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Assessment of heavy metal levels in *Coriandrum sativum* cultivated in Bilaspur's Dhuripara region: A comprehensive study

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ABSTRACT

Irrigation with sewage water in agriculture may result in the uptake and accumulation of toxic heavy metals in edible crops, posing a significant risk to humans. Certain vegetables exhibit higher accumulation rates than others, and it is essential to investigate the extent to which these heavy metals accumulate in soil and the potential risks they pose. This study conducted at an irrigation site in Bilaspur, describes the heavy metal levels in sewage water, soil, and their transportation in various parts of *Coriandrum sativum* (coriander). The study revealed that the heavy metal content in the sewage water, soil and coriander was below the critical limits. The study measured the concentrations of eight different metal ions in various plant parts of *Coriandrum sativum,* cultivated using sewage water. It had relatively high concentrations of lead (Pb) and zinc (Zn) among other metals, however the concentration was below toxic limits. The bioaccumulation factor (BAF) and translocation factor (TF) of these metals indicated minimal accumulation within the plant tissues. Pb showed the highest TF, but its concentration remained within safe limits in the edible portions.

1. INTRODUCTION

With the global population on the rise, the demand for food has increased significantly. However, the limited availability of freshwater resources poses a problem to the sustainability of agricultural practices (Bahari, 1999). With the increasing scarcity of fresh water, farmers have been forced to explore alternative sources, such as sewage, for irrigation (Grewal, 2014). However, it is crucial to investigate the possible hazards linked to sewage water application in agriculture before widespread implementation. The presence of contaminants and pathogens in sewage water could impact crop and human health if consumed (Toze, 2006; Ramteke and Maurice, 2014). In addition, the enduring (long-term) consequences of using sewage water on soil quality and composition need to be thoroughly examined. The accumulation of toxic heavy metals in soil due to sewage water has been a longstanding concern regarding its impact. Sewage water contains various toxic heavy metals originating from different sources, and these elements in vegetables irrigated with this water can have ill effects on human health. Therefore, it is essential to comprehend the extent to which these heavy metals accumulate in soil and the potential risks they pose. Studies have shown that certain vegetables exhibit higher accumulation rates than others, and sewage water irrigation leads to the absorption (uptake) and buildup (accumulation) of these elements in vegetables (Anwar *et al.,* 2016). It is worth noting that certain metals can positively impact plant physiology and biochemical activity at low concentrations, including "the production of metabolized products such as glutathione, oxalic acid, histidine, citrate, and metal-binding proteins" (Yang and Chu, 2011; Younis *et al.,* 2015). However, toxicity can result from elevated levels of these metals and cause metabolic and photosynthetic disturbances. Heavy metals such as As, Pb, Cd, Ni, and Hg pose a risk to human health and the environment (Kiran *et al.,* 2022). These metals can negatively impact stomatal opening, leading to a reduction in photosynthesis (Sharma *et al.,* 2020). They can cause serious health issues such as cardiovascular, renal, and neuronal disorders (Rehman *et al.,* 2018). It is crucial to block the source of contamination to prevent it from entering the food chain and eventually human beings.

Coriandrum sativum (Coriander) is a versatile herb used in different cuisines and is widely grown in India. Cultivating coriander using wastewater can ensure a sustainable and abundant supply. Several studies have shown that it positively affects the plant growth, yield, and helps conserve water. Consuming coriander grown in soil contaminated by heavy metals contaminated soil using wastewater irrigation is unsafe for human health. Heavy metals can accumulate in various plant parts, especially leaves and seeds, and enter the human body when consumed.

It is highly desirable to conduct studies on heavy metal contamination in soil and its accumulation in widely grown leafy vegetables such as coriander, hence, we studied an irrigation site in Bilaspur, where municipal wastewater was used for irrigation.

2. MATERIALS AND METHODS

Study Area

The coordinates of Bilaspur are 22.09°N 82.15°E. On average, Bilaspur is 264 ft above mean sea level, positioned by the Arpa river, fed by rain, and originates from the Maikal range in central India. The geographical location of Dhuripara in Bilaspur Chhattisgarh can be found in Fig. 1, indicated by a black rectangle on the ward map. In addition, Photo 1a shows the wastewater canal, while Photo 1b showcases a field irrigated with wastewater and a bore well utilized to cultivate *Coriandrum sativum*.

Sampling Collection and Techniques (soil, sewage water and various parts of coriander)

The study employed different sample collection techniques to analyze heavy metals in sewage water, groundwater, soil and coriander.

Samples of sewage water were collected during the maximum growth stage of coriander and underwent several pre-treatment methods, including acidification, filtration, and digestion.

Groundwater samples were collected using bore well pumps and monitoring wells, while soil samples were collected through random sampling by the technique described elsewhere (Sarvade *et al.,* 2016).

The vegetable samples, including roots, stems, leaves, pods, and seeds, were harvested at specific times, washed with tap water, and dried before undergoing the digestion and filtration procedures as the other samples.

The metals considered for the study included Fe, Cu, Mn, Zn, Cd, Ni, Pb, and Cr.

The following steps were taken to analyze the heavy metal content of plant parts. First, the plant parts were

Fig. 1. Location of site Dhuripara in Bilaspur Chhatisgarh, indicated by a black rectangle on the map

Photo 1. a) The photographs of the wastewater canal, b) The field irrigated with sewage water and a borewell water for the cultivation of coriander

harvested and collected for analysis. After cutting into small pieces, they were rinsed with distilled water and dried in an oven. Next, the dried plant material was placed in a borosil beaker (digestion vessel) and mixed with 15 ml of concentrated nitric acid (HNO_3). The mixture was then heated over a hot plate until fully digested and allowed to stay overnight. It was followed by adding 2-3 drops of hydrogen peroxide, and the content was finally transferred into a volumetric flask and distilled water was added to make the volume up to 100 ml. The resulting solutions were analyzed using atomic absorption spectroscopy (AAS) (Lab India AA-8000), and chemical analysis was carried out thrice with a reagent blank, utilizing standard reference substances. The obtained data are indicated by mean value ± standard deviation (SD).

