-4}	1.4	2.3×10^{-4}
Fe	-	-	-
Cu	-	-	-
Pb	1.6×10^{-2}	6.2×10^{-3}	4.7×10^{-2}
Zn	-	-	-
Se	-	-	-
Mo	-	-	-
As	2.4×10^{-5}	1.2	4×10^{-5}
Cr	1.1×10^{-3}	4.2×10^{-1}	1.6×10^{-3}
Cd	1.1×10^{-3}	2.5×10^{-1}	1.5×10^{-3}
TCR	1.8×10^{-2}	3.3	5.1×10^{-2}

TCR = Target cancer risk; GW = Ground water; CW = Canal water; SW = Sewage water; - = data not available

Multivariate analysis

Cluster analysis was performed to investigate the relationships among the heavy metals and to discern patterns in their origins and associations. The results of the analysis revealed the presence of three primary clusters. Cluster I comprised Cadmium (Cd), Chromium (Cr), Lead (Pb), and Arsenic (As), indicating a common origin or a strong association among these heavy metals. Cluster II included Zinc (Zn), Selenium (Se), Copper (Cu), Nickel (Ni), and Molybdenum (Mo), suggesting a shared origin or a close relationship among these particular heavy metals. Cluster III exhibited a relationship primarily between Iron (Fe) and the other two clusters, implying a distinct connection or interaction between Iron and the heavy metals in Clusters I and II (Figure 2)

These clusters provide valuable insights into the potential sources and associations of the heavy metals, with Cluster I (Cd-Cr-Pb-As) and Cluster II (Zn-Se-Cu-Ni-Mo) representing groups of heavy metals with common origins or strong associations, respectively.

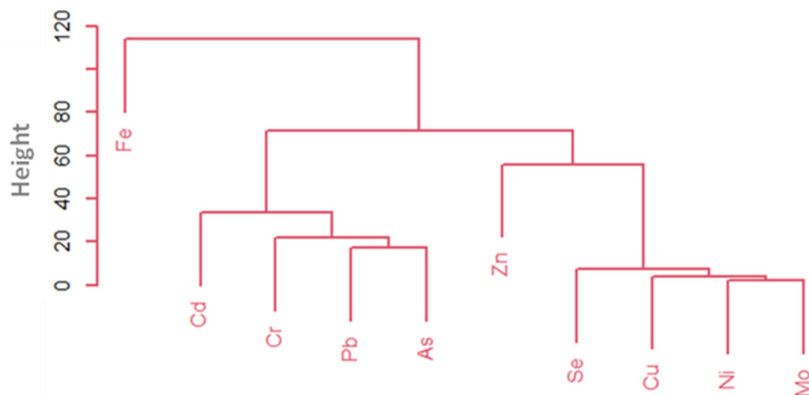


Figure 2. Dendrogram showing hierarchical clusters of measured sampling data

Principal component analysis (PCA) was conducted to assess the distribution of heavy metals in soil, water, and ridge gourd vegetable samples. The analysis revealed the presence of two principal components, namely PC1 and PC2. PC1 accounted for a substantial 89.1% of the total variance, while PC2 contributed to 9.7% of the variance.

The results of this analysis indicated that, with the exception of Zinc (Zn), all the heavy metals exhibited elevated concentrations in the soil samples, thereby confirming their origin in the soil. Interestingly, a notably

higher concentration of Zinc (Zn) was observed in the vegetable samples, suggesting the bioaccumulation of this particular metal in the ridge gourd vegetable samples (Figure 3).

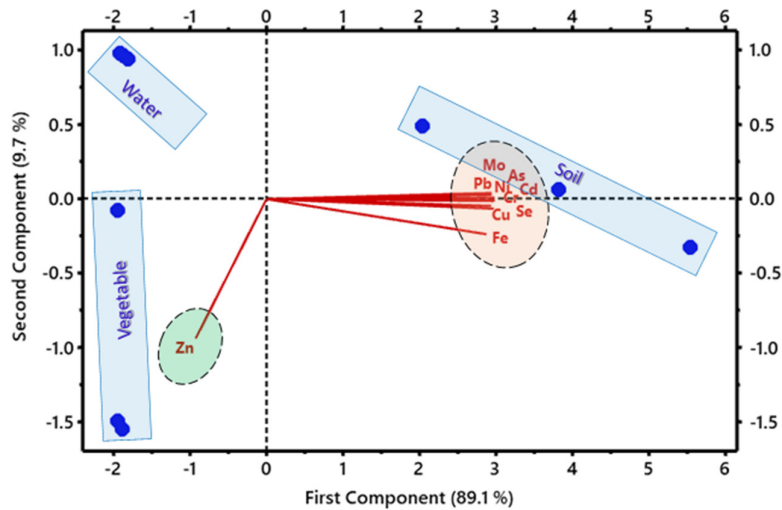


Figure 3. Principal component analysis (PCA) plot showing the association among metals in water (waste, canal & ground water) and soil and vegetable samples

Correlation analysis

Pearson correlation coefficients were calculated to assess the relationships between the concentrations of various metals and metalloids in vegetable samples and samples collected from different irrigation sources (soil, water, and vegetable). From the figure, it is evident that there is a strong positive correlation between the water source and both soil and vegetable samples.

However, when considering the metal and metalloid contents, it's worth noting that Ni, Fe, Cu, and Pb exhibited a negative correlation with Cd, Cr, As, Mo, and Se. In other words, as the concentrations of Ni, Fe, Cu, and Pb increased, the concentrations of Cd, Cr, As, Mo, and Se tended to decrease, and vice versa. This suggests an inverse relationship between these sets of elements in the analysed samples (Figure 4).

