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Assessment of Heavy Metal Contamination in Soil and Water from Agricultural Areas of Gujranwala, Pakistan

^aSundus Akhtar*, ^aAyesha Shafqat, ^aNasira*a School of Botany, Minhaj University Lahore, Pakistan.*

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ABSTRACT

This study assessed the contamination levels of seven heavy metals—copper (Cu), cadmium (Cd), chromium (Cr), zinc (Zn), nickel (Ni), lead (Pb), and cobalt (Co)—in agricultural soil and irrigation water from District Gujranwala, Pakistan. Soil and water samples were collected from fields cultivating *Pisum sativum*, *Triticum aestivum*, and *Allium sativum* in the Nowshera Virkan and Phama Sarai areas. Metal concentrations were determined using atomic absorption spectrophotometry (AAS). Results revealed that all tested metals in soil exceeded permissible limits set by the World Health Organization (WHO, 2013) and the Food and Agriculture Organization (FAO, 2012), with ranges of 43–75 (Cu), 15–41 (Cd), 200–315 (Cr), 51–77 (Zn), 37–54 (Ni), 375–450 (Pb), and 38–45 mg kg⁻¹ (Co). Irrigation water was similarly contaminated, exhibiting elevated concentrations of these metals. The widespread contamination is attributed primarily to uncontrolled discharge of industrial and tannery effluents, which are used for crop irrigation. This practice poses significant risks to soil health, food safety, and public health through bioaccumulation in the food chain. The findings underscore the urgent need for stringent regulation of industrial waste, adoption of remediation strategies, and shifts toward safer irrigation sources to ensure sustainable agriculture and environmental safety in the region.

*Corresponding Author: Sundus Akhtar**Email: dr.sundas@mul.edu.pk*

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INTRODUCTION

Heavy metals represent a significant and persistent class of environmental pollutants due to their toxicity, non-biodegradability, and potential for bioaccumulation in living organisms (Ali, Khan, & Ilahi, 2019). Defined by their high atomic weight and density, metals such as lead (Pb), cadmium (Cd), chromium (Cr), and mercury (Hg) are of particular concern due to their detrimental effects on human health, even at trace concentrations. In contrast, elements like zinc (Zn), copper (Cu), and iron (Fe) are essential micronutrients for biological processes but become toxic when their concentrations exceed critical thresholds (Tchounwou, Yedjou, Patlolla, & Sutton, 2012). The primary pathways for human

exposure include the consumption of contaminated food and water, making the transfer of these metals from polluted environments into agricultural systems a critical public health issue.

Anthropogenic activities are the predominant drivers of heavy metal contamination in contemporary ecosystems. Rapid industrialization, urbanization, mining, improper waste disposal, and the extensive use of fertilizers and pesticides in agriculture have led to the widespread deposition of these elements into soil and water bodies (Wuana & Okieimen, 2011). Industrial effluent, often released untreated or partially treated, is a major point source, carrying a cocktail of metallic pollutants into rivers and irrigation canals. This

contaminated water is subsequently used for crop irrigation, introducing toxins directly into the food chain and leading to the gradual buildup of metals in agricultural soils, a process that compromises soil health and fertility over time (Khalid *et al.*, 2017).

In Pakistan, the challenge of heavy metal pollution is acute, exacerbated by the country's rapid industrial growth, insufficient environmental regulations, and limited wastewater treatment infrastructure. Major industrial hubs, including those in Punjab province, discharge substantial volumes of untreated waste containing high loads of toxic metals into natural waterways (Mahmood & Malik, 2014). Gujranwala, a prominent industrial city known for its ceramics, textiles, and notably, leather tanning industries, faces severe environmental stress. Tanneries are especially notorious for releasing effluents rich in chromium, lead, and cadmium, which permeate local soil and groundwater systems (Ullah, Mohammad, & Khan, 2013). The subsequent use of this polluted water for irrigating surrounding agricultural lands poses a direct threat to food safety and the health of local communities. Therefore, this study aims to assess the concentration

levels of key heavy metals—copper (Cu), cadmium (Cd), chromium (Cr), zinc (Zn), nickel (Ni), lead (Pb), and cobalt (Co)—in soil and water samples collected from agricultural areas in District Gujranwala. By quantifying this contamination and comparing it with international safety standards, the research seeks to evaluate the potential ecological and health risks associated with current agricultural practices. The findings are intended to provide a scientific basis for urging stricter industrial effluent controls, promoting remediation strategies, and informing policy to safeguard environmental quality and public health in the region.