Translocation factor (TF), Bioconcentration factor (BCF) and Bioaccumulation factor (BAF)

The translocation of the metals in plants from root to leaf was measured using TF, which is calculated by dividing the amount of metal present (mg kg^{-1}) in the plant leaf by the amount of metal (mg kg^{-1}) present in the root.

$$TF = \frac{C_{leaf}}{C_{root}}$$

Additionally, the BAF value was determined by dividing the amount of metal present (mg kg^{-1}) in the leaf (in mg kg^{-1}) by the amount of metal present (mg kg^{-1}) in the soil.

$$BAF = \frac{C_{leaf}}{C_{soil}}$$

The BCF was calculated from the ratio of metal present (mg kg^{-1}) in roots and soil.

$$BCF = \frac{C_{root}}{C_{soil}}$$

These measurements are crucial in understanding the movement of trace metals within plants and their potential impact on the environment(Paterson *et al.,* 1990).

3. RESULTS AND DISCUSSION

The results of the evaluations of the wastewater from these sampling sites are as follows:-

Heavy Metals Contents in Sewage Water and Soil Used for Irrigation

The concentration of heavy metals in the sewage water is shown in Tables 1 and 2. The concentration of different metals in soils of control and treatment sites has been shown in Table 3. The same field was divided into two parts for the cultivation of both plants. The concentrations of all heavy metals were higher in treatment sites compared to the control site.

The mean concentration sequence in sewage water was Cr < Cd < Pb < Cu < Ni < Mn < Zn < Fe. For the treatment site, the order was Fe > Mn > Zn > Cr > Cu > Ni > Cd > Pb. The low value of toxic elements (Pb, Cd, Cr, Ni) suggests that sewage water can be used as the limit of detection was well within the permissible values. We can infer that the agricultural soil at sampling site 10 is fit for cultivating the *Coriandrum sativum*.

Iron Content in Sewage Water

All living organisms require iron as an essential trace element. It is crucial for several biological processes,

Table: 1
The maximum and minimum of different values obtained in heavy metal detection of all sampling sites (Site 1 to 10)

Metals	Range obtained		Limits (mg L^{-1}) for drinking purpose
	Min (mg L^{-1})	Max (mg L^{-1})	
Fe	0.450	1.560	0.3
Mn	0.040	0.620	0.1
Cu	0.015	0.046	0.2
Zn	0.120	0.430	2
Cd	0.008	ND	0.01
Ni	0.018	0.032	0.2
Pb	0.004	ND	0.5
Cr	0.012	0.056	0.1

Table: 2
Concentration of heavy metals (mg L^{-1}) in sewage water at different sampling sites (during harvesting month)

Heavy metals	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Mean	SD
Fe	1.930	1.780	1.110	0.820	0.890	0.980	0.670	0.450	1.130	1.560	1.132	0.483
Mn	0.157	0.130	0.040	0.090	0.150	0.050	0.069	0.071	0.396	0.620	0.177	0.186
Cu	0.040	0.060	ND	0.020	0.080	ND	0.080	0.170	0.015	0.046	0.064	0.049
Zn	0.133	0.390	0.590	0.120	0.260	0.220	0.130	0.550	0.340	0.430	0.316	0.172
Cd	0.047	ND	0.010	0.020	0.010	ND	0.050	ND	0.008	ND	0.024	0.019
Ni	0.040	0.040	0.080	ND	0.050	ND	0.070	0.400	0.018	0.032	0.091	0.126
Pb	0.053	0.030	0.060	0.080	0.020	0.074	0.004	0.024	0.033	ND	0.042	0.026
Cr	0.032	0.020	0.030	ND	0.040	0.012	0.034	0.083	ND	0.056	0.038	0.022

ND = Not detectable

Table: 3
Heavy metal content (mg kg^{-1}) in soil at different sampling site

Heavy metals	Treatment field soil (mg kg^{-1})	Control field soil (mg kg^{-1})	Permissible limit (mg kg^{-1})	Critical concentration in soil (mg kg^{-1})
Fe	12.617±0.129	8.573±0.180	15500-96700	20,000 to 550,000
Mn	13.670±0.105	13.470±0.114	20-10,000	1500-3000
Cu	1.197±0.097	1.140±0.062	2-250	60-125
Zn	1.553±0.065	0.457±0.061	1-900	70-400
Cd	0.006±0.002	0.001±0.000	0.01-2.0	3.0-8.0
Ni	0.356±0.010	0.211±0.010	2-750	100
Pb	0.259±0.008	0.006±0.002	2-300	100-400
Cr	0.038±0.005	0.012±0.005	5-1500	75-100