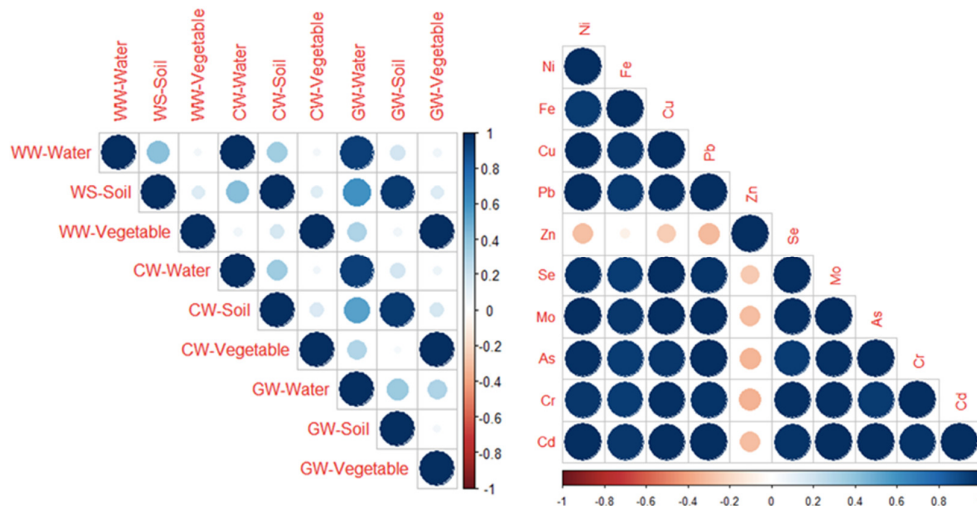


Figure 4. Correlation coefficient of measured sampling data
 GW= Ground water, CW= Canal water, and WW= Wastewater

Discussion

The two pillars of an economy are industrialization and the agricultural industry. Nevertheless, these industries have played a significant role in the environmental contamination of a locality (Zaman *et al.*, 2021; Javaid *et al.*, 2022). Moreover, anthropogenic activities are the primary cause of the pollution of soil and groundwater (Hassan *et al.*, 2021). The production of food crops on these contaminated soils with contaminated irrigation water resulted to the bioaccumulation of potentially toxic substances in plants, which increased significant health risks for people (Riaz *et al.*, 2021; Mununga Katebe *et al.*, 2023). Findings of the current study revealed similar results in which polluted irrigation sources resulted in higher bioaccumulation metals and metalloids in the ridge gourd fruit (Tables 1-3).

It has been reported that irrigation with sewage and canal water leads to metal and metalloid buildup in soil and vegetable samples. Due to soil contamination, crops are ultimately becoming more and more polluted and unfit for human consumption (Miclean *et al.*, 2018). These variations in the metal's accumulation could be attributed to different farming methods used in the research area and other environmental conditions (Cao *et al.*, 2018). Similar results were observed in this study as well. Metals may accumulate in to vegetables when they are watered with wastewater, posing potential health risks to consumers. As wastewater is often contaminated with various metals and metalloids from industrial discharges, urban runoff, and other sources, these contaminants can find their way into the soil and subsequently be taken up by plants during irrigation (Riaz *et al.*, 2021). While Cd levels were much over the acceptable range, heavy metal levels in soil were within the ranges that could be helpful for the correct operation of biological processes (Yu *et al.*, 2022). Substantial concentrations of metalloids and heavy metals have been released into the soil environment, where they are absorbed by plant roots and bioaccumulate in samples of ridge gourd (Sweta and Singh, 2022; Tariq *et al.*, 2023). This buildup of metals and metalloids in the soil, water, and ridge gourd samples in the current study may be caused by dominant industrial land use (Proshad *et al.*, 2019). Similar studies have found high quantities of heavy metals in crops produced in industrial zones (Chowdhury and Rasid, 2016). The concentrations of all metals and metalloids, as well as the elemental composition of flooded soils, were higher in this study than in the data published by Jaishree and Khan (2015). With the exception of a few commonly known harmful metals and metalloids such as As, Cd, Pb, Cr, and Cu, the concentrations of the bulk of the soil samples were within the World Health Organization and European Union authorized ranges (EU, 2006). Because the irrigation water distribution system is more controlled and managed, the improved irrigation water's quality was evident by decreased levels of metals and metalloids.

Rapid industrialization and improper waste management are the primary causes of the accumulation of metals and metalloids in foods (Zaman *et al.*, 2021). Metal and metalloid deposition in groundwater and the soil rhizosphere is caused by natural and man-made sources, and it affects agricultural yield (Mariyanto *et al.*, 2019). Metals and metalloids accumulate in the soil-plant continuum mostly because of human sources such as pesticides and fertilizer residues (Zhou *et al.*, 2020), and usage of industrial and domestic wastewater (Gassama *et al.*, 2015). Metals and metalloids in crop fields are mostly caused by human activity and reckless use of fertilizers which is the major source of metals build up in the soil. In industrialized regions, the concentrations of these potentially hazardous metals and metalloids are frequently higher compared to non-industrialized areas. As a result, there is an accumulation of pollutants in soil and food samples (Luo *et al.*, 2019; Tariq *et al.*, 2023). Similar findings were also observed in the current study as the study site is an industrialized area and mostly the farmer use wastewater as a source of irrigation in this area.

