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# Health risk prognosis of cadmium and lead through food crops grown under sewage and freshwater conditions in District Chiniot

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## Abstract

*One of the major pathways for human intake of potentially toxic elements (PTEs) in developing countries is through food. In Pakistan, untreated municipal effluent is a primary source of PTEs contamination in sewage-irrigated crops. This study was designed to assess the adverse effects of PTEs, particularly cadmium (Cd) and lead (Pb) through contaminated crops. Cadmium (Cd) and lead (Pb) concentrations were analyzed across the soil–water–crop continuum at three sites in Chiniot District: canal water irrigated (site 1), sewage irrigated (site 2), and historically sewage irrigated (site 3). The daily intake of metals (DIM) and health risk index (HRI) were calculated based on crop consumption. In leafy vegetables such as spinach, Cd and Pb levels at site 2 increased by 164.7% and 110.1%, respectively, relative to site 1. The highest Cd concentration was recorded in spinach at site 2 (0.45 mg·kg$^{-1}$), while the lowest was found in zucchini at site 1 (0.036 mg·kg$^{-1}$). Pb levels peaked in spinach at site 2 (1.2 mg·kg$^{-1}$) and were lowest in corn at site 1 (0.11 mg·kg$^{-1}$). Average DIM (mg kg$^{-1}$ day$^{-1}$) values across all sites ranged from: Cd (adult): 2.56×10$^{-5}$ to 8.47×10$^{-5}$, Cd (child): 3.76×10$^{-5}$ to 1.25×10$^{-4}$, Pb (adult): 7.66×10$^{-5}$ to 1.96×10$^{-4}$, Pb (child): 1.12×10$^{-4}$ to 1.96×10$^{-4}$. Corresponding HRI values were: Cd (adult): 2.55×10$^{-2}$ to 8.47×10$^{-2}$, Cd (child): 3.76×10$^{-2}$ to 1.24×10$^{-1}$, Pb (adult): 1.91×10$^{-2}$ to 4.91×10$^{-2}$, Pb (child): 2.82×10$^{-2}$ to 7.32×10$^{-2}$. As all HRI values remained safe below 1, indicating no immediate health risk but it is imperative to address the elevated levels of Cd and Pb in crops.*

**Keywords:** Health risk index, edible crops, toxic metals, sewage irrigation, food safety

## Introduction

Naturally occurring elements in earth crust with higher atomic masses and densities are called heavy metals and generally referred to as PTEs. These are chemically bound with silicates, oxides, carbonates and phosphates in rocks or may occur in metallic or elemental forms (Islam *et al.*, 2025). There are some essential heavy metals required to sustain the life processes in living systems (Groves *et al.*, 1981; Balali-Mood *et al.*, 2025). For instance, Iron plays a major role in the respiratory system, as it is basic constituent of oxygen carrying protein, hemoglobin and a similar role is being played by copper as it transport electron and Oxygen (Redfield *et al.*, 1928). In Zn finger enzyme, Zn plays an important role (Maret, 2013). Similarly, manganese and vanadium play roles in the functioning of different enzymes(Zhou *et al.*, 2024). Iron, copper, and Zn are also important constituents of the human body ranging from 0.01g (Cu) to 5g (Fe) (Iyengar, 1998; Angon *et al.*, 2024). Moreover, some metabolic functions may also be regulated by a few heavy metals (Viczek *et al.*, 2016; Zhou *et al.*, 2024).

Many of these PTEs, mainly Cd and Pb, are highly toxic and can cause harmful health effects even at very low concentrations. Their toxicity depends upon several factors such as the route of exposure, chemical species and specific dose; as well as nutritional status, genetics, gender and age of exposed individuals (Wang *et al.*, 2024). Cd and Pb are priority toxic metals of public health concern due to their high degree of toxicity. These metals are also classified as human carcinogens by US-EPA as they have been associated with cancers in different target organs in humans and animals (Tchounwou *et al.*, 2012).

Soil is an ultimate sink of heavy metals due to its high capacity for cation exchange and organic matter complexation, which sequester contaminants like Cd and Pb from industrial and municipal effluents. There is a huge risk

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of food crop contamination through metal uptake by plants grown in metal contaminated soils (Khan *et al.*, 2026). Once absorbed, PTEs are translocated from the roots to the edible tissues of crops most particularly in leafy vegetables like lettuce (14.52 mg $kg^{-1}$, Pb) and cabbage(1mg $kg^{-1}$, Pb)(Sarheed and Hakeem, 2025), where they enter the human food chain and thus humans experience adverse health effects from metal-contaminated food (Mahmood and Malik, 2014).

Due to their persistent nature, various metals have different potentials of bioaccumulation in humans and have a capability for pathological effects (Ali *et al.*, 2019; Khan *et al.*, 2026). Health risk assessment of metal contaminated food can be made through health risk indices (HRI) of different metals (Mahmood and Malik, 2014). Depending upon the duration of exposure two types of metal toxicities can be observed in living organisms i.e., chronic toxicity due to long term exposure and acute toxicity due to short term exposure of PTEs (Jaishankar *et al.*, 2014; Jomova *et al.*, 2025).

Cadmium is one of the most toxic heavy metals in the environment; its maternal exposure can cause congenital malformations, fetal growth restriction and trace element deficiencies. During adulthood, Cd exposure can result in cardiovascular diseases, including increased heart weight at birth, decrease in cellular energy and hypoxic stress. It also can cause bone marrow damage, osteoporosis, nephrotoxicity and hepatotoxicity (Hudson *et al.*, 2019). Pb in the blood binds to hemoglobin rather than the red blood cell membrane (Guo *et al.*, 2023). and alters the hematological system by the disruption of heme formation through the inhibition of enzyme activity as well as inhibition of the immune system (Pal *et al.*, 2023).

While the bioaccumulation of suspected toxic constituents (PTEs) through wastewater irrigation is a consistently observed global phenomenon, the regional consequences in secondary industrial zones within the Punjab province of Pakistan are often overlooked (Abbas *et al.*, 2025). District Chiniot serves as an empirical case of the industrial-agricultural hub, where the traditional cultivation of vegetables like spinach and cabbage is steadily being substituted with domestic sewage. Unlike the notably supervised industrial zones of Faisalabad and Kasur, Chiniot points to a data scarcity regarding the translocation of contaminants like Cd and Pb through the soil-plant-human continuum. The objective of this investigation was to bridge this gap by providing a high-resolution health risk assessment that considers multiple dietary sources and susceptible populations of the region including both adult and pediatric segments.