including "DNA synthesis, oxygen transportation, and energy production" (Ponka, 2000). Industrial wastewater, agricultural runoff, and domestic sewage are the primary sources of iron in sewage water. High levels of iron in sewage water can lead to the formation of insoluble precipitates, causing blockages in pipes and water treatment systems. Moreover, iron can react with organic compounds and other pollutants in sewage water, forming highly toxic compounds (Coker and Matthews, 1983). In addition to industrial discharges and domestic sewage, natural sources also contribute to the presence of iron in sewage. The iron was present at every sewage collection site. It ranged between 0.450 and 1.930 mg L^{-1}. The minimum Fe content was 0.450 mg L^{-1} at site 8, and the highest was 1.930 mg L^{-1} at site 1. In this study the iron content in the control (borewell water) was 0.28 mg L^{-1}. The Fe content in the soil of the treatment and control site were 8.573 mg L^{-1} and 12.617 mg L^{-1}, respectively. The other reports in various parts of India show considerable variation. In Ariyamangalam, Tiruchirappalli district, Tamil Nadu, the leachate contained 400 mg L^{-1} of Fe (Kanmani and Gandhimathi, 2013). In a study on runoff water in Raipur city, Chhattisgarh, runoff water contained 0.215-0.929 mg L^{-1} of Fe (Ambade, 2015), however, in Kasimpur, Aligarh, the rivulet water contained 8.71 mg L^{-1} (Javed and Usmani, 2013). The lake water at Nagpur had a value between 0.103-0.185 mg L^{-1} and 0.189 - 0.342 mg L^{-1} for iron (Giripunje *et al.,* 2014). In Chitradurga district, Karnataka, the underground water contains iron content ranging from 0 to 0.4 mg L^{-1} (Basavarajappa and Manjunatha, 2015). The groundwater and treatment water in Mathura had Mn content in the range of 0.75 and 0.93 mg L^{-1} (Hayat *et al.,* 2002). Similarly, at Wazirabad and Delhi, the Fe content of treated wastewater ranged between 0.431 and 1 mg L^{-1}(Arora and Saxena, 2005). In Jodhpur, Rajasthan, municipal effluent and canal water had iron contents of 2.66-6.24 and 0.080 mg L^{-1}, respectively (Singh and Bhati, 2005). Similarly, the soil in the districts of "Jorhat, Sivasagar, Dibrugarh, and Tinsukia" located in upper Assam contained 261.0 mg kg^{-1} of iron (Sarma *et al.,* 2016), and the soil in the region of Bagru (Rajasthan) contained 5.9782 mg kg^{-1} of iron (Khan *et al.,* 2022).

Manganese Content in Sewage Water

Manganese is an essential trace mineral in Indian wastewater and is needed in numerous biological activities. However, excessive manganese levels can have detrimental effects on human health, causing neurological disorders and impairing cognitive function. Agricultural runoff also causes manganese contamination in sewage water. The extensive use of fertilizers and pesticides in agriculture causes Mn buildup in soil, which then makes its way into sewage water through rainfall or irrigation (Tiller, 1989). Manganese was found in sewage at ten sites with levels ranging from 0.040-0.620 mg L^{-1}. The Mn content ranged from 0.040 mg L^{-1} at site 3 (lowest) to 0.620 mg L^{-1} at site 4 (highest). The Mn content at the control site soil and treatment site was almost the same, 13.470 mg L^{-1} for control and 13.670 mg L^{-1} for treatment, respectively. According to some previous reports, for rivulet water in Kasimpur, Aligarh, it was 0.21 mg L^{-1} (Javed and Usmani, 2013), for runoff water in Raipur it was 0.148-1.048 mg L^{-1} (Ambade, 2015), in Ariyamangalam, Tiruchirappalli district, Tamil Nadu Leachate it was 8.18 mg L^{-1} (Kanmani and Gandhimathi, 2013), in lake water at Nagpur it ranged between 0.050 to 0.076 mg L^{-1} and 0.074 to 0.094 mg L^{-1} (Giripunje *et al.*, 2014), in groundwater of Moradabad city it ranged from 0.020 to 0.096 mg L^{-1} in pre-monsoon season and mg L^{-1} in post-monsoon season (Saba and Umar, 2016), in Mathura ground and treatment water it was 0.02–0.06 mg L^{-1}, respectively (Hayat *et al.*, 2002), in Wazirabad, Delhi treated wastewater Mn 0.3-2 mg L^{-1} (Arora and Saxena, 2005). For municipal effluent and canal water in Jodhpur, Rajasthan, it was 0.26-0.80 and 0.020 mg L^{-1} , respectively (Singh and Bhati, 2005).

In soil analysis reports, the findings are very different. In the region of Bagru (Rajasthan), it was 4.2093 mg kg^{-1} (Khan *et al.*, 2022). In Jhansi, Bundelkhand, it ranged between 4.65 and 33.950 mg kg^{-1} (Gupta *et al.*, 2021), in the districts of "Jorhat, Sivasagar, Dibrugarh, and Tinsukia" located in upper Assam, it was 627.83 mg kg^{-1} (Sarma *et al.*, 2016) for Punjab, it was 9.0-48.55 mg kg^{-1} (Bhatti *et al.*, 2016) and 13.67 to 25.0 mg g^{-1} (Bhatti *et al.,* 2016).

Copper Content in Sewage Water

Copper is a vital element in biological processes, however, excessive amounts in water and soil can lead to toxicity, affecting aquatic life and soil microorganisms and thus reducing biodiversity and ecosystem health. High quantities of copper can harm the liver and kidneys, induce anemia, and create gastrointestinal issues in people. Copper toxicity in water and soil can be caused by mining, wastewater discharge from some industrial sectors, and agricultural runoff (Zwolak *et al.,* 2019). Our finding for copper (control site) in borewell water was 0.032. In sewage water, it ranged between 0.015 mg L^{-1} and 0.170 mg L^{-1}, and in the soil, it varied from 1.07 to 1.22 mg kg^{-1} in control and treatment sites, respectively. Copper was not detected at sites 3 and 6. Cu content ranged from 0.015 to 0.170 mg L^{-1} among the sites, with the minimum at site 1 and the maximum at site 8. It was 1.140 mg kg^{-1} in the control site and 1.197 mg kg^{-1} at the treatment site soil.

