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Heavy Metals Contamination of Soils and Vegetables Irrigated with Municipal Wastewater: A Case Study of Faisalabad, Pakistan

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Abstract: The long-term usage of industrial wastewater makes heavy metals to accumulate in soil and increases the absorption and accumulation by the plants. Samples of wastewater, soil and vegetables were collected from wastewater drain and agricultural fields of Faisalabad. Collected samples were analyzed in the laboratory for heavy metals and their concentrations were compared with the critical levels of the metals in the edible portion of the vegetables. Results showed that all the samples of wastewater had concentrations of lead and cadmium above safe limit of World Health Organization. The concentrations of all the heavy metals (lead, cadmium, nickel, and zinc) were found to be lower than their standards in all the samples of soil. Levels of heavy metals were higher in the surface soil layer as compared to those in the sub-soil layer. The mean concentrations of lead and nickel were found to be higher than the safe limits in all the vegetables studied. Consumption of such vegetables causes bioaccumulation of heavy metals in the human body that may cause health impacts on local people.

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1. Introduction

Faisalabad is the third largest city of Pakistan, with its fast growing population. It is the hub of industry contributing to the economic development of Pakistan. Important industries in the city are textile industries, flourmills, oil refineries, various engineering units and pharmaceutical industries. Due to extensive growth of textile industry, Faisalabad is also known as "Manchester of Pakistan". Industrial sector produces a large amount of wastewater and it is discharged into drains and then eventually into the rivers. There is no proper system implemented for treatment of effluents. Industrial wastewater is also used for irrigating vegetable fields.

Farmers use wastewater to get an opportunity for direct economic benefits. This is more common in areas where there is a lack of access to other sources of irrigation water. Land application of effluent waste may cause excessive accumulation of heavy metals such as Cr, Ni, and Cd in soil and plants (Torabian and Baghuri, 1996). The accumulation of heavy metals in plants, sediments, sewage, and sludge is a potential risk to human health due to their transformation and uptake by plants and their introduction in food chain (Hough et al., 2004).

The heavy metal contaminations in vegetables, soil, water, sediments and particulate matter affect the drinking water quality, ecological environment, and food chain (Waseem et al., 2014). There are different causes of soil contamination or mobilization of toxic elements in soils, which include irrigation with municipal waste water, soil acidification, fertilizer application, etc. (Tiwaria et al., 2011; Nawaz et al., 2012; Nawaz et al., 2014). The long-term usage of wastewater makes these metals to accumulate in soil and increases the absorption and accumulation by the plants. Significant amounts of heavy metals (Cr, Cu, Ni, Pb, Zn and Cd) were found in wastewater-irrigated soils and food crops in Beijing, China (Khan et al., 2008). Arora et al. (2008) found significant build-up of heavy metals in food crops due to continuous use of wastewater for irrigation in India. Environmental pollution by heavy metals is a problem that has global dimensions and is increasing everyday (Carlos et al., 2005).

The heavy metal can directly damage human beings by impairing mental and neurological function, influencing neurotransmitter production and utilization, and altering numerous metabolic body processes. Municipal wastewater is being applied to grow vegetables in peri-urban areas of Faisalabad. This wastewater might have contaminants including heavy metals. Therefore, the water containing industrial effluent is of great concern for humans utilizing vegetation irrigated by this water. This study focuses on the level of heavy metals in surface and subsoil layers and in the edible parts of different vegetables irrigated with municipal wastewater in the surrounding area of Faisalabad, Pakistan.

2. Materials and Methods

2.1 Sample collection and analysis preparation

Wastewater, soil and plant samples were collected from the field as follows;

Wastewater samples: 20 samples of wastewater were collected from the drains of municipal wastewater (Fig. 1). The samples were collected in plastic bottles and brought to laboratory for chemical analysis. The wastewater samples were filtered before chemical analysis.

