International Journal of Ecology and Environmental Sciences 51: 743-749, 2025
ISSN: 2320-5199 (Online); https://doi.org/10.55863/ijees.2025.0799

Heavy Metals in Soil, Water and Crops of Pardi Taluka of Valsad District, Gujarat, India

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ABSTRACT
This study highlights the contamination of soil, water, and vegetables in Pardi Taluka, Valsad District, Gujarat, due to heavy metals. Samples of fruits and vegetables - specifically coriander, spinach, fenugreek, radish, sapota, rice, and brinjal - were collected from seven selected sites, along with soil and water samples used for irrigation by local farmers. The samples underwent preparation through acid digestion and were analyzed via inductively coupled plasma optical emission spectroscopy at the Center of Excellence Laboratory in Vapi. The analysis focused on heavy metals such as Pb, Cd, Co, Zn, Cu, Ni, and Hg. Results indicated that the concentration of metals in crops followed the order of Zn > Pb > Ni > Cd > Cu > Co > Hg, with zinc exhibiting exceptionally high levels compared to Indian standards, while mercury was not detected. Additionally, the transfer factor calculated from these results demonstrated a high to very high level of metal transfer from soil to plants, posing significant health risks to humans through consumption.

Key words: Heavy metal, Accumulation, Plant, Transfer factor

INTRODUCTION

Heavy metals are naturally occurring elements found in the earth's crust, but their accumulation is exacerbated by agronomic pollution and various anthropogenic activities. Agricultural soil contamination with heavy metals can lead to long-lasting environmental challenges (Chabukdhara et al. 2015). Plants primarily absorb these metals from the soil, especially within the top 25 cm layer, which is commonly impacted by pollutants stemming from human activities (Satpathy et al. 2014, Bhatti et al. 2016). Vegetables, an essential diet component, are consumed both cooked and raw (Jolly et al. 2013), and are the primary pathway through which toxic metals enter the human body. While zinc and copper are vital trace metals required in small quantities for the growth of plants, for animal and human nutrition, excessive concentrations can result in phytotoxicity and zootoxicity (Okogo 2015).

The present study focuses on Pardi Taluka in Valsad District, which encompasses a significant industrial area. Most of the local population is farming vegetables such as fenugreek, spinach, radish, and brinjal, along with rice cultivation. These leafy vegetables serve as a staple food for the villagers. Given the extensive industrial presence, periodic surveys are essential to assess the heavy metal quantity in the crops. The transfer factor (TF value) is determined through heavy metal analysis of water, soil, and crops.

MATERIAL AND METHODS

Study area

Pardi village (20.52ºN - 72.95ºE) in Pardi Taluka, Valsad District of Gujarat, India, is surrounded by significant industrial development. This village has two key GIDC (Gujarat Industrial Development Corporation) areas: Vapi GIDC and Pardi GIDC. These zones are primarily occupied by industries engaged in chemicals, agrochemicals, dye manufacturing, paper production, packaging, and electrical equipment.

Collection of samples

Water samples used for irrigation were collected from various selected sites (Table 1) using thoroughly washed and dried plastic bottles and subsequently sent to the laboratory for further analysis. Soil samples from the field surface weighing approximately 50 to 60 g were collected from a depth

Table 1. Site location and samples collected

Village	Water	Soil	Crop	Location	
Sonwada	Collected	Collected	Brinjal	20.473005°N	73.017060°E
			Rice	20.472982°N	73.018567°E
Rohina	Collected	Collected	Chilli	20.443956°N	73.027408°E
			Rice	20.447496°N	73.030371°E
Ambach	Collected	Collected	Brinjal	20.400952°N	72.992640°E
			Fenugreek	20.401079°N	72.992590°E
			Radish root	20.401197°N	72.992572°E
			Radish leaf	20.401197°N	72.992572°E
Balda	Collected	Collected	Sapota	20.515313°N	72.966882°E
Karvad	Collected	Collected	Tomato	20.356332°N	72.96197°E
			Spinach	20.357042°N	72.96212°E
			Rice	20.357042°N	72.96212°E
Kocharwa	Collected	Collected	Fenugreek	20.368775°N	72.956570°E
Udvada	Collected	Collected	Coriender	20483282°N	7288249°E
Vatar	Collected			20.434948°N	72.898091°E
Palsana near pond	Collected			20.48651°N	72.892928°E
Palsana coastal	Collected			20.483286°N	72.905136°E
Tukwada		Collected		20.419342°N	72.936014°E

of 0-15 cm (Bhatia et al. 2015, Meena et al. 2018) and were air-dried. Each sample was manually crushed using a mortar and pestle and passed through a 2 mm mesh sieve (Sharma et al. 2008). The samples were mixed thoroughly, stored in clean, labelled zip-lock bags, and forwarded to the laboratory for further analysis. Plant samples weighing 250 to 500 g were collected by hand plucking from various sites. Non-edible parts were removed from these samples (Sharma et al. 2008). The samples were thoroughly washed with lukewarm water, cut, sun-dried, and labelled. They were dried until crisp to facilitate grinding into a fine powder using a stainless-steel mixer grinder. The ground samples were then stored in airtight polythene bags with appropriate tags.