According to previous reports, the copper content varied widely. In the rivulet water in Kasimpur, Aligarh, the copper content was 0.86 mg L^{-1} (Javed and Usmani, 2013) in the lake water at Nagpur, it ranged between 0.329 to 0.522 mg L^{-1} and 0.625 to 0.839 mg L^{-1} (Giripunje *et al.*, 2014), in groundwater of Moradabad city it ranged from 0.020 to 0.096 mg L^{-1} in pre-monsoon season and mg L^{-1} in post-monsoon season it ranged from 0.024 to 0.139 mg L^{-1} (Saba and Umar, 2016), and in Mathura ground and treatment water, it was 0.025 mg L^{-1} and 0.04 mg L^{-1}, respectively (Hayat *et al.*, 2002). For municipal effluent and canal water in Jodhpur, Rajasthan, it was 0.250-0.540 mg L^{-1} and 0.0030 mg L^{-1}, respectively (Singh and Bhati, 2005). The earlier reports on copper content in soil also varied. In the region of Bagru (Rajasthan), it was 0.1701 mg kg^{-1} (Khan *et al.*, 2022), Jhansi, Bundelkhand, it ranged between 4.650 and 33.950 mg kg^{-1} (Gupta *et al.*, 2021), in the districts of Jorhat, Sivasagar, Dibrugarh, and Tinsukia located in upper Assam, it was 11.86 mg kg^{-1} (Sarma *et al.*, 2016) for Punjab, it was 9.0-48.55 mg kg^{-1} (Bhatti *et al.*, 2016) and 13.67 to 25.0, (Bhatti *et al.*, 2016) in Ariyamangalam, Tiruchirappalli District, Tamil Nadu leachate, it was 1.92 mg L^{-1} (Kanmani and Gandhimathi, 2013).

Zinc Content in Sewage Water

Zinc is an essential element for plants, but high levels in water and soil can be toxic. Zinc contamination may be due to industrial effluent discharge or runoff from galvanized roofs or pipes (Oubane *et al.,* 2021). In soil, zinc toxicity can result from the overuse of zinc-containing fertilizers or the disposal of industrial waste. Zinc was detected in water samples at all sites. The concentration levels recorded at site 3 and site 4 were 0.590 mg L^{-1} (minimum) and 0.120 mg L^{-1} (maximum), respectively. In soil, it was 0.457 mg kg^{-1} (control site) and 1.555 mg kg^{-1} (treatment site). In this study, zinc content in borewell water was 0.34 mg L^{-1} and varied between 0.120-0.590 mg L^{-1} in sewage sites. The various earlier reports suggest that with the change of source and place, zinc concentration varies significantly. For instance, it was 4.80 mg L^{-1} in Leachate at Ariyamangalam, Tiruchirappalli district, Tamil Nadu (Kanmani and Gandhimathi, 2013), in runoff water of Raipur it was 0.14^{-1}-1.864 mg L^{-1} (Ambade, 2015), in Kasimpur, Aligarh rivulet water, it was 0.30 mg L^{-1} (Javed and Usmani, 2013), in groundwater of Moradabad city it ranged from 0.0531 to 4.662 mg L^{-1} in pre-monsoon season and 0.415 to 5.228 mg L^{-1} in post-monsoon season (Saba and Umar, 2016), in Bareilly district ground-water it was 0.06 mg L^{-1} (Idrees *et al.,* 2018) while in Mathura groundwater and treatment water it was 0.12 and 0.25 mg L^{-1}, respectively (Hayat *et al.*, 2002). Similarly, it was 0.01-0.06 mg L^{-1} in treated wastewater fromWazirabad, Delhi (Arora and Saxena, 2005).

Zn content in the soil ranged from 1.47 to 1.55 mg kg^{-1} in the control and treatment sites, respectively. In the soil of various parts of India, the zinc content was reported to be 3.451 mg kg^{-1}, in the region of Bagru (Rajasthan) (Khan *et al.*, 2022), in Jorhat, Sivasagar, Dibrugarh and Tinsukia districts of upper Assam, it was 144.79 mg kg^{-1} (Sarma *et al.*, 2016), at Jhansi it was 20.875-62.830 mg kg^{-1} (Gupta *et al.*, 2021).

Cadmium Content in Sewage Water

Cadmium (Cd) is a very poisonous heavy metal resulting in severe health issues such as kidney damage and cancer when present in soil or water. Cadmium can enter soil through water and accumulate in plants, making it a hazardous pollutant. Cadmium was not detected at sites 2, 6, 8, and 10. It fluctuated between 0.008-0.050 mg L^{-1}. The Cd ranged from 0.008 mg L^{-1} at site 9 (minimum) to 0.050 mg L^{-1} at site 7 (maximum). For the control and treatment sites, cd content for soil was 0.001 and 0.006 mg kg^{-1}, respectively. Cadium was not detected in borewell water and varied between 0.008-0.050 mg L^{-1} in sewage sites.

The earlier reports indicate that cadmium content changes significantly with the source and place. For instance, it was 4.80 mg L^{-1} in the leachate at Ariyamangalam, Tiruchirappalli district, Tamil Nadu (Kanmani and Gandhimathi, 2013), in runoff water of Raipur it was 0.14-1.864 mg L^{-1} (Ambade, 2015), in Kasimpur, Aligarh rivulet water it was 0.30 mg L^{-1} (Javed and Usmani, 2013), in groundwater of Moradabad city it ranged from 0.0531 to 4.662 mg L^{-1} in pre-monsoon season and 0.415 to 5.228 mg

L^{-1} in post-monsoon season (Saba and Umar, 2016), in Bareilly district groundwater it was 0.06 mg L^{-1} (Idrees *et al.*, 2018), while in Mathura groundwater and treatment water, it was 0.12 mg L^{-1} and 0.25 mg L^{-1}, respectively (Hayat *et al.*, 2002). Similarly, it was 0.01-0.06 mg L^{-1} in the treated wastewater of Wazirabad, Delhi (Arora and Saxena, 2005). For soil, it varied from 0.001 and 0.008 mg kg^{-1} in the control and treatment sites, respectively. In the soil of various parts of India, the Cd content was reported to be 0.15-0.37 mg kg^{-1} in the Pumjab (Bhatti *et al.,* 2016), Jorhat, Sivasagar, Dibrugarh, and Tinsukia districts of upper Assam, at 15.47 mg kg^{-1} (Sarma *et al.*, 2016), and at Jhansi, it was 0.375-8.90 mg kg^{-1} (Gupta *et al.*, 2021).