Soil samples: Soil samples were collected from the vegetable fields at the depth of 0-15 cm and 15-30 cm. 25 samples were collected from each layer. The collected soil samples were air-dried under shade, ground, sieved and mixed thoroughly. The representative samples were collected from the composite samples.

Plant samples: Edible portion of the vegetables were randomly collected for chemical analysis. The vegetables under investigation include totato (*Solanum lycopersicum*), onion (*Allium cepa*), chilli (*Capsicum annuam*) and brinjal (*Solanum melongeana*). The vegetable samples were washed with distilled water, dried under shade, ground and mixed thoroughly to get representative samples for chemical analysis.

2.2 Chemical analysis of the samples

To Prepared soil sample (25 g) was mixed with 50 mL of DTPA (diethylene triamin penta acetic acid) extracting solution at pH 7.3. It was kept on a reciprocal shaker at 120 rpm for 2 h, followed by centrifugation at 5000 rpm for 5 min and collection of supernatants for heavy metal analysis (Lindsay and Norvell, 1978). Samples of edible part of vegetable were digested with tri-acid mixture (HNO_3+$HClO_4$+H_2SO_4; 5:2:1), followed by cooling and filtering through Whatman No.42 filter paper and making volumes up to 100 ml using distilled water.

Levels of heavy metals in soil, wastewater and edible parts of vegetable samples were measured on Atomic Absorption Spectrophotometer (AAS, Shimadzhu-7000, Japan) by using respective hallow cathode lamp using standard solutions of metals. The target heavy metals include Lead (Pb), Cadmium (Cd), Nickel (Ni), Iron (Fe) and Zinc (Zn).

2.3 Data analysis

MS excel was used for data analysis. Arithmetic means and standard deviation were calculated for the data. The levels of heavy metals were also compared with the critical levels of the metals in the edible portion of the vegetables, as recommended by World Health Organization (WHO, 2007).

3. Results and discussion

3.1 Status of heavy metals in wastewater

Table 1 shows minimum, maximum, and mean concentrations of heavy metals for all the collected samples of wastewater from the drain just before application to vegetable fields. The concentrations of Pb and Cd are above safe limit (0.10 and 0.01 mg/L, respectively) in all the samples of wastewater collected from the drain at different time intervals. Mean concentrations of Ni and Zn are lower than their safe limits i.e. 0.2 and 2 mg/L respectively. However, some samples of Ni (7) and Zn (2) were found to have higher concentrations than their safe limits. Higher contents of heavy metals in the wastewater might be due to presence of various types of chemical compounds having different metals. These chemicals might be byproducts of low scale industrial processes which run for short time span. Many other studies found elevated levels of heavy metals in sewage water being applied to agricultural fields to grow different crops including vegetables in different cities of Pakistan (Ehsan et al., 2011; Jagtap et al., 2010; Ensik et al., 2007; Lone et al., 2003). Such wastewater often contains heavy metals in various forms and at different contamination levels.

Table 1: Levels of heavy metals in samples of wastewater

Heavy Metal	Concentration (mg/L)			No. of Samples Above Standard	Safe Limit (mg/L)
	Min	Max	Mean ± SD		
Pb	0.43	1.10	0.88 ± 0.18	20	0.10
Cd	0.05	0.25	0.14 ± 0.05	20	0.01
Ni	0.12	0.24	0.18 ± 0.04	7	0.20
Zn	0.42	2.15	1.09 ± 0.43	2	2.00

Total No. of samples analyzed = 20

Fig. 1: Municipal wastewater drain passing through the agricultural fields in peri-urban area of Faisalabad for irrigation purpose. This image was captured by author during field visit in 2013.

Constant use of such industrial water for growing vegetables may cause bioaccumulation of heavy metals up to toxic levels for health. Heavy metals can enter human bodies through the food chain, consequently causing increased incidence of chronic diseases such as cancer and deformity. (Muller and Anke, 1994). The use of wastewater in agricultural land is a common practice in urban and sub-urban areas of the industrial megacities of Pakistan including Karachi, Lahore and Faisalabad. This is because of the fact that wastewater has nutrients and enhances soil fertility. Hidri et al. (2014) found that the proper management of wastewater for irrigation and regular monitoring of soil health, fertility and quality parameters are essential for successful, safe, and long-term reuse of wastewater for agricultural uses.