The Precambrian meta-volcanic Karana Hills are located across both riverine and plain regions of Chiniot District. These hills act as natural barriers to groundwater flow, trapping contaminants and thereby contributing to the deterioration of water quality in the region (Ahmad *et al.*, 2019). Groundwater and soil quality have been increasingly compromised due to trace element intrusion from rock–water interactions. Elevated concentrations of arsenic and manganese have been detected in groundwater, while Pb levels in river water exceed permissible limits (Yoshida and Ahmad, 2018). Additionally, groundwater samples from Chiniot have revealed concentrations of PTEs including Pb and Cd that surpass recommended safety thresholds (Iram *et al.*, 2019). The district lacks adequate wastewater treatment facilities, and untreated municipal effluent is commonly used for agricultural irrigation, as is the case in many other districts of Punjab (Murtaza and Zia, 2012). While prioritizing such understated districts, this research offers a baseline data for a comprehensive national strategy and paves the way for environmental safety and food security.

This is the first study conducted in Chiniot regarding health risk assessment of Cd and Pb contaminated food crops. To investigate the identified gaps in regional environmental monitoring, this study was carried out with the following specific objectives:

1. To examine the concentrations of Cd and Pb in various irrigation sources (city effluent and canal water) and the concerning repercussions for soil chemistry in Chiniot district.

2. To closely examine the extent of Cd and Pb bioaccumulation within locally grown food crops under irrigation systems.

3. To observe the potential human health risks, including DIM and HRI, arising from the cultivation of these crops.

4. To produce scientific evidence that provides a framework for local health agencies and policy makers to address and diminish industrial pollution.

## Materials and Methods

### Site selection

District Chiniot is situated along the Chenab Riverbank in between the Sargodha and Faisalabad districts of the province

Punjab. Agriculture is the backbone of the district's economy because most of the population is engaged in agricultural activities. Water, soil and crop sampling for this study were conducted from Chiniot-Jhang bypass (31°41'54.9"N 72°57'33.8"E) which was canal water irrigated (site 1), Dera arayian (31°41'55.0"N 72°58'11.0"E) was irrigated by wastewater (site 2), and Mochi wala (31°41'53.7"N 72°58'50.3"E) that was historically wastewater irrigated (site 3) situated in district Chiniot. Wastewater had been used for irrigation purposes for approximately 30 years but now the lands of site 3 are receiving canal water instead of wastewater for growing agricultural crops for the last five years. All the sampling fields were situated along the main drain of district Chiniot which is receiving wastewater of Pindi Bhattian city as well. A variety of industries are situated along with Chiniot-Pindi Bhattian road including rice mills, textile industries, brick kilns and food processing industries. This main drain finally ends up in River Chenab without any treatment. The map of district Chiniot has been given in Figure 1 showing the study area, with the locations of all three sites through GIS mapping.

## Irrigation water sampling

A total of 90 water specimens were procured from three selected locations during the cropping season, 30 samples from each site. To ensure greater accuracy and reliable verification of the analytical results, six composite samples were processed at each 3 sites. Each composite sample was formed by combining five individual samples collected at different intervals from the irrigation source. The samples were collected in 500 ml plastic bottles prewashed with distilled water and transported to the analytical lab of the Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad for PTEs analysis.

## Soil sampling

A total of 90 soil samples were collected from all three sites, 30 samples from each site, once in a season. Six composite samples were prepared from each site including

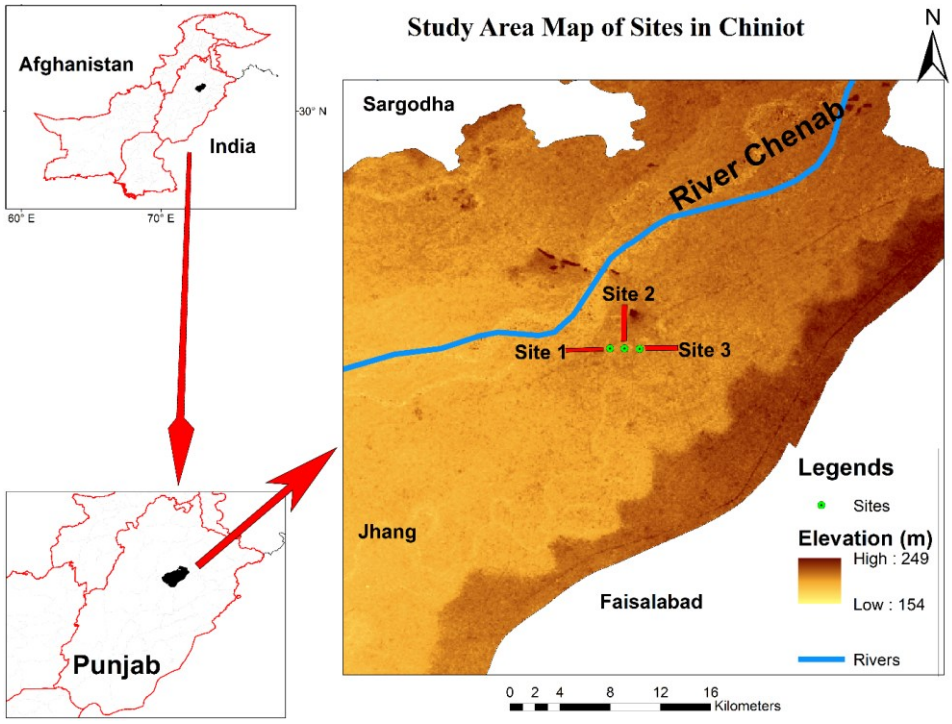



**Figure 1: Map of the district Chiniot showing the locations of sites in the study area**

**Table 1: Parameters of the atomic absorption spectrophotometer during analysis**

| PTEs | Detection Limit | Certified Value | Observed Value | Accuracy Error (%) | Recovery (%) |
|---|---|---|---|---|---|
| Cd (mg $kg^{-1}$) | 0.003 | 54±0.5 | 52.2 | 3.46 | 96.5 |
| Pb (mg $kg^{-1}$) | 0.016 | 0.140±0.001 | 0.139 | 0.91 | 99.1 |

5 grab samples for each composite sample. All soil samples were taken at a depth of 0-15 cm by a stainless-steel auger in plastic bags. The auger was washed with distilled water after every sample so as to avoid contamination (Shehzad *et al.*, 2019).

## Crop and vegetable sampling

Twelve vegetables including both winter and summer seasons were sampled during the year 2021 to 2022. Carrot, spinach, turnip, potato, garlic, onion, mustard and cabbage were sampled in winter (February to March) while tomato, zucchini, bitter gourd, and lady finger were sampled in summer (May to June). Moreover, three major grain crops including rice, wheat and corn were sampled during the same year. All the food crops and vegetables were sampled from same fields selected for soil sampling. One kilogram of each grain crop and vegetables was sampled, 3 samples of all food crops per site were collected. Each sample was collected in plastic bag and transported to the lab. Both winter and summer season's crops were collected and analyzed for Cd and Pb concentration.