Analysis

All analyses were conducted at the Center of Excellence Laboratory in Vapi. For the wet digestion process, 0.5 g of dry samples (such as soil and crops) are carefully weighed and placed into a TFM vessel along with a mixture of 65% nitric acid (HNO_4) and 30% hydrogen peroxide (H_2O_2). The microwave program is then run for 20 minutes at 200ºC. After cooling, the solution is diluted with water before analysis, which uses an inductively coupled plasma optical emission spectrometer (ICP-OES) (Anonymous 2004, 2016).

Transfer factor

The transfer of metals from soil to plant tissue is known as the transfer factor (Mirecki et al. 2015). Metal concentrations in the extracts of soils and plants were calculated based on dry weight. The plant transfer factor (TF) was calculated using the formula:

$$TF=C_{plant} / C_{soil}$$

where C_{plant} represents metal concentrations in the plant extracts and C_{soil} represents the toxic metal concentration in the soil extracts (Jolly et al. 2013). The metal concentrations in the extracts of soils and plants were assessed based on dry weight. A transfer factor (TF) ratio greater than 1 indicates that the plants have accumulated certain elements, while ratios around 1 suggest that these elements do not significantly influence the plants. Conversely, ratios under 1 indicate that the plants exclude these elements from uptake (Mirecki et al. 2015).

RESULTS

Heavy metal analysis (including Pb, Cu, Cd, Zn, Co, Ni, and Hg) was done for water samples collected from various locations in the Pardi District. All nine water samples showed elevated levels of lead presence, with a maximum concentration of 7.82 mg/kg. While copper within permissible limits was detected in 5 samples, cadmium was found only in 4. However, zinc was present in all samples within permissible limits. Cobalt, nickel, and mercury were not detected in the samples. This indicates a significant level of lead contamination in the water used for irrigation (Table 2).

Both copper and cobalt in the nine soil samples from the selected sites exceeded permissible limits. At the same time, lead, cadmium, and nickel were found within prescribed ranges, with mean values of 17.83, 0.34, and 53.74 mg/kg, respectively. Zinc levels were generally within permissible limits, except for one sample from the Udvada site, which recorded a concentration of 243.69 mg/kg; the mean zinc value was 96.48 mg/kg. Mercury was not detected in any soil samples (Table 3).

A total of 14 crop samples were collected from selected sites and analyzed for metal accumulation. The results revealed significant levels of metal presence in the crops. Out of the 14 samples, 7

Table 2. Concentration (mg/kg) of heavy metals in water samples

Place	Source	Pb	Cu	Cd	Zn	Co*	Ni	Hg
Ambach	Borewell	**0.14**	ND	ND	0.62	ND	ND	ND
Kocharwa	Borewell	**7.02**	ND	ND	0.55	ND	ND	ND
Tukwada	Borewell	**0.14**	ND	ND	0.67	ND	ND	ND
Karvad	Borewell	**0.13**	0.01	ND	0.62	ND	ND	ND
Rohina	Borewell	**0.22**	ND	ND	0.62	ND	ND	ND
Vatar	Borewell	**7.82**	0.01	0.04	2.71	ND	ND	ND
Palsana, near Pond	Borewell	**0.95**	0.02	0.05	2.80	ND	ND	ND
Palsana, costal	Borewell	**0.77**	0.01	0.05	3.65	ND	ND	ND
Udwada	Borewell	**0.68**	0.01	0.04	4.68	ND	ND	ND
	MPL	**0.01**	**0.05**	**0.003**	**5.00**	**0.05-1.5**	**0.02**	**0.001**

MPL: Maximum permissible limit (BIS); *WHO standard (Anonymous 1996); ND- Not detected