The accessibility of metals from the soil to the fruit was shown by the enrichment coefficient for metals and metalloids (Ugulu *et al.*, 2019). The composition of the soil, the type of metal, and the type of plant all affect how much metal and metalloids accumulate in the ridge gourd fruit of the plant (Noor *et al.*, 2023). The high transfer values for elements such as Cd, Zn, and Ni from soil to plant indicate that ridge gourd vegetable

have accumulated significant amounts of the respective metals. Due to an increase in metal content in soil, metal concentration in plants also increased (Elgarahy *et al.*, 2021). Similar findings were also noticed in the current study. The daily intake of metals by humans determines how hazardous they are (Ugulu *et al.*, 2022). The current study's observation of the Cd, Pb, and Cr enrichment coefficient from soil to vegetable was similar to that of (Kumar *et al.*, 2022). The ability of a plant's transport system to transfer metals within the plant from the root to the shoot is indicated by a transfer coefficient greater than 1.

Health risk analysis involves assessing the exposure levels of these metals through vegetable consumption and comparing them to established safety standards and guidelines. The concentration of metals in wastewater, soil, and ridge gourd vegetable, as well as consumption patterns, all play crucial roles in determining potential health risks (Hassan *et al.*, 2021; Riaz *et al.*, 2021). Heavy metals and metalloids (HMMs) have been reported to cause a wide range of adverse impacts on a significant part of the environment including human beings (Njuguna *et al.*, 2019). Many studies indicate and highlight the serious impacts of HMMs on human health (Ahmad *et al.*, 2019; Guo *et al.*, 2022). Various HMMs such as Hg, As, Cr, Cd, and Pb have been found to be carcinogens at elevated levels (Machate, 2023). This study focused on health risks, particularly heavy metal-induced cancer. Health hazard indices are developed to assess the risks to human health associated with eating food crops that have been contaminated with various kinds of heavy metals (Ashfaq *et al.*, 2022). The measured elements such as Ni, Cr, Pb, As, and Cd had cancer risk values >1 in vegetable samples in this study, which may be attributed to a significant buildup to the bioaccumulation of these toxic metals in the edible items. Consumption of heavy metal-infected vegetables (particularly Ni, Pb, As, and Cd) proved more harmful to human health than intake of contaminated fruits (Shaheen *et al.*, 2016). Heavy metal pollution, notably Pb and Mn, have been linked to Alzheimer's disease and Mg, was discovered in vegetables grown near a Pb-Zn mine (Mahfooz *et al.*, 2020). It was revealed that combined Pb and Cd health hazards were seen rather than the impacts of either metal alone (Atamaleki *et al.*, 2021). Monitoring and analysis are essential to identify areas where contamination is high, enabling authorities to implement appropriate measures to mitigate risks and safeguard public health (Bawwab *et al.*, 2022; Singh *et al.*, 2022). The presence and movement of heavy metals are dependent upon many soil factors such as organic carbon, pH, cation exchange capacity, mineral and clay concentrations, and oxidation-reduction. The process of speciation and solubility of heavy metals in soil are primarily affected by soil pH, which has the most negative effect among all soil factors. The solubility of heavy metals increases with a decrease in pH, leading to higher plant accumulation and absorption. This can pose possible health risks and the health of consumers (Mununga Katebe *et al.*, 2023; Tariq *et al.*, 2023).

Conclusions

This study provided a detailed insight into the present scenario of ridge gourd contamination and human health risk estimations in the industrialized zone. This study indicated low levels of metals were found in ridge gourd samples irrigated by ground water. On the other hand, Pb, and Cd levels in ridge gourd samples irrigated with sewage water were higher than safe limits. Pb and Cd levels in ridge gourd samples irrigated with canal water were also higher than safe limits. Consumption of ridge gourd irrigated with wastewater may pose a health risk, according to the health risk criteria. It was found that ridge gourds grown in sewage water and canal water were the most dangerous, while ridge gourds grown in groundwater were the best for human health. Except for Cd other metals and metalloids showed hazard index values below one. The highest hazard index was noted from the canal water as compared to the rest of the irrigation sources. This study underlined the need of measuring the metal and metalloid levels from urban agricultural lands and their associated irrigation water sources and encouraged the achievement of different Sustainable Development Goals (SDGs) including "Zero hunger". The findings of this study might be utilized to develop new monitoring programs especially in urban areas and encourage individuals to take precautions i.e., promoting awareness among farmers and

consumers about safe irrigation practices, proper washing, and cooking methods to reduce contamination of different irrigation streams and the hazards of eating infected crop produce.

Authors' Contributions

Conceptualization, Q.u.Z. and K.S.; methodology, M.W., K.A.; software, H.M.A., M.M.A.A., M.M., A.A. and M.U.; formal analysis, M.W., A.A., M.M., M.U., and K.A.; investigation, K.S. and Q.u.Z.; resources, M.W., H.M.A. and M.M.; data curation, A.A., K.S., M.U., H.M.A., M.M.A.A. and K.A.; writing—original draft preparation, A.A., M.W., K.S. H.M.A. and M.M.A.A.; writing—review and editing, M.M., Q.u.Z., M.U. and K.A.; supervision, Q.u.Z.; project administration, Q.u.Z.; funding acquisition, H.M.A., M.M.A.A. and A.A. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