Nickel Content in Sewage Water

Nickel is a vital element in small amounts for the effective functioning of biological processes but is toxic at high levels. The WHO has set a limit of 0.02 mg L^{-1} for nickel in drinking water (WHO, 2011). Nickel can accumulate in sludge in sewage water, leading to potential contamination of soil during its application as fertilizer. In soil, nickel toxicity can affect plant growth and development. The nickel content in the sewage varied from 0.004 to 0.08 mg L^{-1}. It was undetected at sites 4 and 6. At site 8, the highest value (0.40 mg L^{-1}) was recorded, while at site 9, the lowest value (0.018 mg L^{-1}) was observed. Our finding for nickel in borewell water was 0.012 mg L^{-1}. In soil, the nickel contents at the control and treatment sites were 0.212 and 0.346 mg kg^{-1}, respectively. The other reports are for Kasimpur, Aligarh river water, it was 0.12 mg L^{-1} (Javed and Usmani, 2013), and in groundwater of Moradabad city, it ranged from 0.025 to 0.126 mg L^{-1} in pre-monsoon season and 0.020 to 0.096 mg L^{-1} in post-monsoon season (Saba and Umar, 2016). In Mathura, the groundwater and treatment water had nickel contents of 0.25 and 0.36 mg L^{-1}, respectively (Hayat *et al.*, 2002). However, at Wazirabad, Delhi, treated wastewater was not detected (Arora and Saxena, 2005).

For soil, it ranged from 0.212 to 0.346 mg kg^{-1} in the control and treatment sites, respectively. The other reports of Cd contamination are at "Jorhat, Sivasagar, Dibrugarh, and Tinsukia" districts of upper Assam, the soil had 58.97 mg kg^{-1} of nickel (Sarma *et al.*, 2016), whereas at Jhansi, it ranged from 5.420 to 51.050 mg kg^{-1} (Gupta *et al.*, 2021).

Lead Content in Sewage Water

Lead is an extremely poisonous heavy metal that can cause serious health problems if ingested or inhaled. Lead contamination in drinking, sewage water, and soil can be a public health concern. Lead exposure can lead to developmental delays in children and cause neurological and cognitive problems in adults(Tangahu *et al.,* 2011). Lead pollution in water sources can be attributed to industrial wastewater discharge, disposal of waste or hazardous electronic waste, and lead-based paints. The lead (Pb) content in the sewage varied from 0.004 to 0.080 mg L^{-1}. The minimum value (0.004) was reported at site 7, and the maximum value (0.080) was reported at site 4. It was undetected at sampling site 10. It was undetected in bore well water. Various earlier reports have indicated that Pb content significantly changes with changes in the source and place. In Ariyamangalam, Tiruchirappalli district, Tamil Nadu, groundwater contained 1.85-5.15 mg L^{-1} of Pb (Kanmani and Gandhimathi, 2013). In Raipur city, the runoff water contained 0.115-0.48 mg L^{-1} of Pb (Ambade, 2015), whereas, in the lake water in Nagpur, the Pb content ranged from 0.046-0.081 and 0.074-0.105 mg L^{-1} (Giripunje *et al.*, 2014). The groundwater and treatment water at Mathura contained 0.01 and 0.02 mg L^{-1} of Pb, respectively (Hayat *et al.*, 2002). It remained undetected in treated wastewater in Wazirabad, Delhi (Arora and Saxena, 2005). The groundwater of Moradabad City, Uttar Pradesh, contained 0.060-1.707 mg L^{-1} and 0.051-0.247 mg L^{-1} of Pb (Saba and Umar, 2016).

For soil, it varied from 0.005-0.251mg kg^{-1} in the control and treatment sites, respectively in our sites. The soil of the Punjab region has Pb contents varying between 2.83 and 9.17 mg kg^{-1} (Bhatti *et al.,* 2016[a]) and 5.5-9.67 mg kg^{-1}, respectively (Bhatti *et al.*, 2016[b]). The "Jorhat, Sivasagar, Dibrugarh, and Tinsukia" districts of upper Assam had an extremely high Pb content of 73.62 mg kg^{-1} (Sarma *et al.*, 2016), whereas, at Jhansi, Pb in soil varied between 4.155 and 24.520 mg kg^{-1} (Gupta *et al.*, 2021).

Chromium Content in Sewage Water

Chromium is a natural element of the earth's crust, soil, and water. It exists in two forms - Cr (VI) and Cr (III). While Cr (VI) can be harmful and even cause cancer, Cr (III) is necessary for the health of both animals and humans. Exposure to high levels of hexavalent chromium [Cr(VI)] can cause various health problems, including lung, kidney, liver, and skin diseases (Nath *et al.,* 2005). In soil, Cr (VI) can be taken up by plants, posing health risks for humans and animals consuming them. Similarly, Cr (VI) can accumulate in aquatic organisms, affecting aquatic life and the humans who consume them. In this study, chromium was not present at the sampling locations 4 and 9. A minimum concentration of 0.012 mg L^{-1} was found at site 6, while the highest concentration of 0.083 mg L^{-1} was detected at site 8. The Cr content in bore water for our investigation was 0.005 mg L^{-1}. The other reports are for rivulet water, Kasimpur, Aligarh, it was 0.10 mg L^{-1} (Javed and Usmani, 2013). In the groundwater of Moradabad city it ranged from 0.048-0.072 mg L^{-1} in the pre-monsoon season and 0.036 to 0.071 mg L^{-1} in the post-monsoon season (Saba and Umar, 2016), and in groundwater and treatment water at Mathura, it varied between 0.02-0.04 mg L^{-1} (Hayat *et al.*, 2002). At Wazirabad, Delhi-treated wastewater was not detected (Arora and Saxena, 2005).