3.2 Status of heavy metals in agricultural soils

Table 2 shows minimum, maximum, and mean concentrations of heavy metals for all the collected samples of soil from the fields during their growing season of the selected vegetables. The concentrations of all the heavy metals (Pb, Cd, Ni, and Zn) were found to be lower than their standards in all the samples of soil collected from the fields. It is important to note the concentrations of heavy metals were found to be higher in the surface soil layer (0-15 cm) than those in the sub-soil layer (15-30 cm). These findings are consistent with those of Hu et al. (2013). This is due to heavy application of municipal wastewater as irrigation water to grow vegetables in the fields. Heavy metal contents of the soil were found higher than their concentration in samples of wastewater. This might be due to continual wastewater application and the accumulation of heavy metals in the soil. Higher levels of heavy metals in Pakistani soils are also reported by other studies (Mushtaq and Khan, 2010; Ismail et al., 2014). Although the concentrations of all heavy metals are below than their safe limits, but these metals can accumulate in the edible portion of vegetables, enter to food chain and can cause toxic health effects in human beings (Hough et al., 2004).

3.3 Status of heavy metals in vegetables

Figure 2 shows the mean concentration of heavy metals in edible portion of the selected vegetables and their comparisons with WHO standards. The mean concentration of Pb and Ni in all vegetables were higher than their standards. These results are consistent with the findings of Lone et al. (2003) that the accumulation concentrations of Ni and Pb were much higher than their permissible levels.

The average concentrations of Zn were also higher, particularly in onion and tomato. The application of wastewater causes changes in the physicochemical characteristics of soil system and subsequently heavy metal uptake by vegetables. The concentrations of heavy metals in edible parts of vegetables were higher in wastewater-irrigated vegetables than their concentrations in freshwater-irrigated plants (Arora et al., 2008).

Vegetables accumulate metals such as Cd and Pb, which may cause adverse health impacts on humans due to excessive dietary intake of those vegetables (Hough et al., 2004; Cobb et al., 2000).

Table 2: Levels of heavy metals in samples of agricultural soils

Heavy Metal	Soil Depth (cm)	Concentration (mg/kg)			No. of Samples Above Standard	Safe Limit (mg/kg)
		Min	Max	Mean ± SD		
Pb	00-15	7.54	41.45	15.90 ± 8.70	0	300
	15-30	2.65	23.64	12.04 ± 6.20	0	
Cd	00-15	0.12	1.34	0.72 ± 0.41	0	3
	15-30	0.09	0.87	0.33 ± 0.19	0	
Ni	00-15	1.53	6.87	3.58 ± 2.64	0	75
	15-30	1.05	5.43	2.64 ± 1.24	0	
Zn	00-15	2.76	10.86	6.35 ± 2.83	0	300
	15-30	1.93	9.78	5.68 ± 2.45	0	