- Aderinola OJ, Kusemiju V, Clarke EO, Anetekhai MA, Adu A (2012). A. Bio-accumulation of heavy metals in Silver catfish-*Chrysichthys nigrodigitatus*, *Tilapia zillii* and *Macrobrachium macrobrachion* caught in Badagry creek, Lagos, Nigeria. *International Journal of Transportation Science and Technology* 2:34-47.
- Adil N, Ashraf K, Munir M, Mohiuddin M, Abbasi A, Riaz U, Aslam A, Marey SA, Hatamleh AA, Zaman Qu (2023). Pesticides, heavy metals and plasticizers: contamination and risk assessment of drinking-water quality. *Sustainability* 15:13263. <https://doi.org/10.3390/su151713263>
- Ahmad K, Wajid K, Khan ZI, Ugulu I, Memoona H, Sana M, Nawaz K, Malik IS, Bashir H, Sher M (2019). Evaluation of potential toxic metals accumulation in wheat irrigated with wastewater. *Bulletin of Environmental Contamination and Toxicology* 102:822-828. <https://doi.org/10.1007/s00128-019-02605-1>

- Ahmed W, Zaman Qu, Mehmood F, Abbasi A, Ashraf K, Fatima K, Nazir S, Komal N, Waqas M (2022). The potential of commercial compost in reducing heavy metals and metalloids phytoaccumulation in maize. *Pakistan Journal of Botany* 55. [http://dx.doi.org/10.30848/PJB2023-2\(25\)](http://dx.doi.org/10.30848/PJB2023-2(25))
- Alam M, Khan M, Khan A, Zeb S, Khan MA, Amin NU, Sajid M, Khattak AM (2018). Concentrations, dietary exposure, and human health risk assessment of heavy metals in market vegetables of Peshawar, Pakistan. *Environmental Monitoring and Assessment* 190:505. <https://doi.org/10.1007/s10661-018-6881-2>
- Alsafran M, Usman K, Rizwan M, Ahmed T, Al Jabri H (2021). The carcinogenic and non-carcinogenic health risks of metal(oid)s bioaccumulation in leafy vegetables: a consumption advisory. *Frontiers in Environmental Science* 9:742269. <https://doi.org/10.3389/fenvs.2021.742269>
- Anonymous (2018-19). Agriculture statistics of Pakistan. <https://www.pbs.gov.pk/agri-stat-tables>
- Anwar S, Nawaz MF, Gul S (2016). Uptake and distribution of minerals and heavy metals in commonly grown leafy vegetable species irrigated with sewage water. *Environmental Monitoring Assessment* 188:541. <https://doi.org/10.1007/s10661-016-5560-4>
- Asad Z, Ashfaq M, Inam-Ul-Haq M, Irshad G, Khan MA (2022). Current status and molecular characterization of zucchini yellow mosaic virus (ZYMV) infecting ridge gourd (*Luffa acutangula* L) in different regions of Punjab, Pakistan. *Pakistan Journal of Botany* 54:467-474.
- Ashfaq A, Khan ZI, Ahmad K, Ashraf MA, Hussain MI, Elghareeb EM (2022). Hazard of selenium metal contamination in vegetables grown in municipal solid waste amended soil: Assessment of the potential sources and systemic health effects. *Agricultural Water Management* 271:107768. <https://doi.org/10.1016/j.agwat.2022.107768>
- Ashraf I, Ahmad F, Sharif A, Altaf AR, Teng H (2021). Heavy metals assessment in water, soil, vegetables and their associated health risks via consumption of vegetables, District Kasur, Pakistan. *SN Applied Sciences* 3:1-16. <https://doi.org/10.1007/s42452-021-04547-y>
- Atamaleki A, Yazdanbakhsh A, Fallah S, Hesami M, Neshat A, Fakhri Y (2021). Accumulation of potentially harmful elements (PHEs) in lettuce (*Lactuca sativa* L.) and coriander (*Coriandrum sativum* L.) irrigated with wastewater: a systematic review and meta-analysis and probabilistic health risk assessment. *Environmental Science and Pollution Research* 28:13072-13082. <https://doi.org/10.1007/s11356-021-13115-1>
- ATSDR (2004). Toxicological profile for copper. Agency for Toxic Substances and Diseases Registry. <https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=206&tid=37>
- Atta MI, Zehra SS, Dai DQ, Ali H, Naveed K, Ali I, Sarwar M, Ali B, Iqbal R, Bawazeer S, Ali I, Abdel-Hameed UK (2023). Amassing of heavy metals in soils, vegetables and crop plants irrigated with wastewater: Health risk assessment of heavy metals in Dera Ghazi Khan, Punjab, Pakistan. *Frontiers in Plant Sciences* 13:1080635. <https://doi.org/10.3389/fpls.2022.1080635>
- Bajkani JK, Amin H, Sidiqi S, Raza I, Ali A, Pasand S, Muhammad F (2023). Cost analysis of hybrid vegetable production and its impact on farmer's income in Baluchistan, Pakistan. *Pakistan Journal of Biotechnology* 20:42-50. <https://doi.org/10.34016/pjbt.2023.20.01.750>
- Bawwab M, Qutob A, Al Khatib M, Malassa H, Shawahna A, Qutob A (2022). Evaluation of heavy metal concentrations in soil and edible vegetables grown in compost from unknown sources in Al-Jiftlik, Palestine. *Journal of Environmental Protection* 13:112-125. <https://doi.org/10.4236/jep.2022.131007>
- Begum HA, Hamayun M, Sadiq A, Ali K, Rauf M, Khan W (2020). Cholinesterase enzyme inhibition and antioxidant bioassays of *Malus baccata* (L.) Borkh.; An approach to cure Alzheimer's disease. *Biosciences Research* 17:2799-2806.
- Cao C, Zhang Q, Ma ZB, Wang XM, Chen H, Wang JJ (2018). Fractionation and mobility risks of heavy metals and metalloids in wastewater-irrigated agricultural soils from greenhouses and fields in Gansu, China. *Geoderma* 328:1-9. <https://doi.org/10.1016/j.geoderma.2018.05.001>
- Chary NS, Kamala CT, Raj DSS (2008). Assessing risk of heavy metals from consuming food grown on sewage irrigated soils and food chain transfer. *Ecotoxicology and Environmental Safety* 69:513-524. <https://doi.org/10.1016/j.ecoenv.2007.04.013>
- Chauhan G, Chauhan UK (2014). Human health risk assessment of heavy metals via dietary intake of vegetables grown in wastewater irrigated area of Rewa, India. *International Journal of Sciences and Research Publications* 4:1-9.
- Chowdhury N, Rasid MM (2016). Heavy metal contamination of soil and vegetation in ambient locality of ship breaking yards in Chittagong, Bangladesh. *Journal of Environmental Science, Toxicology and Food Technology* 10:20-27.