MATERIALS AND METHODS

Survey and collection of water and soil samples

For the collection of water and soil samples a survey was carried out in different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai). For that about four different water and soil samples from various fields i.e., *Pisum sativum*, *Triticum aestivum* and *Allium sativum* were collected from the tested areas and preserved in plastic bottles and plastic bags (Figure 1).

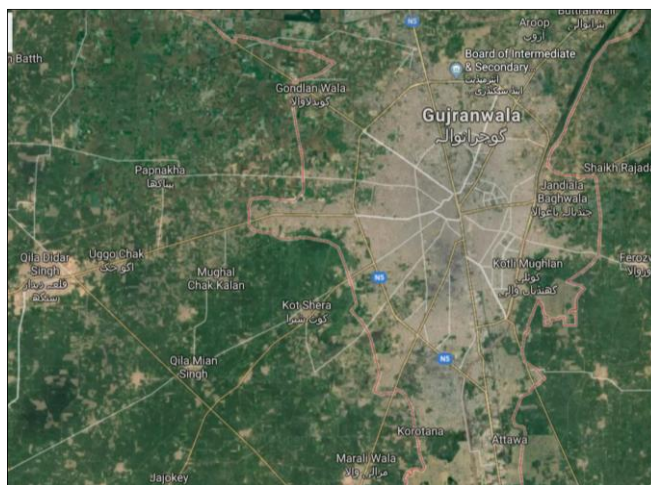


Figure 1. Selected areas of district Gujranwala, Pakistan.

<https://www.google.com/maps/place/Gujranwala,+Punjab,+Pakistan/@32.129165,74.0931733,22292m/data=!3m1!1e3!4m5!3m4!1s0x391f2983d520eb29:0x6fb33af85e7a368!8m2!3d32.1876919!4d74.1944529>

Estimation of heavy metal in soil samples

The collected soil samples from various fields *P. sativum*, *T. aestivum* and *A. sativum* were passed through a 100-mesh sieve. After oven-drying the soil samples at 70 °C until a constant weight was achieved, the samples weighing 50 mg were grounded to powder with mortar and pestle. All samples were passed through a 40-mesh

nylon plastic sieve after drying. Furthermore, the soil samples were digested in 10 mL of concentrated nitric acid (HNO₃). Digestion of the samples were continued until complete dissolution was achieved. After that, seven different metal ions (copper, cadmium, chromium, zinc, nickel, lead and cobalt) concentration were analyzed on Z-5000 Polarized Zeeman Atomic

Absorption Spectrophotometer (AAS).

Estimation of heavy metal in water samples

About 10 mL of collected water samples from the tube well of various selected fields of *P. sativum*, *T. aestivum* and *A. sativum* were digested in 10 mL of strong nitric acid (HNO₃). Digestion of the samples were continued until complete dissolution was achieved. Furthermore, seven different metal ions (copper, cadmium, chromium, zinc, nickel, lead and cobalt) concentration were analyzed on Z-5000 Polarized Zeeman Atomic Absorption Spectrophotometer (AAS).

Atomic absorption spectrophotometer

Atomic absorption spectroscopy (AAS) is a spectro-analytical practice for the quantitative purpose of chemical rudiments by means of the incorporation of ocular emission (light) by free atoms in the gaseous situation. This method is used in analytical chemistry designed for influential the meditation of a exacting component (the analyte) in a illustration to be analyzed. AAS can be worn to conclude over 70 diverse rudiments in solution, or straight in solid samples through electro thermal vaporization, and is worn in toxicology, biophysics and pharmacology research.

Statistical analysis

Statistic 8.1 was employed for statistical analysis. Moreover, the correlation was calculated by using Origin Pro.

RESULTS

Estimation of heavy metal in soil

Estimation of copper (Cu)

The quantification of copper (Cu) in soil collected from different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai) is illustrated in Figure 2. It was noticed that the concentration of copper in various selected fields i.e., *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 43 mg kg⁻¹, 54 mg kg⁻¹ and 75 mg kg⁻¹, likewise.

Estimation of cadmium (Cd)

The quantification of cadmium (Cd) in soil collected from different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai) is depicted in Figure 3. It was found that the concentration of cadmium in various selected fields i.e., *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 22 mg kg⁻¹, 15mg kg⁻¹ and 41 mg kg⁻¹, correspondingly.