In the soil, it ranged between 0.011 and 0.042 mg kg^{-1} for the control and treatment sites, respectively. The values reported for other regions were 21.37-75.70 mg kg^{-1} (Bhatti *et al.*, 2016) in Punjab and 8.86-35.58 mg kg^{-1} (Saba and Umar, 2016) in Moradabad, respectively. The districts of "Jorhat, Sivasagar, Dibrugarh, and Tinsukia" located in upper Assam, were highly contaminated due to mining, and Cr was found to be 158.66 mg kg^{-1} (Sarma *et al.*, 2016).

The heavy metal levels in both the sewage water and the contaminated soil fall within permissible limits, and are mostly lower than levels reported in other parts of India (according to cited work), significantly reduces concerns about potential health risks associated with coriander cultivation in Dhuripara. Moreover, sewage water can be potentially used for irrigation in a sustainable way, promoting water conservation and reducing reliance on freshwater sources.

Bioaccumulation of Heavy Metals in Plant Parts

The buildup of heavy metals in several plant components, such as the root, stem, leaves, and coriander seeds, may negatively affect plant and human health. Plants can absorb metals from the soil and accumulate them in their tissues, resulting in a process known as phytoextraction, which is essential for many biological functions. However, excessive metal accumulation can harm the plant and may even lead to its death. Understanding the mechanisms behind metal accumulation in plants is thus critical for developing strategies to improve plant growth and productivity while minimizing the risks associated with metal toxicity.

The amount of heavy metals in the different parts of coriander plant has been shown in Tables 4 and 5 for control and treatment, respectively.

Iron Content in Coriander Plant

In the borewell water-irrigated coriander plant, the roots contained the highest amount of Fe (7.310 mg kg^{-1}), whereas it was lowest in the seed (1.073 mg kg^{-1}). In contrast, in the sewage-irrigated coriander plant, the leaf had the highest iron content (11.915 mg kg^{-1}), whereas the seeds had the lowest (1.341 mg kg^{-1}). The order of Fe content was root > stem > leaf > seed. According to Sahito *et al.* (2016), the Fe content ranged from 107 to 138 mg kg^{-1}, and the order was root > leaf > shoot (Sahito *et al.,* 2016). Similarly, Sinha *et al.* (2006) reported a range of 1107.08-2634.59 mg kg^{-1}, and the order was root > leaf (Sinha *et al.*, 2006). Other reports have shown iron content in leaves ranging from 0.64-0.72 mg kg^{-1} (Khan *et al.*, 2018), 1855.23-2994.30 µg g^{-1}, 0.075 mg g^{-1} (Hussain *et al.*, 2022), 530.25-2365.70 µg g^{-1} (Sultana *et al.,* 2022) and 0.07-3.64 mg kg^{-1} (Hussain *et al.*, 2023).

Table: 4
Concentrations of heavy metals (mg kg^{-1}) in different plant parts of coriander and soil under control condition

Heavy metal	Root	Stem	Leaf	Seed	Soil
Fe	7.310±0.014	5.666±0.013	2.362±0.017	1.073±0.007	8.573±0.180
Mn	0.676±0.008	1.004±0.007	0.352±0.007	0.417±0.005	13.470±0.114
Cu	0.146±0.008	0.171±0.009	1.184±0.008	0.177±0.010	1.140±0.062
Zn	1.302±0.009	1.535±0.007	1.154±0.009	1.081±0.007	1.457±0.061
Cd	ND	ND	ND	ND	0.001±0.000
Ni	BDL	BDL	BDL	BDL	0.211±0.010
Pb	0.065±0.004	0.140±0.005	0.078±0.003	0.019±0.007	0.076±0.002
Cr	0.005±0.003	0.008±0.001	0.010±0.002	0.006 ±0.004	0.012±0.005

ND = Not Detected BDL = Below detection limit

Table: 5
Concentrations of heavy metals (mg kg^{-1}) in different plant parts of coriander and soil under treated condition

Heavy metal	Root	Stem	Leaf	Seed	Soil
Fe	11.985±0.521	8.700±0.187	4.512±0.115	1.341±0.058	12.617±0.129
Mn	0.939±0.010	1.188±0.007	0.514±0.010	0.596±0.000	13.670±0.105
Zn	1.582±0.012	1.755±0.007	1.432±0.009	1.687 ±0.005	1.197±0.097
Cu	0.166±0.020	0.185±0.003	1.509±0.043	0.245 ±0.032	1.553 ±0.065
Cd	0.005 ±0.003	0.004±0.003	0.005 ±0.003	0.003 ±0.002	0.006 ±0.002
Ni	BDL	BDL	BDL	BDL	0.211 0.010
Pb	0.133 ±0.014	0.147±0.046	0.150 ±0.025	0.108 ±0.014	0.259 ±0.008
Cr	0.024 ±0.009	0.019±0.006	0.026 ±0.007	0.024 ±0.007	0.038 ±0.005

Manganese Content in Coriander Plant

In the control site, the minimum Mn content was found in the leaf, whereas the maximum was found in the stem, with values of 0.052 and 1.004 mg kg^{-1}, respectively. The stem had the lowest concentration among all the parts of the treatment site plant, and the maximum was in the leaf, with values of 0.007 and 0.017 mg kg^{-1}, respectively. The order of Mn content was stem > root > seed > leaf. Other studies have reported Mn content ranging from 0.04 to 3.36 mg kg^{-1} (Hussain *et al.*, 2023) in their plant tissues, 54.73 mg kg^{-1} in roots and 358.67 mg kg^{-1} in shoots (Ramesh and Moorthy, 2012), 36.5-324.6 mg kg^{-1} (Sultana *et al.*, 2022), and 21.65 mg kg^{-1} (Gupta *et al.*, 2022) in leaves. Sinha *et al.* (2006) found that the Mn content varied from 46.73 to 49.72 mg kg^{-1} in roots and 61.24-65.64 mg kg^{-1} in leaves, with the order being root > leaf (Sinha *et al.*, 2006).