- Cui YJ, Zhu YG, Zhai RH, Chen DY, Huang YZ, Qiu Y, Liang JZ (2004). Transfer of metals from soil to vegetables in an area near a smelter in Nanning, China. *Environment International* 30:785-791. <https://doi.org/10.1016/j.envint.2004.01.003>
- Dembitsky VM, Rezanka T (2003). Natural occurrence of arseno compounds in plants, lichens, fungi, algal species, and microorganisms. *Plant Sciences* 165:1177-1192. <https://doi.org/10.1016/j.plantsci.2003.08.007>
- Elgarahy AM, Elwakeel KZ, Mohammad SH, Elshoubaky GA (2021). A critical review of biosorption of dyes, heavy metals and metalloids from wastewater as an efficient and green process. *Cleaner Engineering and Technology* 4:100209. <https://doi.org/10.1016/j.clet.2021.100209>
- Estefan G, Sommer R, Ryan J (2013). Methods of soil, plant, and water analysis: A manual for the West Asia and North Africa region. International Center for Agricultural Research in the Dry Areas (ICARDA) 3:65-119.
- European Union (2006). Commission Regulation (EC) No. 1881/2006 of 19 December 2006 Setting Maximum Levels for Certain Contaminants in foodstuffs. Official Journal of the European Union 2006, 364:5-24.
- Gassama UM, Bin Puteh A, Abd-Halim MR, Kargbo B (2015). Influence of municipal wastewater on rice seed germination, seedling performance, nutrient uptake, and chlorophyll content. *Journal of Crop Science and Biotechnology* 18:9-19. <https://doi.org/10.1007/s12892-014-0091-4>
- Guo J, Zhang Y, Liu W, Zhao J, Yu S, Jia H, Zhang C, Li Y (2022). Incorporating *in vitro* bio-accessibility into human health risk assessment of heavy metals and metalloid (As) in soil and pak choi (*Brassica chinensis* L.) from greenhouse vegetable production fields in a megacity in Northwest China. *Food Chemistry* 373:131488. <https://doi.org/10.1016/j.foodchem.2021.131488>
- Gupta N, Yadav KK, Kumar V, Krishnan S, Kumar S, Nejad ZD, Khan MM, Alam J (2021). Evaluating heavy metals contamination in soil and vegetables in the region of North India: Levels, transfer and potential human health risk analysis. *Environmental Toxicology and Pharmacology* 82:103563. <https://doi.org/10.1016/j.etap.2020.103563>
- Gupta N, Yadav KK, Kumar V, Kumar S, Chadd RP, Kumar A (2019). Trace elements in soil-vegetables inter-face: translocation, bioaccumulation, toxicity and amelioration - a review. *Science Total Environment* 651:2927-2942. <https://doi.org/10.1016/j.scitotenv.2018.10.047>
- Haque MM, Niloy NM, Khirul MA, Alam MF, Tareq SM (2021). Appraisal of probabilistic human health risks of heavy metals in vegetables from industrial, non-industrial and arsenic contaminated areas of Bangladesh. *Heliyon* 7:e06309. <https://doi.org/10.1016/j.heliyon.2021.e06309>
- Hassan F, Mehmood F, Zaman Q, Iqbal DN, Rehman R, Aslam F, Sagar S, Masood N, Nazir A, Iqbal M (2021). Evaluation of physicochemical properties and metallic contents in vegetables irrigated with water from different sources. *Polish Journal of Environmental Studies* 30:1943-1947. <https://doi.org/10.15244/pjoes/125563>
- Huber M, Rembiałkowska E, Średnicka D, Bügel S, Van De Vijver LPL (2021). Organic food and impact on human health: assessing the status quo and prospects of research. *NJAS-Wageningen. Journal of Life Sciences* 58:103-109. <https://doi.org/10.1016/j.njas.2011.01.004>
- Hussain, MM, Hina A, Saeed A, Sabahat S, Jannat FT, Aslam M (2017). Impact of heavy metals on plants and animals in relation to sewage water-A review. *Science Technology and Development* 36:215-226.
- IFOAM (2022). Organic Agriculture and Its Benefits for Climate and Biodiversity; IFOAM: Brussels, Belgium, pp 1-16.
- Ihedioha JN, Okoye COB, Onyechi UA (2014). Health risk assessment of zinc, chromium, and nickel from cow meat consumption in an urban Nigerian population. *International Journal of Occupational and Environmental Health* 20:281-288. <https://doi.org/10.1179/2049396714Y.0000000075>
- Islam MS, Hoque MF (2014). Concentrations of heavy metals in vegetables around the industrial area of Dhaka city, Bangladesh and health risk assessment. *International Food Research Journal* 21:2121-2126. <https://doi.org/10.1016/j.wsee.2020.07.001>
- Jaishree A, Khan TI (2015). Assessment of heavy metals' risk on human health via dietary intake of cereals and vegetables from effluent irrigated land Jaipur district, Rajasthan. *International Journal of Innovative Research in Science Engineering and Technology* 4:5142-5148.
- Jaiswal DK, Krishna R, Chouhan GK, de Araujo Pereira AP, Ade AB, Prakash S, Verma SK, Parsad R, Yadav J, Verma JP (2022). Bio-fortification of minerals in crops: current scenario and future prospects for sustainable agriculture and human health. *Plant Growth Regulations* 98:5-22. <https://doi.org/10.1007/s10725-022-00847-4>