Estimation of chromium (Cr)

The quantification of chromium (Cr) in soil collected from different areas of District Gujranwala (area:

Nowshera Virkan, Phama Sarai) is showed in Figure 4. It was observed that the concentration of chromium in various selected fields i.e., *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 240 mg kg⁻¹, 200mg kg⁻¹ and 315 mg kg⁻¹, correspondingly.

Estimation of zinc (Zn)

The quantification of zinc (Zn) in soil collected from different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai) is given in Figure 5. The results revealed that the concentration of zinc in various selected fields i.e *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 77 mg kg⁻¹, 65mg kg⁻¹, 55 mg kg⁻¹ and 51 mg kg⁻¹, correspondingly.

Estimation of nickel(Ni)

The quantification of nickel (Ni) in soil collected from different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai) is illustrated in Figure 6. The observation showed that the concentration of nickel in various selected fields i.e *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 44mg kg⁻¹, 37mg kg⁻¹ and 54 mg kg⁻¹, respectively.

Estimation of lead(Pb)

The quantification of lead (Pb) in soil collected from different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai) is depicted in Figure 7. The analysis showed that the concentration of lead in various selected fields i.e., *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 450mg kg⁻¹, 400mg kg⁻¹ and 375 mg kg⁻¹, correspondingly.

Estimation of Cobalt(Co)

The quantification of cobalt (Co) in soil collected from different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai) is showed in Figure 8. The analysis exhibited that the concentration of cobalt in various selected fields i.e., *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 38mg kg⁻¹, 49mg kg⁻¹ and 45 mg kg⁻¹, correspondingly.

Estimation of heavy metal in water

Estimation of copper (Cu)

The quantification of copper (Cu) in water collected from different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai) is illustrated in Figure 9. It was noticed that the concentration of copper in various selected fields i.e., *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 50 ppm, 78 ppm and 65ppm, correspondingly.

Estimation of cadmium (Cd)

The quantification of cadmium (Cd) in water collected

from different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai) is depicted in Figure 10. It was found that the concentration of cadmium in various selected fields i.e., *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 30ppm, 22ppm and 35ppm, correspondingly.

Estimation of chromium (Cr)

The quantification of chromium (Cr) in water collected from different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai) is showed in Figure 11. It was observed that the concentration of chromium in various selected fields i.e., *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 300 ppm, 250 ppm and 275 ppm, correspondingly.

Estimation of zinc (Zn)

The quantification of zinc (Zn) in water collected from different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai) is given in Figure 12. The results revealed that the concentration of zinc in various selected fields i.e., *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 40 ppm, 83 ppm and 100 ppm, correspondingly.

Estimation of Nickel(Ni)

The quantification of nickel (Ni) in water collected from different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai) is illustrated in Figure 13. The observation showed that the concentration of nickel in various selected fields i.e., *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 30 ppm, 42 ppm and 15 ppm, correspondingly.

Estimation of lead(Pb)

The quantification of lead (Pb) in water collected from different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai) is depicted in Figure 14. The analysis showed that the concentration of lead in various selected fields i.e., *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 40 ppm, 28 ppm and 42 ppm, correspondingly.

Estimation of cobalt(Co)

The quantification of cobalt (Co) in water collected from different areas of District Gujranwala (area: Nowshera Virkan, Phama Sarai) is showed in Figure 15. The analysis exhibited that the concentration of cobalt in various selected fields i.e., *Pisum sativum*, *Triticum aestivum* and *Allium sativum* was 22 ppm, 10 ppm and 15 ppm, respectively.