Copper Content in Coriander Plant

At the control site, Cu was primarily contained in the leaf (1.184 mg kg^{-1}) and lowest in its root (0.146 mg kg^{-1}). In the plant irrigated with sewage, the leaf had the highest concentration, and the root had the lowest concentration (1.509 and 0.166 mg kg^{-1}, respectively). The Cu content order at both sites was leaf > seed > stem > root. According to Anwar *et al*. (2016), the bioaccumulation of copper was root > leaf > shoot, with values ranging between 0.0005 and 0.004 mg kg^{-1}. Khan *et al.* (2018) reported a value of 0.02 mg kg^{-1} in leaves. Ramesh and Moorthy (2012) found a range of 3.58-60.77 mg kg^{-1}(Rameshand Moorthy, 2012). Bhatia *et al.* (2015) reported a of 0.23 mg kg^{-1} in leaves, whereas Gupta *et al.* (2008) reported a range of 20.8-28.6 mg kg^{-1} for the vegetable as a whole (Gupta *et al.*, 2008).

Zinc Content in Coriander Plant

Zinc (Zn) content in the control site plant was highest in the stem (1.035 mg kg^{-1}) and lowest in the seed (1.081 mg kg^{-1}). Meanwhile, in the treatment site plant, it was highest in the stem (1.755 mg kg^{-1}) and lowest in the leaf (1.432 mg kg^{-1}). The order of Zn content followed stem > seed > root > leaf. However, according to Anwar *et al.*, 2016 a range of 0.020-0.430 mg kg^{-1} for stems and 0.015-0.170 mg kg^{-1} for leaves was reported. The bioaccumulation order was leaves > roots > shoots by Anwar *et al.* (Anwar *et al.*, 2016). In leaves, Khan *et al.* discovered a Zn content range of 0.57-0.66 mg kg^{-1} (Khan *et al.*, 2018), whereas Ramesh and Moorthy reported a Zn content range of 9.98-99.56 mg kg^{-1} (Ramesh and Moorthy, 2015). Bhatia *et al.,* found a considerably low Zn content in leaves, which was 0.0369 mg kg^{-1} (Bhatia *et al.*, 2015). However, Gupta *et al.* (2008) reported a high accumulation of Zn metal ranging from 126.5-149 mg kg^{-1} (Gupta *et al.*, 2008).

Cadmium Content in Coriander Plant

Cadmium was undetected in any plant part of coriander at the control site plant, whereas it was almost the same in root, stem, and leaf (0.005 mg kg^{-1} and 0.004 mg kg^{-1}) and a minimum 0.003 mg kg^{-1} in the seed at the treatment site irrigated coriander plant. In the treatment wastewater, the order of Cd content was root > leaf > stem > seed. However, at the control site, no cadmium was detected. Ramesh and Moorthy reported a similar finding where cadmium was undetectable (Ramesh and Moorthy, 2012). Anwar *et al.* found a value of 0.0038-0.00497 mg kg^{-1} and found that the order of bioaccumulation was stem > root > leaf. According to Bhatia *et al.*, the value was 0.14 mg kg^{-1} in leaves (Bhatia *et al.*, 2015). In contrast, Mani *et al.,* reported an exceptionally high level of contamination ranging from 61.9 to 120.9 µg L^{-1} and 199-415.9 µg L^{-1} in control and wastewater-irrigated crops (Mani *et al.,* 2012). Gupta *et al.* also reported a range of 9-26.9 µg kg^{-1} (Gupta *et al.*, 2008).The order of Cd content followed root, leaf > stem > seed in treatment wastewater. Cadium was not detected at the control site. In a similar report, it was undetectable (Ramesh and Moorthy, 2012). Anwar *et al.* reported a value of 0.0038-0.00497 mg kg^{-1}, and the order of bioaccumulation was stem > root > leaf (Anwar *et al.*, 2016), Bhatia *et al.* reported a value of 0.14 mg kg^{-1} in leaves (Bhatia *et al.*, 2015).

Nickel Content in Coriander Plant

Ni ranged from 0.15 and 1.58 mg kg^{-1} in different plant parts at the control site, while it ranged between 0.17 and 0.68 mg kg^{-1} at the treatment site. The maximum value was found in the seed, and the minimum was in the stem at the control site. On the contrary, the maximum concentration was in the leaf (1.118) and the minimum (0.544) was in the stem at the treatment site. Our investigation found that the order of Ni content was root > leaf > stem > seed. According to various studies, the nickel content in coriander leaves ranges from 0.08-0.14 mg kg^{-1} (Khan *et al.*, 2018) to 24.7-68.9 mg kg^{-1} (Gupta *et al.*, 2008), and 1.70-4.50 mg kg^{-1} (Sultana *et al.*, 2022). Souri *et al.* reported a value of 0.27 mg kg^{-1} in edible parts of coriander(Souri *et al.,* 2018), while Gupta *et al.* reported a value of 2.12 mg kg^{-1} (Gupta *et al.*, 2022). However, in a report by Abdella *et al.*, nickel remained undetected (Abdella *et al.,* 2018).