Total No. of samples analyzed = 25

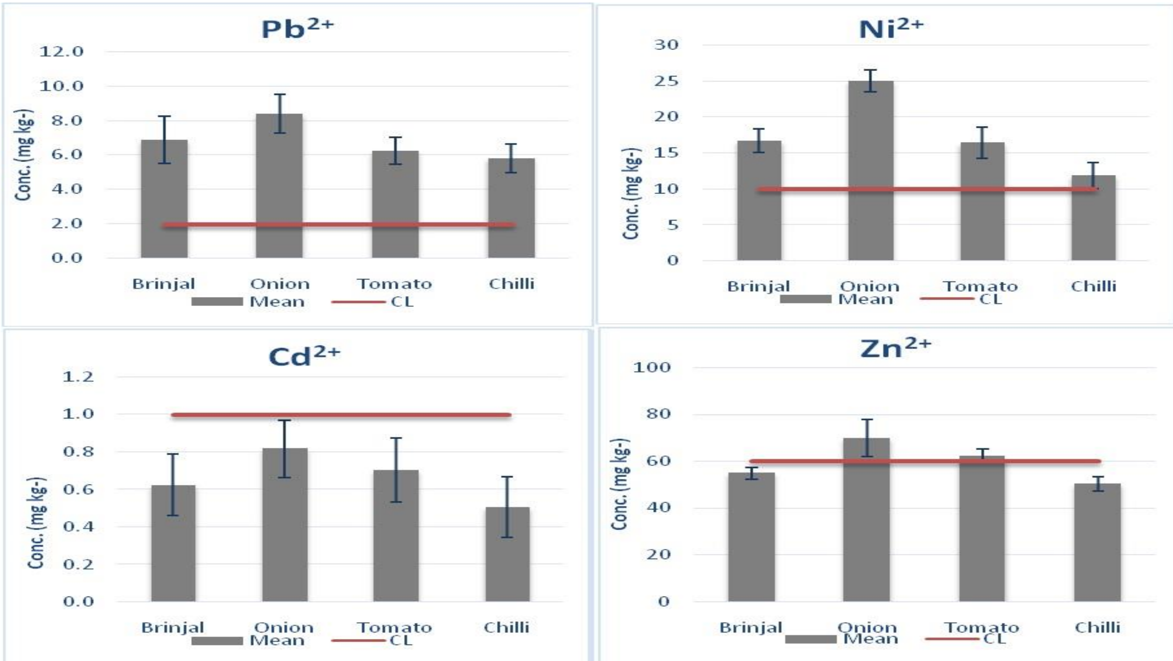

Fig. 2: Levels of heavy metals in edible part (fruit) of selected vegetables and their comparison with critical limit (CL) of WHO, 2007.

Lead can cause specific changes in gene and protein expression and the injurious effects on a cellular level (Gillis et al., 2012). Consumption of very high levels of Cd severely irritates the stomach, resulting vomiting and diarrhea. Its longer exposure leads to a buildup in the kidneys and possible kidney disease, fragile bones and lung damage (Martin and Griswold, 2009). The health risk assessment depends on soil physical and chemical characteristics, vegetable type and vegetable's consumption rate (Khan et al., 2015)

Plants grown on a contaminated soil irrigated with municipal or industrial wastewater can absorb heavy metals in the form of mobile ions present in the soil through their roots and get absorbed and bio-accumulated in different parts of vegetable plants. These vegetable are sold in different markets of cities, especially Faisalabad. Exposure to high levels of Pb by vegetable consumption can severely damage the kidney and brain, causing death (Martin and Griswold, 2009). Consumption of such vegetables results in the bioaccumulation of Pb in the human body that causes toxic effects on several organs, such as kidneys, liver, lungs and spleen, leading to a variety of biochemical defects in human (Guerra et al., 2012).

4. Conclusion

Heavy metals concentration was monitored in different vegetables irrigated with wastewater in adjacent areas of Faisalabad city of Pakistan. This study indicated that the vegetables analyzed were heavily contaminated with the heavy metals, particularly lead, nickel and zinc. Moreover, highest concentrations of heavy metals were found in onion bulb followed by brinjal, tomato and chili fruit. For most of the samples, the concentrations of heavy metals present were above permissible levels that may cause severe health implications. Excessive uptake of dietary heavy metals can cause a number of serious health problems. Consumption of contaminated vegetables causes a decrease in immunological deficiencies, impaired psycho-social behavior, and intrauterine growth retardation due to depletion of some essential nutrients in the body. Heavy metal-contaminated food is also cause of disabilities associated with malnutrition and a high prevalence of upper gastrointestinal cancer. Industrial or municipal wastewater should be treated before application to agricultural fields. Thus there is an urgent need to create awareness among farmers about the effects of heavy metals on the human health.

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