- Javaid S, Ashraf K, Sultan K, Siddique MH, Ali HM, Chen Y, Zaman QU (2022). Risk assessment of potentially toxic metals and metalloids in soil, water and plant continuum of fragrant rice. *Agronomy* 12:2480. <https://doi.org/10.3390/agronomy12102480>
- Khan MU, Malik RN, Muhammad S (2013). Human health risk from Heavy metal via food crops consumption with wastewater irrigation practices in Pakistan. *Chemosphere* 93:2230-2238. <https://doi.org/10.1016/j.chemosphere.2013.07.067>
- Kumar P, Kumar S, Singh RP (2022). Severe contamination of carcinogenic heavy metals and metalloid in agro-ecosystems and their associated health risk assessment. *Environmental Pollution* 301:118953. <https://doi.org/10.1016/j.envpol.2022.118953>
- Kumar S, Prasad S, Yadav KK, Shrivastava M, Gupta N, Nagar S, Bach QV, Kamyab H, Khan SA, Yadav S, Malav LC (2019). Hazardous heavy metals contamination of vegetables and food chain: role of sustainable remediation approaches - a review. *Environmental Research* 179:108792. <https://doi.org/10.1016/j.envres.2019.108792>
- Liu WH, Zhao JZ, Ouyang ZY, Söderlund L, Liu GH (2005). Impacts of sewage irrigation on heavy metals distribution and contamination. *Environ International* 31:805-812. <https://doi.org/10.1016/j.envint.2005.05.042>
- Lü H, Cai QY, Jones KC, Zeng QY, Katsoyiannis A (2014). Levels of organic pollutants in vegetables and human exposure through diet: a review. *Critical Reviews in Environmental Science and Technology* 44:33. <https://doi.org/10.1080/10643389.2012.710428>
- Luo L, Mei K, Qu L, Zhang C, Chen H, Wang S, Di D, Huang H, Wang Z, Xia F, Dahlgren RA, Zhang M (2019). Assessment of the Geographical Detector Method for investigating heavy metal source apportionment in an urban watershed of Eastern China. *Science Total Environment* 653:714-722. <https://doi.org/10.1016/j.scitotenv.2018.10.424>
- Machate DJ (2023). Anthropogenic hyperactivity for natural resources increases heavy metals concentrations in the environment: Toxicity of healthy food and cancer risks estimated. *Journal of Trace Elements in Medicine and Biology* 2023:100057.
- Mahfooz Y, Yasar A, Gujjian L, Ul Islam Q, Akhtar ABT, Rasheed R, Irshad S, Nadeem U (2020). Critical risk analysis of metals toxicity in wastewater irrigated soil and crops: a study of a semi-arid developing region. *Scientific Reports* 10:12845. <https://doi.org/10.1038/s41598-020-69815-0>
- Malik Z, Ahmad M, Abassi GH, Dawood M, Hussain A, Jamil M (2017). Agrochemicals and soil microbes: interaction for soil health. In: Hashmi MZ (Ed). *Xenobiotics in the Soil Environment: Monitoring, Toxicity and Management*. Springer International Publishing, pp 139-152. https://doi.org/10.1007/978-3-319-47744-2_11
- Manzoor J, Sharma M, Wani KA (2018). Heavy metals in vegetables and their impact on the nutrient quality of vegetables: A review. *Journal of plant Nutrition* 41:1744-1763. <https://doi.org/10.1080/01904167.2018.1462382>
- Mariyanto M, Amir MF, Utama W, Hamdan AM, Bijaksana S, Pratama A, Yunginger R, Sudarningsih S (2019). Heavy metal contents and magnetic properties of surface sediments in volcanic and tropical environment from Brantas River, Jawa Timur Province, Indonesia. *Science of the Total Environment* 675:632-641. <https://doi.org/10.1016/j.scitotenv.2019.04.244>
- Marzec Z, Koch W, Marzec A, Żukiewicz-Sobczak W (2014). Dietary exposure to cadmium, lead and nickel among students from south-east Poland. *Annals of Agricultural and Environmental Medicine* 21:825-828. <https://doi.org/10.5604/12321966.1129941>
- Miclean M, Cadar O, Levei L, Senila L, Ozunu A (2018). Metal contents and potential health risk assessment of crops grown in a former mining district (Romania). *Journal of Environmental Science and Health Part B* 53:595-601. <https://doi.org/10.1080/03601234.2018.1473966>
- Mohammadi M, Yari J, Saghadzadeh AR, Saghadzadeh M, Sobhanardakani S, Geravandi S, Afkar A, Salehi SZ, Valipour A, Biglari H, Hosseini SA, Rastegarimehr BA (2018). Health risk assessment of heavy metals in people consuming Sohan in Qom, Iran. *Toxin Reviews* 37:278-286.
- Mununga Katebe F, Raulier P, Colinet G, Ngoy Shutcha M, Mpundu Mubemba M, Jijakli MH (2023). Assessment of heavy metal pollution of agricultural soil, irrigation water, and vegetables in and nearby the cupriferous city of Lubumbashi (Democratic Republic of the Congo). *Agronomy* 13:357. <https://doi.org/10.3390/agronomy13020357>
- Naafe M, Nabi G, Irshad M, Khan MN, Ali S, Hayat R (2022). Influence of pinching on growth and yield of bottle gourd (*Lagenaria siceraria*). *Pure Applied Biology* 11:891-901. <http://dx.doi.org/10.19045/bspab.2022.110091>