## Samples preparation for AAS

All the samples of multiple food stuff were washed with tap water followed by distilled water. These samples were air dried and then placed into an oven at 60℃ until complete dryness. The oven dried samples were then ground into fine powdered form. These fine powdered samples (1g) were digested with the help of a mixture of $HNO_3$ (20 mL) and $HClO_4$ (4 mL) in a ratio of 5:1. Digestion mixture was then placed on hot plate for 45 minutes until the transparent and clean solution was obtained (Alam *et al.*, 2018; Kasozi *et al.*, 2018). The volume in the digestion flasks was made up to 100 mL by distilled water after filtration with Whatman No. 42 filter paper (Mansour and Sidky, 2002). Sewage and canal water samples were filtered while soil samples were treated with Ammonium bicarbonate-DTPA (AB-DTPA) to obtain extract for metal analysis (Soltanpour, 1985; Gürbüz, 2025). Both Cd and Pb were determined in the samples using an atomic absorption spectrometer (Analytik Jena novAA 800 F). Precision and accuracy including some other parameters of AAS for each analyzed element are given in Table 1.

## Human health risk assessment

Health risk assessment of metal contaminated crops was calculated using different models developed by USEPA. The models are given as below.

## Daily intake of metals (DIM)

Daily intake of vegetables by adult and children was calculated according to the study conducted by Jan *et al*. (2010). DIM was calculated by the following equation (Chary *et al.*, 2008).

$$DIM = \frac{C\ (metal) \times C\ (factor) \times D\ (food\ intake)}{B\ (Average\ weight)}$$

Where, C (metal), C (factor), D (food) intake and B (average weight) represent the heavy metal concentrations in plants (mg $kg^{-1}$), conversion factor (0.085), daily intake of vegetables and average body weight, respectively. Daily intake values of food crops and average body weight of adults and children were calculated (Jan *et al.*, 2010). Daily intake of food crops was 0.250 $kg^{-1}$ $person^{-1}$ $day^{-1}$ for adult while 0.165 for children was used in this study. Average body weight of an adult and a child were used as 73 kg and 32.7 kg, respectively (Newerli-Guz, 2017).

## Health risk index (HRI)

The health risk indices for Pb and Cd by consumption of contaminated food were calculated by following equation developed by Jan *et al*. (2010).

$$\text{HRI} = \frac{DIM}{Rfd}$$

HRI should be < 1, the daily intake of metals (DIM) and reference oral dose (Rfd) value for Pb and Cd were 0.004 and 0.001 mg $kg^{-1}$ body weight $day^{-1}$, respectively (Council, 2014; Tang *et al.*, 2024).

## Statistical analyses

All the collected data was subjected to one-way ANOVA ($p< 0.05$) and the Tukey's HSD test was performed using SPSS 20.0 to find out the significant difference in metal concentrations of different food crops.

## Quality control

To assure the quality of analytical procedure, every sample was analyzed thrice by using certified standard materials. The standards were tested after every 10 samples to verify the precision and accuracy of the instrument.

## Results and Discussion

## PTEs in irrigation water

Highest concentration of Cd was observed at site 2 (0.06 mg $L^{-1}$) while the lowest concentration (0.012 mg $L^{-1}$) was observed at site 1. The average concentrations of Cd were 0.01 mg $L^{-1}$, 0.06 mg $L^{-1}$ and 0.01 mg $L^{-1}$ at site 1, 2 and 3, respectively. The observed Cd concentrations were recorded higher than recommended values of WHO (0.01

mg $^{L-1}$) at site 2. The average concentrations of Pb were 0.04 mg $L^{-1}$, 0.1 mg $L^{-1}$ and 0.04 mg $L^{-1}$ at site 1, 2 and 3, respectively. Highest concentration of Pb was 0.12 mg $L^{-1}$ at site 2 while lowest Pb concentration was 0.04 mg $L^{-1}$ at site 3. These results are shown in Figure 2. The concentration of Pb stabilized below the critical limits at all sites. The concentrations of both Cd and Pb at Site 2 were prominently higher ($p < 0.05$) from both site 1 and site 3 as expected because the site 2 was irrigated with raw city effluent. In the same vein, there was no significant difference ($p > 0.05$) between site 1 and site 3 for both Cd and Pb concentrations as both sites were irrigated with canal water. The order of metal concentration for irrigation water of all sites is found to be site 2 > site 3 > site 1.

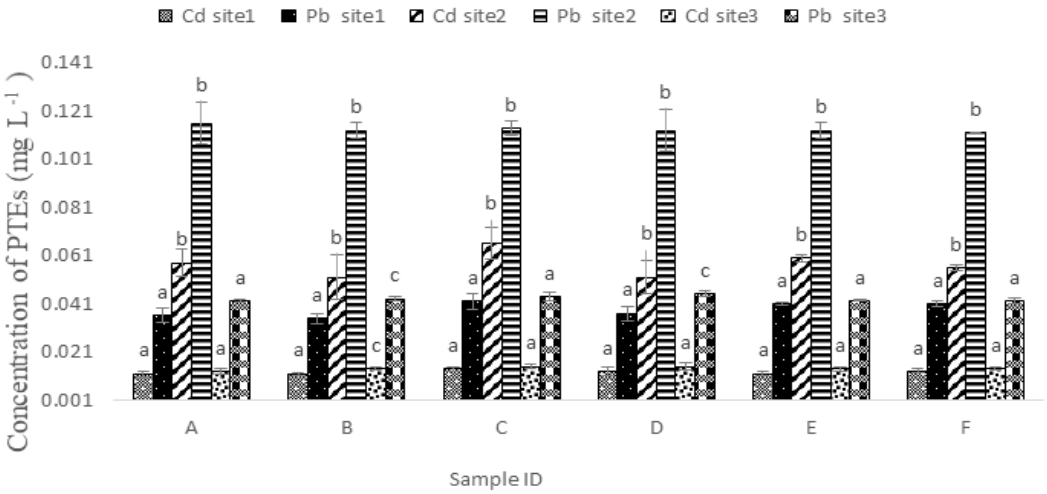



**Figure 2: Concentration of PTEs in irrigation water at all sites. Data are presented as Mean ± SEM (n=6). Lowercase letters (a, b, c,) on the bars indicate significant differences between groups ($p < 0.05$) based on One-Way ANOVA followed by Tukey's HSD post-hoc test; bars sharing the same letter are not significantly different**