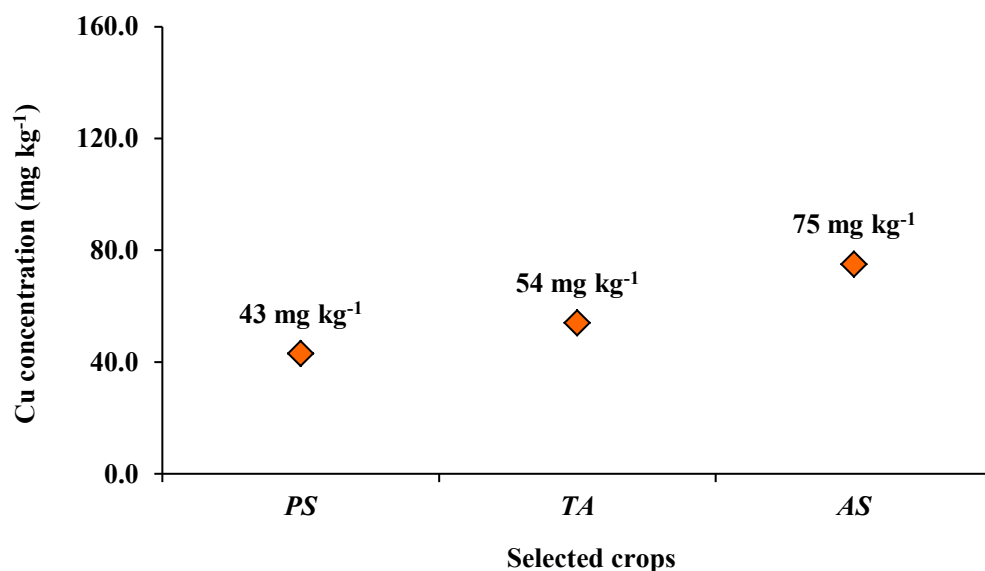


Figure 2. Concentration of copper (Cu) in various samples of soil collected from District Gujranwala. PS: *Pisum sativum* TA: *Triticum aestivum* AS: *Allium sativum*.

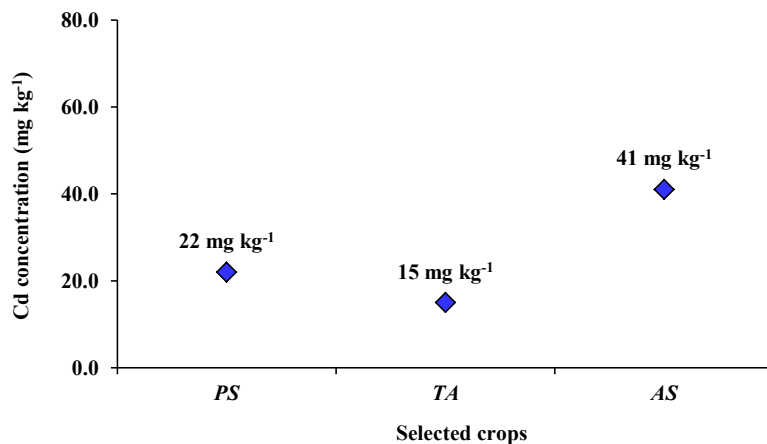


Figure 3. Concentration of cadmium (Cd) in various samples of soil collected from District Gujranwala. PS: *Pisum sativum* TA: *Triticum aestivum* AS: *Allium sativum*.

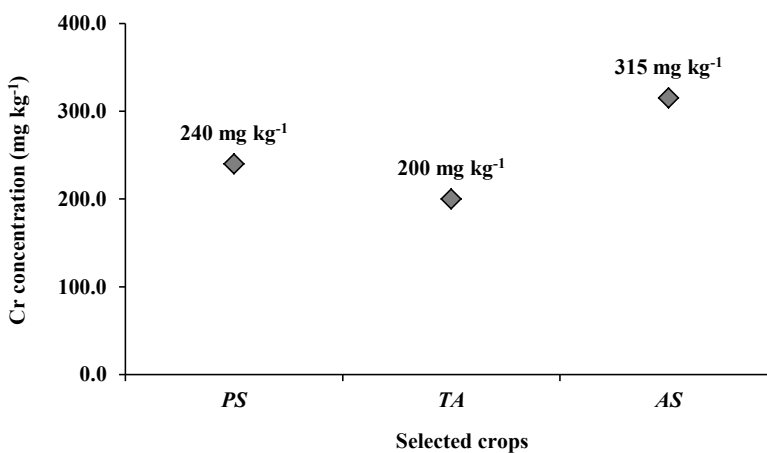


Figure 4. Concentration of chromium (Cr) in various samples of soil collected District Gujranwala. PS: *Pisum sativum* TA: *Triticum aestivum* AS: *Allium sativum*.

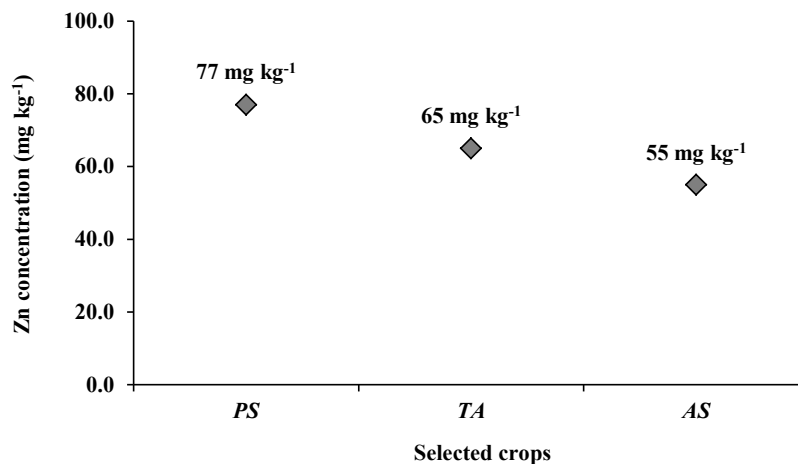


Figure 5. Concentration of zinc (Zn) in various samples of soil collected from District Gujranwala. PS: *Pisum sativum* TA: *Triticum aestivum* AS: *Allium sativum*.