- Nagajyoti PC, Lee KD, Sreekanth TVM (2010). Heavy metals, occurrence and toxicity for plants: a review. *Environmental Chemistry Letters* 8:199-216. <https://doi.org/10.1007/s10311-010-0297-8>
- Njagi JM, Akunga DN, Njagi MM, Ngugi MP, Njagi EM (2017). Heavy metal concentration in vegetables grown around dumpsites in Nairobi City County, Kenya. *World Environment* 7:49-56. <https://doi.org/10.5923/j.env.20170702.03>
- Njuguna SM, Makokha VA, Yan X, Gituru RW, Wang Q, Wang J (2019). Health risk assessment by consumption of vegetables irrigated with reclaimed waste water: a case study in Thika (Kenya). *Journal of Environmental Management* 231:576-581. <https://doi.org/10.1016/j.jenvman.2018.10.088>
- Noor AE, Un Nisa Z, Sultana S, Al-Ghanim KA, Al-Misned F, Riaz MN, Ahmed Z, Mahboob M (2023). Heavy metals toxicity in spinach (*Spinacia oleracea*) irrigated with sanitary wastewater in rural areas. *Journal of King Saud University-Science* 35:102382. <https://doi.org/10.1016/j.jksus.2022.102382>
- Olsen SR, Cole CV, Watanabe FS, Dean LA (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Department of Agriculture. USA pp 939.
- Prasad S, Yadav KK, Kumar S, Chadd RP, Kumar A (2021). Chromium contamination and effect on environmental health and its remediation: a sustainable approach. *Journal of Environmental Management* 285:112174. DOI: <https://doi.org/10.1016/j.jenvman.2021.112174>
- Proshad R, Kormoker T, Islam MS, Chandra K (2019). Potential health risk of heavy metals via consumption of rice and vegetables grown in the industrial areas of Bangladesh. *Human and Ecological Risk Assessment: An International Journal* 26:921-943. <https://doi.org/10.1080/10807039.2018.1546114>
- Riaz U, Aslam A, Zaman Q, Sabiha J, Rehman G, Shazia I, Sana J, Ghulam M, Moazzam J (2021). Cadmium contamination, bioavailability, uptake mechanism and remediation strategies in soil-plant-environment system: A critical review. *Current Analytical Chemistry* 17:49-60. <https://doi.org/10.2174/1573411016999200817174311>
- Risku-Norja H, Mäenpää I (2007). MFA model to assess economic and environmental consequences of food production and consumption. *Ecological Economics* 60:700-711.
- Ryan J, Garabet S, Harmsen K, Rashid AA (1996). Soil and plant analysis manual adapted for West Asia and North Africa region. International Center for Agricultural Research in the Dry Areas (ICARDA). Aleppo, Syria.
- Shaheen N, Irfan IN, Khan S, Islam S, Ahmed K (2016). Presence of heavy metals in fruits and vegetables: health risk implications in Bangladesh. *Chemosphere* 152:431-438. <https://doi.org/10.1016/j.chemosphere.2016.02.060>
- Sharma B, Sarkar A, Singh P, Singh RP (2017). Agricultural utilization of biosolids: a review on potential effects on soil and plant grown. *Waste Management* 64:117-132. <https://doi.org/10.1016/j.wasman.2017.03.002>
- Simonsen LO, Brown AM, Harbak A, Kristensen BI, Bennekou P (2011). Cobalt uptake and binding in human red blood cells. *Blood Cells, Molecules and Diseases* 46:266-276. <https://doi.org/10.1016/j.bcmd.2011.02.009>
- Singh A, Sharma A, Verma RK, Chopade RL, Pandit PP, Nagar V, Aseri V, Choudhary SK, Awasthi G, Awasthi KK, Sankhla MS (2022). Heavy metal contamination of water and their toxic effect on living organisms. In: Dorta D, De Oliveira DP (Eds). *The Toxicity of Environmental Pollutants* <https://doi.org/10.5772/intechopen.105075>
- Srivastava V, de Araujo ASF, Vaish B, Bartelt-Hunt S, Singh P, Singh RP (2016). Biological response of using municipal solid waste compost in agriculture as fertilizer supplement. *Review in Environmental Science and Biology* 15:677-696. <https://doi.org/10.1007/s11157-016-9407-9>
- Srivastava V, Sarkar A, Singh S, Singh P, De Araujo AS, Singh RP (2017). Agroecological responses of heavy metal pollution with special emphasis on soil health and plant performances. *Frontiers in Environmental Sciences* 5:64. <https://doi.org/10.3389/fenvs.2017.00064>
- Sun C, Zhang Z, Cao H, Xu M, Xu L (2019). Concentrations, speciation, and ecological risk of heavy metals in the sediment of the Songhua River in an urban area with petrochemical industries. *Chemosphere* 219:538-545. <https://doi.org/10.1016/j.chemosphere.2018.12.040>
- Sweta, Singh B (2022). A review on heavy metal and metalloids contamination of vegetables: addressing the global safe food security concern. *International Journal of Environment and Analytical Chemistry* 1-22. <https://doi.org/10.1080/03067319.2022.2115890>
- Tariq F, Wang X, Saleem MH, Khan ZI, Ahmad K, Malik SI, Munir M, Mahpara S, Mehmood N, Ahmad T, Memona H (2021). Risk assessment of heavy metals in basmati rice: Implications for public health. *Sustainability* 13:8513. <https://doi.org/10.3390/su13158513>