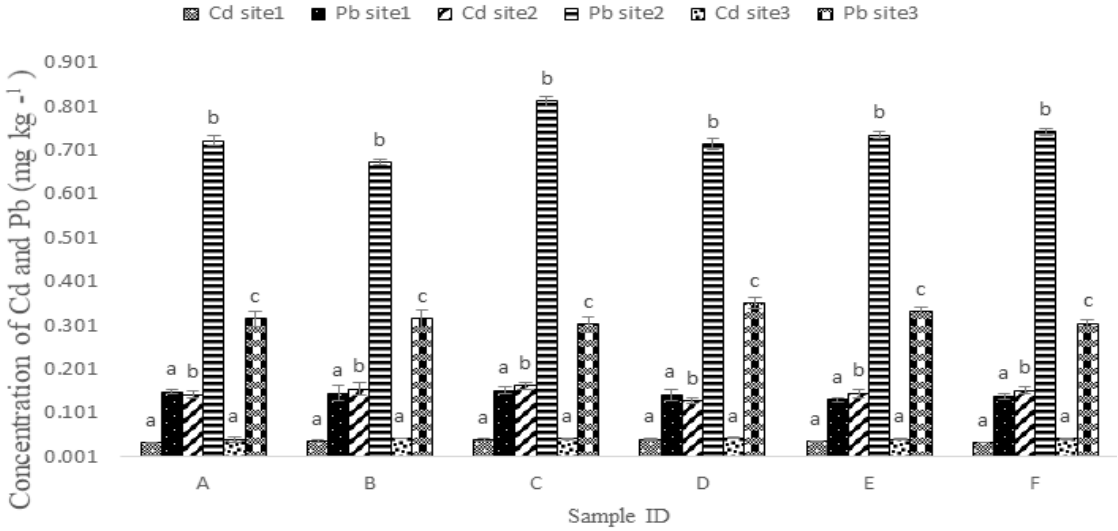



**Figure 3: Concentration of PTEs in soil at all sites. Data are presented as Mean ± SEM (n=6). Lowercase letters (a, b, c,) on the bars indicate significant differences between groups ($p < 0.05$) based on One-Way ANOVA followed by Tukey's HSD post-hoc test; bars sharing the same letter are not significantly different**

Farmers need excessive amounts of water for crop production in developing countries due to the lack of modern irrigation techniques. The presence of an increased amount of some nutrients also attracts farmers to use wastewater due to scarce water conditions (Murtaza *et al.*, 2015; Rehman *et al.*, 2015). A major silent threat for PTEs in wastewater used on agricultural lands is the production of highly attractive crops at massive levels (Chukwuemeka and Hephzibah, 2018; Sonone *et al.*, 2020; Kumari and Mishra, 2021).

According to Hamid *et al.* (2016) the level of Pb in irrigation water of their study was 4.8 mg $L^{-1}$ which exceeded from the National Environmental Quality Standards (NEQS) level 0.5 mg $L^{-1}$. Their result is much higher that our finding for wastewater concentration of Pb (0.12 mg $L^{-1}$) at Site 2 but lower than the WHO standards (5 mg $L^{-1}$) (Hamid *et al.*, 2016). The elevated level of Pb may cause damage to plant cells and also deteriorate the quality of irrigated soil and eventually inducing neurotoxicity, oxidative stress and hematological disorders in animals and humans (Duzgoren-Aydin, 2007; Sarker *et al.*, 2015). Similarly the Cd concentration in a study was observed 4 mg $L^{-1}$ is consistent with results of other studies conducted in Pakistan (Mahmood and Malik, 2014). Our findings for Cd concentration of wastewater in Chiniot (0.65 mg $kg^{-1}$) however, was different from those of Mahmood and Malik (2014). The concentrations of both Cd and Pb were higher in almost all the samples of Rohi drain, Kasur(Hamid *et al.*, 2016).

Wastewater irrigation not only raises the level of soil organic carbon, but also leads to a high density of carboxyl and phenolic functional groups, causing a large number of binding sites for $Pb^{2+}$ and $Cd^{2+}$. As a result, stable organometallic complexes are formed that limit metal mobility and promote surface soil accumulation (Munir *et al.*, 2026). It is obvious from the above discussion that irrigation water in Chiniot is less contaminated and relatively safe than some other parts of the country however, it is still not recommended for irrigation purposes.

## PTEs in soil

Maximum concentration of Cd in soil observed at site 2 was 0.16 mg $kg^{-1}$ while lowest concentration 0.03 mg $kg^{-1}$ was at site 1. The average concentrations of Cd in soil were 0.04 mg $kg^{-1}$, 0.15 mg $kg^{-1}$ and 0.04 mg $kg^{-1}$ on site 1, 2 and 3, respectively. The average concentrations of Pb in soil found 0.15 mg $kg^{-1}$, 0.74 mg $kg^{-1}$ and 0.32 mg $kg^{-1}$ at site 1, 2 and 3, respectively. Highest concentration of Pb was 0.83 mg $kg^{-1}$ at site 2, while lowest (0.14 mg $kg^{-1}$) at site 3. The results have been presented in Figure 3. The difference in concentration of both Cd and Pb for site 2 was significantly higher ($p< 0.05$) shown in Figure 3 with different superscripts from both sites 1 and 3 because the site 2 was irrigated with raw city effluent while site 3 was historically irrigated with wastewater but presently irrigated with clean water. Likewise, there was significantly no difference ($p > 0.05$) between site 2 and site 3 for both Cd and Pb concentrations and represented by same superscripts in Figure 3.

A study conducted in Portugal showed higher values of soil Cd and Pb than the permissible limits of WHO (Ávila *et al.*, 2017). Contrary to that our outcomes depicted different results for site 1 while similar for site 2 and 3. Correspondingly, in Jhang the values of Cd for soil were exceeding the permissible limits set by European Union (Tariq *et al.*, 2021). Fonge *et al*. (2021) stated that the Cd soil content were greater than the WHO limits in their findings (Fonge *et al.*, 2021). Sustained water utilization accentuates the cation exchange capacity of the soil by adding suspended solids and organic particles (Munir *et al.*, 2026). This enhances the soil's ability to adsorb various metal cations, which is the root cause for the high bioaccumulation index (BAI) in plant tissues such as spinach and cabbage. Mehmood and Malik(2014) reported that Muhammad *et al*. (2011) found a very high concentration of Cd 5.6 mg $kg^{-1}$ (Muhammad *et al.*, 2011) that was far higher than the current study.