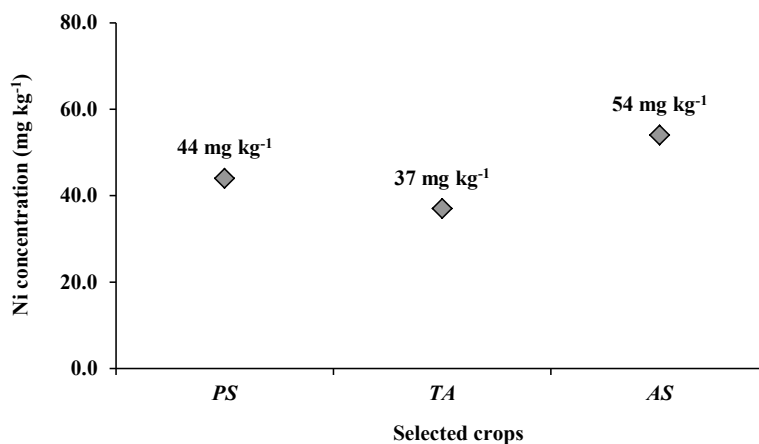


Figure 6. Concentration of nickel (Ni) in various samples of soil collected from District Gujranwala. *PS: Pisum sativum* *TA: Triticum aestivum* *AS: Allium sativum*.

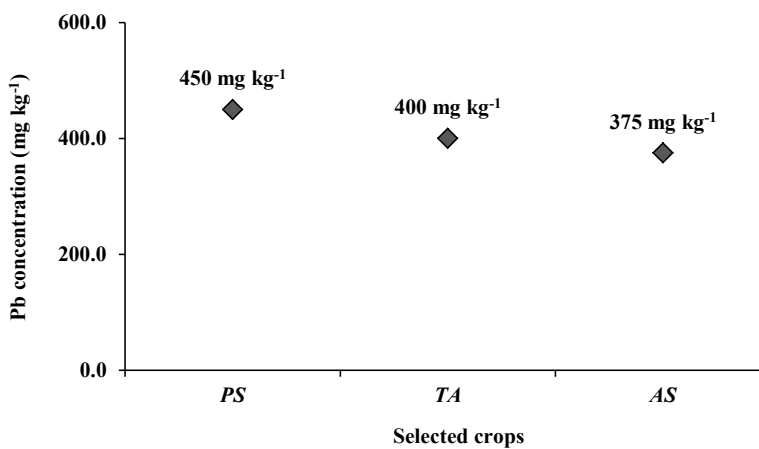


Figure 7. Concentration of lead (Pb) in various samples of soil collected from District Gujranwala. *PS: Pisum sativum* *TA: Triticum aestivum* *AS: Allium sativum*.

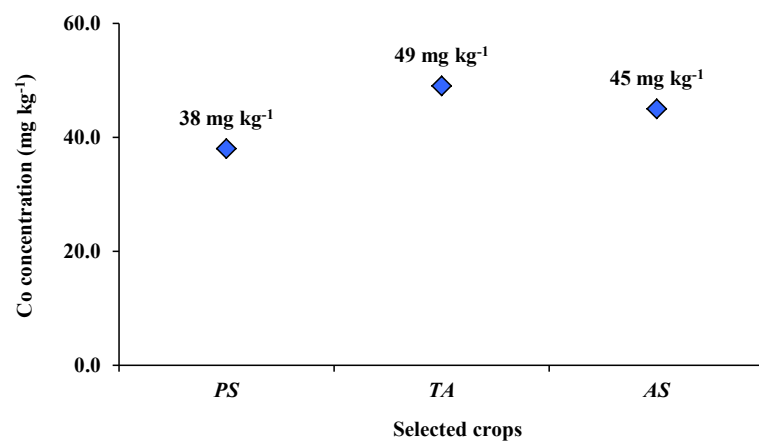


Figure 8. Concentration of lead (Pb) in various samples of soil collected from District Gujranwala. *PS: Pisum sativum* *TA: Triticum aestivum* *AS: Allium sativum*.