- Tariq Y, Ehsan N, Riaz U, Nasir R, Khan WA, Iqbal R, Elansary HO (2023). Assessment of heavy metal (oid) s accumulation in eggplant and soil under different irrigation systems. *Water* 15:1049. <https://doi.org/10.3390/w15061049>
- Taylor C, Golding J, Emond A (2015). Adverse effects of maternal lead levels on birth outcomes in the ALSPAC study: A prospective birth cohort study. *Bjog International Journal of Obstetrics and Gynecology* 122: 322-328. <https://doi.org/10.1111/1471-0528.12756>
- Tóth G, Hermann T, DaSilva MR, Montanarella LJEI (2016). Heavy metals in agricultural soils of the European Union with implications for food safety. *Environmental Pollution* 88:299-309. <https://doi.org/10.1016/j.envint.2015.12.017>
- Ugulu I, Khan ZI, Rehman S, Ahmad K, Munir M, Bashir H, Nawaz K (2019). Trace metal accumulation in *Trigonella foenum-graecum* irrigated with wastewater and human health risk of metal access through the consumption. *Bulletin of Environmental Contamination and Toxicology* 103:468-475. <https://doi.org/10.1007/s00128-019-02673-3>
- Ugulu I, Khan ZI, Rehman S, Ahmad K, Nawaz K, Munir M, Bashir H (2022). Heavy metal accumulation in goosefoot (*Chenopodium album* L.) irrigated with wastewater. *Pakistan Journal of Analytical & Environmental Chemistry* 23:225-236. <http://dx.doi.org/10.21743/pjaec/2022.12.05>
- US-EPA (1992). United States Environmental Protection Agency Molybdenum; CASRN 1992, 7439-98-7, Washington, DC, USA. <https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?>
- US-EPA (2000). United States Environmental Protection Agency. Risk-Based Concentration Table. United States Environmental Protection Agency. Philadelphia, PA, USA.
- US-EPA (2002). Volume II-Food Ingestion Factors. In *Exposure Factors Handbook*; EPA/600//P-95/002Fa; United States Environmental Protection Agency: Washington, DC, USA.
- US-EPA (2005). United States Environmental Protection Agency. Zinc and compounds; CASRN 7440-66-6. Washington DC, USA https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0426_summary.pdf.
- US-EPA (2010). United States Environmental Protection Agency – US EPA. Risk-based concentration table. Washington: US EPA.
- Welz B, Sperling M (1999). *Atomic absorption spectrometry*. Third Edition, Wiley-VCH, Verlag GmbH, Weinheim, Germany.
- 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, Ethiopia. *International Journal of Food Control* 4:9. <https://doi.org/10.1186/s40550-017-0053-y>
- World Health Organization (WHO) (1996). *Permissible Limits of Heavy Metals in Soil and Plants*; WHO: Geneva, Switzerland.
- Wuana RA, Okieimen FE (2011). Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. *ISRN Ecology* 12:402647. <https://doi.org/10.5402/2011/402647>
- Yu H, Chen F, Ma J, Khan ZI, Hussain MI, Javaid I, Ahmad K, Nazar S, Akhtar S, Ejaz A, Sohail M, Nadeem M, Hamid Y, Ur Rahman MH (2022). Comparative evaluation of groundwater, wastewater and canal water for irrigation on toxic metal accumulation in soil and vegetable: Pollution load and health risk assessment. *Agricultural Water Management* 264:107515. <https://doi.org/10.1016/j.agwat.2022.107515>
- Zaman Q, Rashid M, Nawaz R, Hussain A, Ashraf K, Latif M, Heile AO, Mehmood F, Salahuddin S, Chen Y (2021). Silicon fertilization: a step towards cadmium-free fragrant rice. *Plants* 10:2440. <https://doi.org/10.3390/plants10112440>
- Zhou H, Yang W, Zhou X, Liu L, Gu JF, Wang WL, Zou JL, Tian T, Peng PQ, Liao BH (2016). Accumulation of heavy metals in vegetable species planted in contaminated soils and the health risk assessment. *International Journal of Environmental Research and Public Health* 13:289. <https://doi.org/10.3390/ijerph13030289>
- Zhou J, Du B, Liu H, Cui H, Zhang W, Fan X, Cui J, Zhou J (2020). The bioavailability and contribution of the newly deposited heavy metals (copper and lead) from atmosphere to rice (*Oryza sativa* L.). *Journal of Hazardous Materials* 384:121285. <https://doi.org/10.1016/j.jhazmat.2019.121285>
- Zhuang P, McBride MB, Xia H, Li N, Li Z (2009). Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, South China. *Science of the Total Environment* 407:1551-1561. <https://doi.org/10.1016/j.scitotenv.2008.10.061>

Zia UU, Niazi AR, Ahmad Z, Alharby HF, Waraich EA, Abbasi A, Iqbal MA, Ahmed S, Hina S (2023). Dose optimization of silicon for boosting arbuscular mycorrhizal fungi colonization and cadmium stress mitigation in maize (*Zea mays* L.). Environmental Science and Pollution Research. <https://doi.org/10.1007/s11356-023-26902-9>

Zwolak A, Sarzyńska M, Szpyrka E, Stawarczyk K (2019). Sources of soil pollution by heavy metals and their accumulation in vegetables: a review. Water Air & Soil Pollution 230:164. <https://doi.org/10.1007/s11270-019-4221-y>



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