The soil at Site 2 acts as a reservoir for Cd and Pb, where long-term wastewater application has exceeded the natural buffering capacity of the soil. Importantly, Site 3 (historically irrigated with wastewater) maintained elevated Pb levels that manifests sustained functionality in the soil matrix even after the primary source of contamination input has been removed. This spatial variation validates that the "hotspot" of contamination in Chiniot is primarily related to local irrigation practices instead of consistent atmospheric deposition patterns. However, the preceding analysis reflects that the current soil condition of Chiniot is better compared to the other areas of Pakistan.

## PTEs in plants

The concentration of Cd was recorded highest in crops at site 2 for spinach (0.45 mg $kg^{-1}$) while the lowest concentration (0.036 mg $kg^{-1}$) was found in zucchini at site 1. The average Cd concentrations in crops was found to be 0.09, 0.29 and 0.19 mg $kg^{-1}$ at site 1, 2 and 3, respectively. These results are shown in Figure 5. The observed Cd concentrations in crops were lower than the WHO

recommended value (0.2 mg $kg^{-1}$) at Site 1 but was much higher at Site 2 and 3. The average concentrations of Pb in crops were 0.26, 0.7 and 0.4 mg $kg^{-1}$ at site 1, 2 and 3, respectively. Highest concentration of Pb observed was 1.2 mg $kg^{-1}$ in spinach of site 2 while lowest Pb concentration was 0.11 mg $kg^{-1}$ in corn at site 1. The results are shown in Figure 5. The average concentration of Pb was lower at site 1 than the WHO permissible limits (0.3mg $kg^{-1}$) but higher at site 2 and 3. The difference in concentration of both Cd and Pb for crops of site 2 was significantly higher ($p< 0.05$) than the levels found here at both sites 1 and 3. Different letters in superscripts demonstrated this difference in both Figures 4. And 5. Site 1 was canal water- irrigated while site 3 was

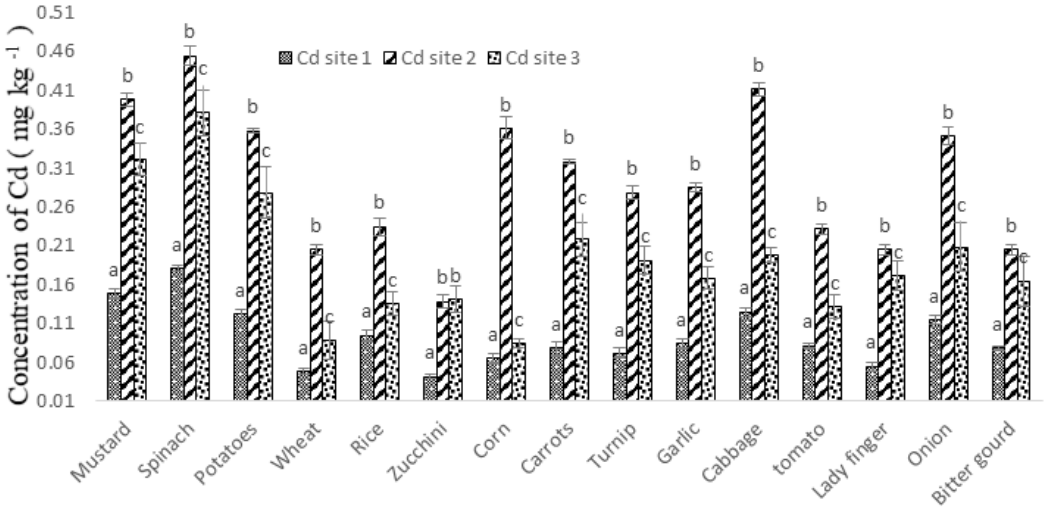



**Figure 4: Cd concentration in food crops at different sites of Chiniot. Data are presented as Mean ± SEM (n=15). Lowercase letters (a, b, c,) on the bars indicate significant differences between groups ($p < 0.05$) based on One-Way ANOVA followed by Tukey's HSD post-hoc test; bars sharing the same letter are not significantly different**

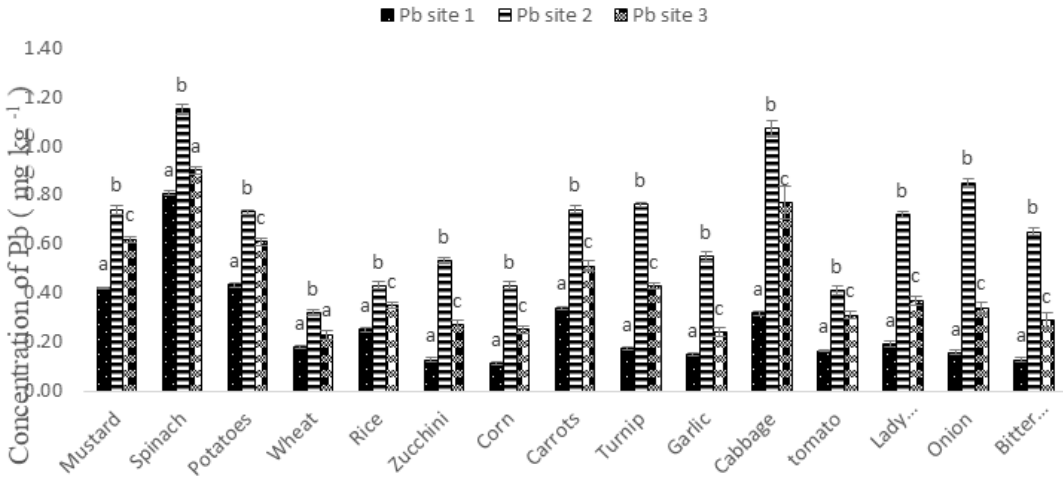



**Figure 5: Pb concentration in crops at different sites of Chiniot. Data are presented as Mean ± SEM (n=15). Lowercase letters (a, b, c,) on the bars indicate significant differences between groups ($p < 0.05$) based on One-Way ANOVA followed by Tukey's HSD post-hoc test; bars sharing the same letter are not significantly different**