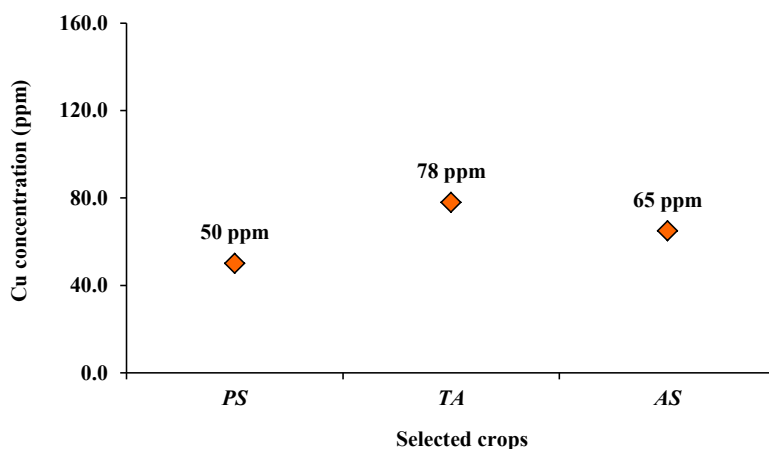


Figure 9. Concentration of copper (Cu) in various samples of water collected from District Gujranwala. *PS: Pisum sativum* *TA: Tritichum aestivum* *AS: Allium sativum*.

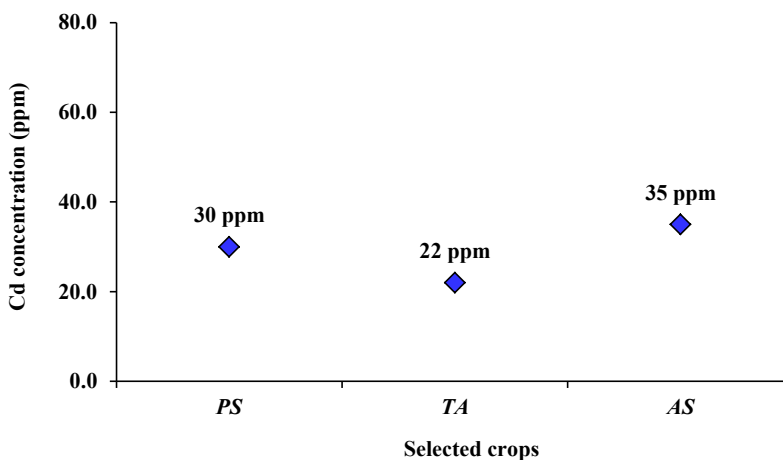


Figure 10. Concentration of cadmium (Cd) in various samples of water collected District Gujranwala. *PS: Pisum sativum* *TA: Tritichum aestivum* *AS: Allium sativum*.

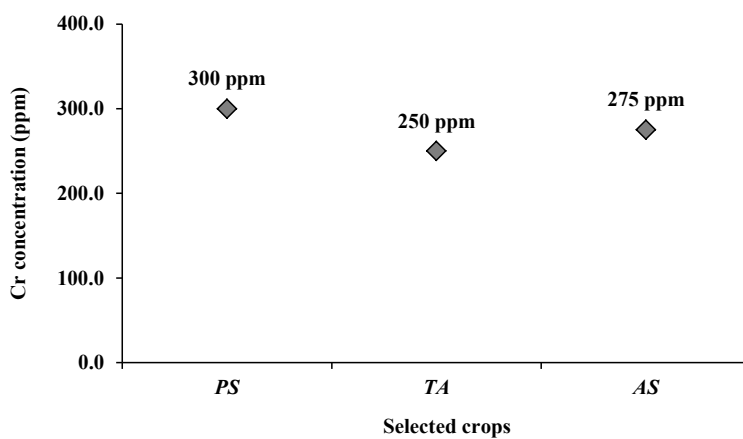


Figure 11. Concentration of chromium (Cr) in various samples of water collected District Gujranwala. *PS: Pisum sativum* *TA: Tritichum aestivum* *AS: Allium sativum*.