Table 3. Concentration (mg/kg) of heavy metals in soil samples

Place	Pb*	Cu	Cd*	Zn	Co	Ni	Hg**
Sonwada	12.67	**110.65**	0.08	115.31	**77.65**	77.72	0
Rohina	9.25	**68.38**	0	78.16	**22.53**	38.95	0
Ambach	9.28	**60.64**	0	64.51	**26.89**	41.08	0
Balda	11.29	**66.53**	0.13	91.76	**27.33**	43.57	0
Karvad (Methi)	16.38	**54.92**	0.02	58.4	**26.62**	50.78	0
Karvad (Tomato)	13.86	**53.94**	0.02	57.13	**25.74**	56.66	0
Kocharva	13.76	**68.36**	0.01	67.21	**27.49**	69.56	0
Udwada	53.89	**100.57**	2.85	**243.69**	**37.82**	56.72	0
Tukwada	20.12	**77.35**	0	92.16	**28.36**	48.63	0
MPL	250-500	**30**	3-6	**200**	**17**	80	0.5

MPL-Maximum permissible limits based on WHO guideline (Anonymous 1996); *Indian standard (BIS), **European standard, ND- Not detected exhibited elevated lead concentrations, ranging from a low of 1.15 mg/kg in sapota (Balda) to a high of 165.07 mg/kg in radish (Ambach). The average lead concentration across the samples was 28.14 mg/kg, significantly exceeding the permissible limit. Four samples demonstrated high accumulation levels of cadmium, with the lowest concentration recorded at 0.02 mg/kg in tomato (Karvad) and the highest at 3.55 mg/kg in fenugreek (Kocharva). The mean cadmium concentration was 0.922 mg/kg, within the permissible limit. Zinc concentrations were elevated in 9 out of the 14 samples, with the lowest level at 10.33 mg/kg in sapota (Balda) and the highest at 344.55 mg/kg in fenugreek (Ambach). The mean zinc concentration was 151.041 mg/kg, significantly surpassing the permissible limit. Eight samples indicated high nickel concentrations, with the lowest being 0.34 mg/kg in spinach (Karvad) and the highest

Table 4. Concentration (mg/kg) of heavy metals in plant samples

Village	Crops	Pb	Cu	Cd	Zn	Co*	Ni	Hg**
Sonwada	Brinjal	1.59	19.33	0.01	32.88	0.04	**2.04**	0
	Rice	**6.36**	6.19	0	**226.36**	0	**1.45**	0
Rohina	Chilli	1.38	12.59	0	34.31	0.21	**2.86**	0
	Rice	**4.38**	5.02	0	**130.26**	0	**3.42**	0
Ambach	Brinjal	1.36	12.46	0.06	32	0	0	0
	Fenugreek	**50.46**	12.18	**3.02**	**344.55**	0.31	0.87	0
	Radish root	**5.44**	2.93	0	**122.96**	0	1.21	0
	Radish leaf	**165.07**	7.72	0.38	**122.85**	0	1.03	0
Balda	Sapota	1.15	1.63	0	10.33	0	0	0
Karwad	Tomato	1.21	10.21	0.02	30.63	0.04	0.42	0
	Spinach	**46.68**	12.91	**2.73**	**325.91**	0.16	0.34	0
	Rice	**11.35**	4.82	0	**121.34**	4.82	**2.42**	0
Kocharwa	Fenugreek	**52.17**	15.14	**3.55**	**327.52**	0.73	**2.33**	0
Udvada	Coriender	**45.36**	16.15	**3.15**	**252.79**	0	**2.74**	0
	MPL	**2.5**	**30**	**1.5**	**50**	**50**	**1**	**1**

MPL-Maximum permissible limit (BIS); *WHO/FAO standard; **FSSAI guideline, ND- Not detected

Table 5. Heavy metal transfer factor of the crops

Village	Crops	Pb	Cu	Cd	Zn	Co	Ni	Hg
Sonwada	Brinjal	0.125	0.174	0.125	0.285	0.000	0.026	0
	Rice	0.501	0.0559	0	**1.963**	0	0.018	0
Rohina	Chilli	0.149	0.1841	0	0.438	0.009	0.073	0
	Rice	0.473	0.073	0	**1.666**	0	0.087	0
Ambach	Brinjal	0.147	0.182	0	0.409	0	0	0
	Fenugreek	**5.437**	0.200	0	**5.341**	0.011	0.021	0
	Radish Root	0.586	0.048	0	**1.906**	0	0.029	0
	Radish leaf	**17.787**	0.127	0	**1.904**	0	0.025	0
Balda	Sapota	0.101	0.024	0	0.112	0	0	
Karwad	Tomato	0.087	0.189	1	0.536	0.001	0.007	0
	Spinach	**2.849**	0.235	0	**5.580**	0.006	0.006	0
	Rice	0.692	0.087	0	**2.077**	0.181	0.047	0
Kocharwa	Fenugreek	**3.791**	0.221	0	**4.873**	0.026	0.033	0
Udvada	Coriender	0.841	0.160	**1.105**	**1.037**	0	0.048	0