**Table 2: Daily intake of Cd in adults and children due to the consumption of the edible portion of the crop at all three sites of Chiniot**

| Crop | Daily intake of metal (mg $kg^{-1}day^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Site 1 | | Site 2 | | Site 3 | |
| | Adult | Child | Adult | Child | Adult | Child |
| **Mustard** | 4.2E-05 | 6.1E-05 | 0.00011 | 0.00017 | 9.2E-05 | 0.00014 |
| **Spinach** | 5.1E-05 | 7.6E-05 | 0.00013 | 0.00019 | 0.00011 | 0.00016 |
| **Potatoes** | 3.4E-05 | 5.0E-05 | 0.00010 | 0.00015 | 8.0E-05 | 0.00012 |
| **Wheat** | 1.3E-05 | 1.9E-05 | 0.00006 | 0.00009 | 2.4E-05 | 3.6E-05 |
| **Rice** | 2.6E-05 | 3.9E-05 | 0.00007 | 0.00010 | 3.8E-05 | 5.6E-05 |
| **Zucchini** | 1.1E-05 | 1.6E-05 | 0.00004 | 0.00006 | 4.0E-05 | 5.9E-05 |
| **Corn** | 1.7E-05 | 2.6E-05 | 0.00010 | 0.00015 | 2.3E-05 | 3.4E-05 |
| **Carrots** | 2.1E-05 | 3.1E-05 | 0.00009 | 0.00013 | 6.2E-05 | 9.1E-05 |
| **Turnip** | 1.9E-05 | 2.9E-05 | 0.00008 | 0.00012 | 5.4E-05 | 8.0E-05 |
| **Garlic** | 2.3E-05 | 3.4E-05 | 0.00008 | 0.00012 | 4.8E-05 | 7.0E-05 |
| **Cabbage** | 3.5E-05 | 5.1E-05 | 0.00012 | 0.00017 | 5.6E-05 | 8.3E-05 |
| **Tomato** | 2.2E-05 | 3.3E-05 | 0.00007 | 0.00010 | 3.7E-05 | 5.4E-05 |
| **Lady finger** | 1.5E-05 | 2.1E-05 | 0.00006 | 0.00009 | 4.9E-05 | 7.1E-05 |
| **Onion** | 3.2E-05 | 4.7E-05 | 0.00010 | 0.00015 | 5.9E-05 | 8.7E-05 |
| **Bitter gourd** | 2.1E-05 | 3.1E-05 | 0.00006 | 0.00009 | 4.7E-05 | 6.9E-05 |

**Table 3: Daily intake of Pb in adults and children due to the consumption of the edible portion of the crop at all three sites of Chiniot**

| Crop | Daily intake of metal (mg $kg^{-1}day^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Site 1 | | Site 2 | | Site 3 | |
| | Adult | Child | Adult | Child | Adult | Child |
| **Mustard** | 0.00012 | 0.00018 | 0.00022 | 0.00032 | 0.00018 | 0.00027 |
| **Spinach** | 0.00023 | 0.00035 | 0.00034 | 0.00049 | 0.00026 | 0.00039 |
| **Potatoes** | 0.00013 | 0.00019 | 0.00021 | 0.00031 | 0.00018 | 0.00026 |
| **Wheat** | 5.2E-05 | 7.7E-05 | 9.5E-05 | 0.00014 | 6.8E-05 | 0.00010 |
| **Rice** | 7.3E-05 | 0.00011 | 0.00013 | 0.00018 | 0.00010 | 0.00015 |
| **Zucchini** | 3.7E-05 | 5.4E-05 | 0.00015 | 0.00023 | 8.0E-05 | 0.00012 |
| **Corn** | 3.3E-05 | 4.9E-05 | 0.00013 | 0.00019 | 7.5E-05 | 0.00011 |
| **Carrots** | 9.9E-05 | 0.00015 | 0.00022 | 0.00032 | 0.00015 | 0.00022 |
| **Turnip** | 5.0E-05 | 7.4E-05 | 0.00022 | 0.00033 | 0.00013 | 0.00019 |
| **Garlic** | 4.4E-05 | 6.4E-05 | 0.00016 | 0.00024 | 7.2E-05 | 0.00011 |
| **Cabbage** | 9.2E-05 | 1.4E-04 | 0.00031 | 0.00046 | 0.00023 | 0.00033 |
| **Tomato** | 4.8E-05 | 7.0E-05 | 0.00012 | 0.00018 | 9.0E-05 | 0.00013 |
| **Lady finger** | 5.5E-05 | 8.1E-05 | 0.00021 | 0.00031 | 0.00011 | 0.00016 |
| **Onion** | 4.6E-05 | 6.7E-05 | 0.00025 | 0.00037 | 9.9E-05 | 0.00015 |
| **Bitter gourd** | 3.7E-05 | 5.4E-05 | 0.00019 | 0.00028 | 8.6E-05 | 0.00013 |

sewage-irrigated in past but currently irrigated with clean water.

The migration of metals from the soil to the sampled crops revealed distinct variations in bioaccumulation patterns. In

leafy vegetables, especially spinach and cabbage, the highest concentrations of Cd and Pb were documented, with spinach at Site 2 showing a 164.7% increase in Cd. This results from the high transpiration rate and large surface area of leafy tissues, which facilitate the upward movement of metals through the xylem. Furthermore, the presence of other metals in the soil, variation in pH, and the intensity of pollution also condition this process, resulting in apparent contrasts in bioaccumulation at different locations(Rahman *et al.*, 2024). Among agricultural food crops, vegetables have a major role in metal uptake, being hyper-accumulative in nature and resulting in greater injury to human health than any other crop (Chukwuemeka and Hephzibah, 2018). Toxic metal intake proportion through food is 65%, water 20% and from air is 15% (Clayton *et al.*, 2002). According to a study conducted in Swabi, Pakistan, several vegetables including cabbage, spinach, onion, garlic contain exceeding concentration of both Cd and Pb was observed higher than the WHO guidelines (Ali *et al.*, 2021). The findings of our study were in consonance with Ali *et al.* (2021) as major food crops grown with the wastewater of Chiniot also cross the permissible limits of WHO. Moreover, these findings are also similar to the current study in case of cabbage, spinach and underground vegetables. Tariq *et al*. (2021) reported a very huge concentration of Cd (2.70 mg $kg^{-1}$ to 9.80 mg $kg^{-1}$) in grain crops grown in district Jhang in contrast to our observations which are quite less in district Chiniot. Satpathy *et al*. (2014) depicted lower concentration of Cd in food crops than above descriptive findings (Satpathy *et al.*, 2014). In another study the Pb found 1.36 mg $kg^{-1}$ in Cameroon (Fonge *et al.*, 2021), was higher than the WHO permissible limits. In other regions of Pakistan the Pb level in vegetables ranges from 0.03 mg $kg^{-1}$ to 44 mg $kg^{-1}$ (Khan *et al.*, 2010). Similar type of results were reported by Farooq *at al*., in edible and leafy portion 27.5 mg $kg^{-1}$ and 15.6 mg $kg^{-1}$ of vegetables respectively (Farooq *et al.*, 2008). This obtained data imply that the vegetables and food crops grown in Chiniot are fairly less contaminated than some other parts of the country indicating comparatively reduced anthropogenic activities in the environment.