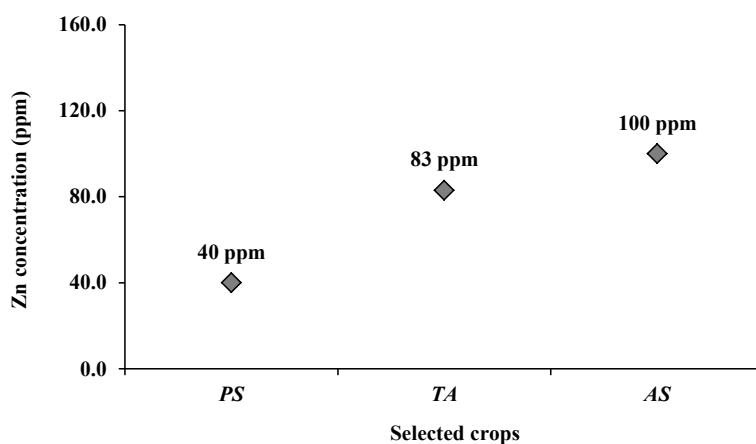


Figure 12. Concentration of zinc (Zn) in various samples of water collected from District Gujranwala. *PS: Pisum sativum* *TA: Tritichum aestivum* *AS: Allium sativum*.

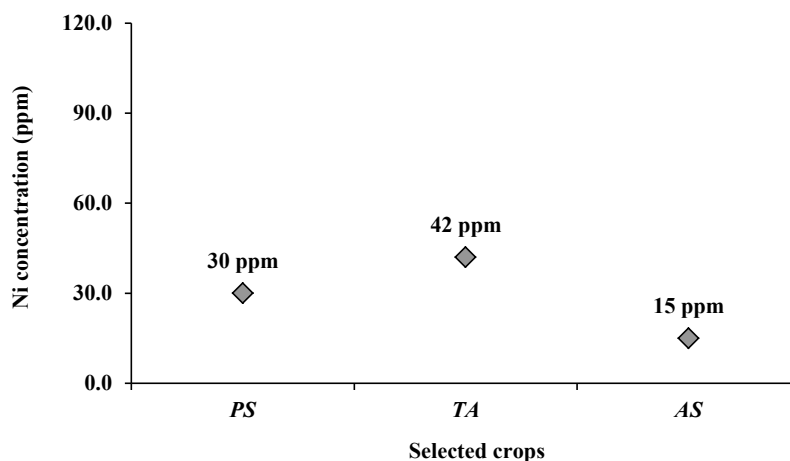


Figure 13. Concentration of nickel (Ni) in various samples of water collected from District Gujranwala. *PS: Pisum sativum* *TA: Tritichum aestivum* *AS: Allium sativum*.

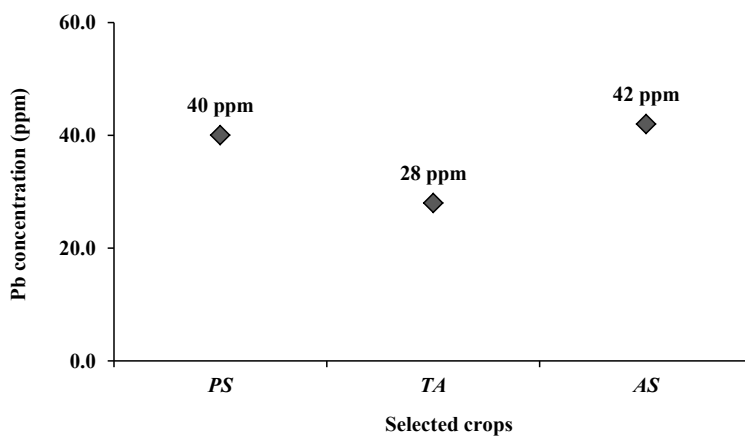


Figure 14. Concentration of lead (Pb) in various samples of water collected from District Gujranwala. *PS: Pisum sativum* *TA: Tritichum aestivum* *AS: Allium sativum*.

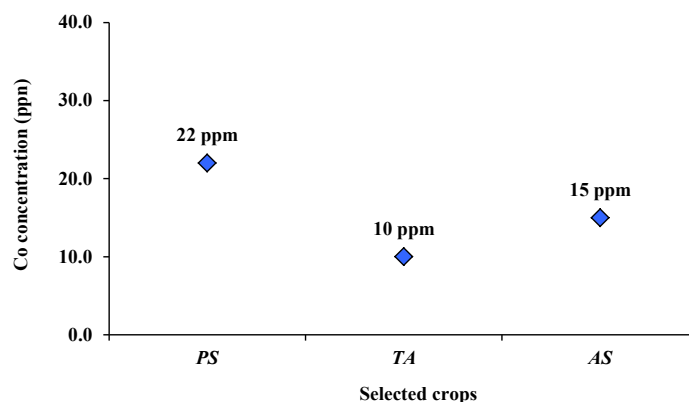


Figure 15. Concentration of cobalt (Co) in various samples of water collected from District Gujranwala. *PS: Pisum sativum* *TA: Triticum aestivum* *AS: Allium sativum*.