reaching 3.42 mg/kg in rice (Rohina), resulting in a mean concentration of 1.50 mg/kg, also exceeding the permissible limit. In contrast, copper and cobalt concentrations remained within permissible limits for all 14 samples. At the same time, mercury was not detected in any samples (Table 4). Understanding the Transfer factor (TF) is essential for predicting how heavy metals can accumulate in agricultural products, which has significant implications for food safety and environmental health. The highest TF values observed were for lead and zinc compared to other metals (Table 5). Four samples exhibited TF values greater than 1 for Pb, and nine had TF values exceeding 1 for Zn. Notably, the highest TF value for Pb was recorded at 17.789 in radish leaves, while the highest for Zn was 5.580 in spinach. In contrast, copper and nickel displayed TF ratios of less than 1,

DISCUSSION

The analysis of the water samples reveals a significant concentration of lead. Similar results were documented in a study conducted in the industrial belt of Vapi, where lead levels varied between 0.13 and 0.440 mg/kg (Patel and Das 2015). A study also discovered even higher lead concentrations in the Khasardi River in Mumbai, ranging from 8.6 to 33.9 mg/kg (Lokhande et al. 2011).

Regarding soil sample results, there were elevated levels of copper and cobalt, consistent with research surrounding the industrial area of Surat. The copper levels in this region ranged from 77.1 to 137.5 mg/kg, while cobalt levels spanned from 24.4 to 51.3 mg/kg (Krishna and Govil 2007). Furthermore, another study identified high cobalt levels in the soil of Punjab, where concentrations ranged from 9.66 mg/kg to 19.28 mg/kg, surpassing permissible limits (Sharma et al. 2018).

Various studies have reported similar findings regarding the accumulation of metals in crops. One investigation revealed higher-than-permissible levels of lead, copper, and zinc in crop shoots from Punjab, with concentrations measuring 11.0-36.00, 8.6-171.89, and 17.3-135.3 mg/kg, respectively (Malik et al. 2010). Lead content in cucumbers exceeded permissible limits in the middle and eastern districts of Saudi Arabia, with recorded levels of 6.98 and 6.7 μg/g, respectively. This increase in lead levels has been attributed to heavy traffic emissions (Ali and Al-Qahtani 2012). Additionally, research indicated that cadmium levels in garlic surpassed the WHO/FAO permissible limit of 0.37 mg/kg, as reported in Maharashtra (Mawari et al. 2022).

The elevated concentrations of lead, zinc, and nickel detected in the crop samples from this study underscore the importance of calculating the transfer factor (TF), which quantifies the extent of metal transfer from soil to crops. Earlier studies have reported high TF values consistent with our study, for instance, the TF value of lead in spinach 7.74 (Patel et al. 2019) and cadmium in grass 1.35 (Yan et al. 2012), both indicating significant uptake potential in leafy vegetation. The plant transfer factor thus functions not only as a bioindicator of soil contamination but also as a predictive tool for estimating heavy metal accumulation in agricultural produce. It can serves as an index for assessing metal bioavailability in plants. This factor is vital for predicting the absorption of these metals by agricultural products. The transfer factor offers valuable insights into the mechanisms by which toxic metals enter plant tissues from the soil, helping to evaluate the potential risks associated with soil contamination by heavy metals, especially in agricultural settings (Sagagi et al. 2022).

CONCLUSIONS

The water analysis indicates elevated lead (Pb) levels, which render it unsuitable for irrigation or drinking without prior treatment. Soil results reveal the presence of copper (Cu) and cobalt (Co), both utilized as micronutrient fertilizers. Notably, crop lead (Pb) and zinc (Zn) levels are increasing simultaneously; however, crop results show more variability than water and soil findings. This suggests that individual plants exhibit differing capacities for metal accumulation. For example, although soil samples revealed high concentrations of copper and cobalt, these metals were not present in significant amounts in the crops, indicating a variance in accumulation abilities among different plant species. This can be assessed using the transfer factor (TF). The TF values suggest that certain crops, especially leafy vegetables, can accumulate lead (Pb) and zinc (Zn). These plants may be classified as hyperaccumulators and have potential applications in phytoremediation. Conversely, crops with elevated TF values present health risks to humans and animals due to their direct link to the food chain. Consuming these contaminated crops could introduce heavy metals into the food system, adversely affecting the environment. As such, these crops should not be cultivated for consumption but can instead be used to identify and remediate contaminated soil.

Authors' contributions: Both the authors contributed equally.

Conflict of interest: Authors declare no conflict of interest.

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Received: 8th May 2025
Accepted: 7th July 2025