## Health risk assessment of PTEs in humans

### Daily intake of metals for children

The DIM (child) value of Cd was recorded highest in spinach (1.93E-04) at site 2 while lowest (1.57E-05) in zucchini at site 1. The average DIM (child) values of Cd in crops were 3.76E-05, 1.25E-04 and 8.03E-05 on site 1, 2 and 3; respectively. The noted Cd DIM (child) values in crops were found to be lower at site 1 but remained higher at site 2 and 3 as these sites were irrigated with sewage water. The average DIM (child) values of Pb in crops were detected 1.28E-04, 2.89E-04 and 1.87E-04 at site 1, 2 and 3, respectively. Highest DIM (child) value of Pb was documented 4.95E-04 for spinach at site 2 while lowest Pb DIM (child) value was found to be 4.86E-05 for corn at site 1. The difference in DIM (child) values of both Cd and Pb for crops of site 1 was measured significantly lower ($p$<0.05) for both site 2 and 3 as expected because the site 2 was irrigated with municipal wastewater while site 3 was historically irrigated with wastewater in past. Analogously, there was no significant difference ($p$ > 0.05) between crops of site 2 and site 3 for both Cd and Pb DIM (child) values. The order of DIM (child) in crops of all sites is given as, site 2 > site 3 > site 1. These results can be seen in Tables 2 and 3.

### Daily intake of metals for adults

The DIM (adult) value of Cd was found to be highest for spinach (1.31E-04) at site 2 while lowest (1.07E-05) for zucchini at site 1. The average DIM (adult) values of Cd in crops were observed 2.56E-05, 8.47E-05 and 5.45E-05 at site 1, 2 and 3, respectively. The observed Cd DIM (adult) values in crops were found to be lower at site 1 but higher at site 2 and 3. The average DIM (adult) values of Pb in crops were observed 7.66E-05, 1.96E-04 and 1.27E-04 at site 1, 2 and 3, respectively. Highest DIM (adult) value of Pb was found to be 3.36E-04 for spinach at site 2 but lowest for corn 3.3E-05 at site 1. These results can be observed in Table 2 and 3. The difference in DIM (adult) values of both Cd and Pb for crops of site 1 was considerably lower ($p$ < 0.05) from both site 2 and 3 as expected because the site 2 was irrigated with wastewater while site 3 was historically irrigated with wastewater but currently irrigated with clean water. Similarly, there was no significant difference ($p$ > 0.05) observed between crops of site 2 and site 3 for both Cd and Pb DIM (adult) values.

### Health risk index for children

The results regarding health risk assessment for both Cd and Pb can be visualized in Tables 4 and 5. The highest HRI (child) value for Cd was recorded in spinach (1.931E-01) at site 2 while lowest (1.5E-02) in zucchini at site 1. The average HRI (child) values of Cd in crops were 3.76E-02, 1.24E-01 and 8.03E-02 at site 1, 2 and 3, respectively. The observed Cd HRI (child) values in crops were recorded lower at site 1 compared to site 2 and 3. The average HRI (child) values of Pb in crops were observed 2.82E-02, 7.23E-02 and 4.68E-02 at site 1, 2 and 3, respectively. Highest HRI (child) value for Pb was 1.23E-01 in spinach at site 2 while lowest Pb HRI (child) value was found to be 1.21E-02 for corn at site 1. The difference in HRI (child) values of both Cd and Pb for crops of site 1 was observed

statistically significant ($p < 0.05$) at both site 2 and 3 as expected because the site 2 was irrigated with city wastewater while site 3 was historically irrigated with wastewater. Similarly, there was no significant difference ($p > 0.05$) between crops at site 2 and site 3 for both Cd and Pb HRI (child) values.

## Health risk index for adults

The HRI (adult) value of Cd was recorded highest in spinach (1.3E-01) at site 2 that was in spinach while lowest (1.06E-02) in zucchini at site 1. The average HRI (adult) values of Cd in crops remained 2.56E-02, 8.46E-02 and 5.45E-02 on site 1, 2 and 3, respectively. The observed Cd HRI (adult) values in crops were recorded lower at site 1 while it appeared higher at site 2 and 3. The average HRI (adult) values of Pb in crops were observed 1.91E-02, 4.91E-02 and 3.17E-02 at site 1, 2 and 3, respectively. Highest HRI (adult) value of Pb was 8.39E-02 in spinach of site 2 while lowest Pb HRI (adult) value was 8.24E-03 in corn at site 1. The difference in HRI (adult) values of both Cd and Pb for crops of site 1 was statistically significant ($p < 0.05$) from both site 2 and 3 as expected because the site 2 was irrigated with raw city effluent while site

**Table 4: Health risk index (HRI) for Cd due to the consumption of the edible portion of the crop at all sites of Chiniot**

| Crop | Site 1 | | Site 2 | | Site 3 | |
|---|---|---|---|---|---|---|
| | Adult | Child | Adult | Child | Adult | Child |
| **Mustard** | 0.042 | 0.061 | 0.114 | 0.169 | 0.092 | 0.136 |
| **Spinach** | 0.051 | 0.076 | 0.131 | 0.193 | 0.110 | 0.162 |
| **Potatoes** | 0.034 | 0.050 | 0.103 | 0.152 | 0.080 | 0.117 |
| **Wheat** | 0.013 | 0.019 | 0.058 | 0.086 | 0.024 | 0.036 |
| **Rice** | 0.026 | 0.039 | 0.067 | 0.099 | 0.038 | 0.056 |
| **Zucchini** | 0.011 | 0.016 | 0.039 | 0.057 | 0.040 | 0.059 |
| **Corn** | 0.017 | 0.026 | 0.104 | 0.153 | 0.023 | 0.034 |
| **Carrots** | 0.021 | 0.031 | 0.091 | 0.134 | 0.062 | 0.091 |
| **Turnip** | 0.019 | 0.029 | 0.080 | 0.117 | 0.054 | 0.080 |
| **Garlic** | 0.023 | 0.034 | 0.082 | 0.120 | 0.048 | 0.070 |
| **Cabbage** | 0.035 | 0.051 | 0.118 | 0.174 | 0.056 | 0.083 |
| **Tomato** | 0.022 | 0.033 | 0.066 | 0.097 | 0.037 | 0.054 |
| **Lady finger** | 0.015 | 0.021 | 0.058 | 0.086 | 0.049 | 0.071 |
| **Onion** | 0.032 | 0.047 | 0.101 | 0.149 | 0.059 | 0.087 |
| **Bitter gourd** | 0.021 | 0.031 | 0.058 | 0.086 | 0.047 | 0.069 |