DISCUSSION

The present study found that the agricultural soils and irrigation water in District Gujranwala contain alarmingly high concentrations of toxic heavy metals. In soil, the concentrations of copper ($43\text{--}75\text{ mg kg}^{-1}$), cadmium ($15\text{--}41\text{ mg kg}^{-1}$), chromium ($200\text{--}315\text{ mg kg}^{-1}$), zinc ($51\text{--}77\text{ mg kg}^{-1}$), nickel ($37\text{--}54\text{ mg kg}^{-1}$), lead ($375\text{--}450\text{ mg kg}^{-1}$), and cobalt ($38\text{--}45\text{ mg kg}^{-1}$) all exceeded the permissible limits established by the World Health Organization (WHO, 2013) and the Food and Agriculture Organization (FAO, 2012). This widespread contamination classifies the sampled areas firmly within a "danger zone" for agricultural activity and food safety. The persistent irrigation of crops with metal-laden water directly facilitates the translocation of these contaminants from soil into plant tissues, thereby introducing them into the food chain (Khalid *et al.*, 2017). This bioaccumulation pathway represents a significant and direct risk to consumer health, as chronic dietary exposure to metals like lead and cadmium is linked to renal dysfunction, neurological disorders, and carcinogenesis (Jaishankar, Tseten, Anbalagan, Mathew, and Beeregowda, 2014).

The parallel contamination observed in water samples is a critical finding that underscores the interconnectedness of environmental pollution in the region. The elevated levels of metals in irrigation water are likely a primary vector for soil pollution. This phenomenon can be attributed to several geochemical factors that govern metal mobility. Specifically, the solubility and bioavailability of heavy metals are profoundly influenced by soil pH, organic matter

content, and redox potential (Wuana & Okieimen, 2011). In alkaline conditions, which are common in many Pakistani soils, certain metals like chromium may become more soluble and mobile, exacerbating leaching into groundwater and uptake by plants. The continuous application of such contaminated water creates a vicious cycle, where metals are not only absorbed by crops but also accumulate in the soil matrix, degrade its microbial health, and potentially leach into underlying aquifers, posing a long-term threat to water resources (Ullah, Mohammad and Khan, 2013).

The findings of this study are consistent with a growing body of research documenting severe heavy metal pollution in Pakistan's industrial and agricultural belts. Earlier investigations by Khan *et al.* (1992) and Butt *et al.* (2005) reported similar contamination trends in Faisalabad, a major industrial city. Likewise, Jawahar and Javed (1997) found elevated metal levels in the Sheikhpura and Maredke areas, while Mian and Ahmad (1997) corroborated this pattern in Rawalpindi. More recent studies continue to highlight this national crisis. For instance, Alam *et al.* (2020) reported dangerous accumulations of cadmium and lead in vegetables grown in peri-urban areas of Punjab, directly linking them to wastewater irrigation. This consistency across time and location points to systemic failures in industrial effluent management and environmental regulation, suggesting that the problem in Gujranwala is not isolated but part of a widespread environmental and public health challenge (Mahmood and Malik, 2014).

In conclusion, the vicinity of Gujranwala is critically contaminated with multiple heavy metals, and the

continued use of this polluted water for irrigation constitutes a major agricultural and public health hazard. The data clearly indicate that without intervention, the cycle of soil degradation, crop contamination, and groundwater pollution will intensify. Therefore, immediate and multifaceted management strategies are imperative. These must move beyond mere monitoring to include the enforcement of industrial effluent treatment, the promotion of phytoremediation and soil amendment technologies to immobilize metals, and a shift towards safer irrigation sources. Furthermore, there is an urgent need for policy reform and the stringent implementation of environmental protection laws to halt pollution at its source. Public awareness campaigns are equally crucial to inform farmers and consumers about the risks and to foster community-led initiatives for environmental stewardship (Ali, Khan, and Ilahi, 2019). Addressing this issue is essential for ensuring sustainable agriculture and protecting population health in the region.

CONFLICT OF INTEREST

The authors affirm that the research was conducted without any commercial or financial affiliations that could be perceived as potential conflicts of interest.

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