**Table 5: Health risk index (HRI) for Pb due to the consumption of the edible portion of the crop at all sites of Chiniot**

| Crop | Site 1 | | Site 2 | | Site 3 | |
|---|---|---|---|---|---|---|
| | Adult | Child | Adult | Child | Adult | Child |
| **Mustard** | 0.03057 | 0.04503 | 0.05410 | 0.07970 | 0.04561 | 0.06719 |
| **Spinach** | 0.05870 | 0.08649 | 0.08393 | 0.12367 | 0.06598 | 0.09722 |
| **Potatoes** | 0.03154 | 0.04646 | 0.05313 | 0.07827 | 0.04463 | 0.06576 |
| **Wheat** | 0.01310 | 0.01930 | 0.02377 | 0.03503 | 0.01698 | 0.02502 |
| **Rice** | 0.01819 | 0.02681 | 0.03129 | 0.04611 | 0.02547 | 0.03753 |
| **Zucchini** | 0.00922 | 0.01358 | 0.03857 | 0.05683 | 0.01989 | 0.02931 |
| **Corn** | 0.00825 | 0.01215 | 0.03154 | 0.04646 | 0.01868 | 0.02752 |
| **Carrots** | 0.02474 | 0.03646 | 0.05410 | 0.07970 | 0.03736 | 0.05504 |
| **Turnip** | 0.01261 | 0.01859 | 0.05579 | 0.08221 | 0.03154 | 0.04646 |
| **Garlic** | 0.01092 | 0.01608 | 0.04003 | 0.05897 | 0.01795 | 0.02645 |
| **Cabbage** | 0.02305 | 0.03395 | 0.07787 | 0.11473 | 0.05628 | 0.08292 |
| **Tomato** | 0.01189 | 0.01751 | 0.03032 | 0.04468 | 0.02256 | 0.03324 |
| **Lady finger** | 0.01383 | 0.02037 | 0.05288 | 0.07792 | 0.02741 | 0.04039 |
| **Onion** | 0.01140 | 0.01680 | 0.06210 | 0.09150 | 0.02474 | 0.03646 |
| **Bitter gourd** | 0.00922 | 0.01358 | 0.04730 | 0.06970 | 0.02159 | 0.03181 |

3 was historically irrigated with wastewater. These results can be seen in Tables 4 and 5.

Extensive research has been conducted on health risks associated with the consumption of metal-contaminated foods from modern agriculture. Agricultural crops provide the basic nutritional requirements to humans including a wide variety of vitamins, macronutrients and micronutrients (Zhuang *et al.*, 2009; Sonone *et al.*, 2020) A significant degree of health risk is associated with the potentially toxic elements in crops grown in metal-contaminated soils (Hejna *et al.*, 2018). The greatest transfer of PTEs such as As, Ni, Zn and Cu is, in part, controlled by the soil plant barrier, while for Cd this barrier does not work in a proper fashion. The lack of this barrier for Cd and Pb in plants make them the most opportunistic toxic metals (Dudka and Miller, 1999). Human exposure to these toxic metals comes from multiple sources, but dietary intake is the greatest source, compared to all others (Okereafor *et al.*, 2020).

Current study shows that many of the vegetables grown with wastewater irrigation have higher concentration of both Cd and Pb, implying a constant health risk for the local people that consume these crops for long time. Once metals have entered the human body, they are transported through the blood to different tissues and organs. As metals are persistent and non-biodegradable in nature, they deposit in the fatty tissues of different organs and remain as a constant threat for adverse influence on essential body functions by disrupting the metabolic processes (Hu, 2002). The exposure dose, time and chemical form of a metal are directly related to the severity of the pathological effects on the individual. Toxic metals affect the human health by promoting oxidative stress (Navas-Acien *et al.*, 2005; Prozialeck *et al.*, 2006), enzyme inactivation and weakening of antioxidant defense system (Balali-Mood *et al.*, 2021).

The value of health risk index HRI > 1 of any food crop indicates that the people consuming such crops are at greater risk of their health being impaired (Ali *et al.*, 2021). According to Ali *et al.* (2021) the health risk index for both children and adults greater than 1.0 indicate higher risk to their health by consuming the food crops grown in Swabi, Pakistan. This study shows that HRI > 0.2 only for spinach consumption by children, suggesting that consumption of food crops grown in district Chiniot carries limited health risk.

By contrast, a study conducted in Portugal reported that the local inhabitants of some villages consuming sewage irrigated crops were at much greater risk, with the reported health risk indices for children and adults being 2.72 and 2.22, respectively (Ávila *et al.*, 2017). Another study conducted in Rohi drain, Kasur revealed health risk indices that were HRI > 1 for Pb from consumption of Arvi plant (Hamid *et al.*, 2016). Tariq *et al* (2021) likewise reported results that are similar to those of the current study.

This study does not establish current consumption levels as an immediate health risk (risk < 1), with many crops being contaminated above international safety limits. It points to a greater sensitivity in children, where the risk level was approximately 28% higher than in adults, which is nevertheless a public health concern. Although current exposure levels may not induce an imminent toxicity, lifelong bioaccumulation of Pb and Cd through the Chiniot food chain may precipitate chronic nephrotoxicity or neurodevelopmental delays. This suggests a need for environmental monitoring to prevent these metals from building up in the population's bodies over time.

## Conclusion

The current analysis delivers a comprehensive spatial and demographic assessment of the health risks associated with PTEs in the food chain of Chiniot district. The study furnishes the evidence that current HRI for Cd and Pb remains below the safety threshold of 1.0. The excessive accumulation of these metals to spinach, cabbage, and various subterranean vegetables creates a gateway for contaminants into the local food system. A crucial aspect of the current investigation is the spatial correlation of risk; notably, the vulnerability of Site 2 indicates that local wastewater irrigation can create contamination hotspots even in districts with lower anthropogenic activity than industrial hubs like Faisalabad or Kasur. In addition, the study positions children as a highly vulnerable population who are nevertheless inherently prone to risk and face a disproportionately higher risk of long-term toxic effects than adults. Public health authorities should strictly enforce the effluent treatment standards for all industrial and municipal discharges used for peri-urban agriculture in Chiniot. It is recommended that the Health Department urgently initiate periodic blood metal screening for children at site 2 to reduce the risks of chronic lifetime exposure. Agricultural extension services should encourage local farmers to shift high-accumulation leafy vegetables (such as spinach) to less sensitive crops in high-risk areas. The intrusion of toxic elements into the food chain can be minimized and human health should be prioritized.

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## Competing Interests

The authors have no competing interests.

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