Lead Content in Coriander Plant

The leaf in the control site of the coriander plant had the highest Pb content, measuring at 0.140 mg kg^{-1}. Meanwhile, a minimum of 0.019 mg $kg^{-1}$was found in the seed. At the treatment site, the highest Pb content was also found in the leaf (0.158 mg kg^{-1}), and the lowest in the seed at (0.108 mg kg^{-1}). In this study the order of Pb content was leaf > stem > root > seed. Farooq *et al.* reported a Pb variation between 1.531-2.652 mg g^{-1} with the order being leaf > stem > root

(Farooq *et al.,* 2008). Gaur *et al.*, reported a much higher value of 5.47-350.88 µg kg^{-1}, 4.92-300.24 µg kg^{-1}, 2.12-60.58 µg kg^{-1} with the order of root > stem > leaf (Gaur *et al.,* 2017). According to Mani *et al.*, the root and leaf had Pb contents of 1.98-3.87 mg kg^{-1} and 1.57-2.54 mg kg^{-1}, respectively, with the order being root > leaf (Mani *et al.*, 2012). Khan *et al.*, found that the Pb content in coriander leaves varied between 0.21-0.29 mg kg^{-1} (Khan *et al.*, 2018). Ramesh and Moorthy reported a range of 54.69-75.5 µg kg^{-1} (Ramesh and Moorthy, 2012), while Bhatia reported 2.32 mg kg^{-1} (Bhatia *et al.*, 2015) and Gupta *et al.* reported 25-35.3 µg kg^{-1} in leaves (Gupta *et al.*, 2008).

Chromium Content in Coriander Plant

Chromium content at the control site in the coriander ranged between 0.005 and 0.010 mg kg^{-1}. The maximum value was found in the leaf and minimum in the root. At the treatment site, it ranged between 0.019 and 0.026 mg kg^{-1}. The maximum was in the leaf, and the minimum was in the root and seed. The order of Cr content was leaf > root > seed > stem. According to Farooq *et al.*, the amount of Cr in leaf, stem, and root was 0.502 mg kg^{-1}, 0.874 mg kg^{-1}, and 0.369 mg kg^{-1}, respectively (Farooq *et al.*, 2008). The order of concentration was stem > root > leaf. Ramesh and Moorthy reported that the concentration of Cr content in root and shoot was 8.46 µg kg^{-1} and 127.27 µg kg^{-1}, respectively (Ramesh and Moorthy, 2012). In a report by Gupta *et al.*, the Cr levels in leaves were between 39.7-56 µg kg^{-1} (Gupta *et al.* 2008). Sinha *et al.* (2006) reported a range of 43.68-75.45 µg kg^{-1} and 27.41-83.06 µg kg^{-1} for root and leaf, respectively. The order of concentration was root > leaf (Sinha *et al.*, 2006).

Maximum Permissible Limits of Heavy Metals in Vegetables (India)

The Table 5 provides indicative maximum permissible limits (MPLs) for some heavy metals in vegetables grown in India.

The above data suggest that the results obtained for the heavy metal content in the edible parts of the coriander is within the maximum permissible limits of the heavy metals in vegetables grown in India as per the guidelines of FSSAI (FSSAI, 2011).

Determination and uptake of heavy metal levels understanding how plants absorb, move, and accumulate metals in various areas, from agriculture to environmental research is essential. These mechanisms affect a plant's ability to withstand and collect heavy metals and its growth and development. Based on the data from Tables 3 and 4, the values of the TF, BAF, and bioconcentration factor are indicated in Table 6.

The results suggest that heavy metal absorption and translocation in plants may be influenced by “mobility and competition with other metals” (Gupta *et al.,* 2019). The treatment site generally had a higher TF for most metals than the control site, except for zinc and lead. *Coriandrum sativum* showed a high lead transport capacity at the control site, with TF values for Pb and Zn being highest at the control site and for Cu and Cd at the treatment site. This suggests that these metals are more mobile in nature.

Notably, the TF values for Cd and Zn from soil to crop indicated a potent accumulation of these metals by vegetables, with Pb being transported to the leaves of *Coriandrum sativum* rather than concentrated in the roots. The study also discovered that roots and leaves had a noticeably higher content of Cd at treatment site.

Interestingly, while most metals accumulated in roots, Mn, Zn, and Pb were accumulated more in stems. Additionally, in crops cultivated using sewage water, Pb accumulated in leaves, Mn in stem, and Zn in seeds. The BAF order was Mn > Zn > Pb > Cr > Ni > Cd > Fe > Cu. Zn was accumulated in higher levels, followed by Pb, Cr, Cd, Cu, Ni, Mn, and Fe (as revealed by their BCF values) in areas irrigated with sewage water. Generally, the mechanism that controls trace element bioaccumulation involves the influx and efflux of metals from the medium (such as soil and water) into plants and various parts (Gupta *et al.,*

Table: 6
Maximum permissible limits (MPLs) of heavy metals in vegetables

Metal	MPLs (mg kg^{-1})	Reference
Iron (Fe)	-	Not individually regulated
Manganese (Mn)	400	FSSAI (2018)
Copper (Cu)	40	FSSAI (2018)
Zinc (Zn)	60	FSSAI (2018)
Cadmium (Cd)	0.2	FSSAI (2018)
Nickel (Ni)	20	FSSAI (2018)
Lead (Pb)	0.3	FSSAI (2018)
Chromium (Cr)	2.0	FSSAI (2018)

Table: 7
Translocation factor, bio-accumulation factor, and bio-concentration factor of heavy metals in Coriander under control and treatment condition

Heavy metals	Control site			Treatment site		
	TF	BAF	BCF	TF	BAF	BCF
Fe	0.85	0.28	0.32	0.95	0.36	0.38
Mn	0.05	0.03	0.52	0.07	0.04	0.55
Cu	0.13	1.04	8.09	1.32	1.20	0.90
Zn	2.85	2.53	0.89	0.11	0.97	9.09
Cd	-	-	-	0.94	0.94	1.00
Ni	-	-	-	0.75	0.66	0.87
Pb	10.78	13.00	1.21	0.51	0.58	1.13
Cr	0.41	0.81	2.00	0.64	0.70	1.10

2019). While most metals showed low mobility in plants, Pb, Cd, and Zn had a potent accumulation in vegetables and were transported to the leaves of *Coriandrum sativum*. Similar results were earlier reported (Khan *et al.,* 2018; Gupta *et al.,* 2022; Hussain *et al.,* 2023; Souri *et al.,* 2018).

4. CONCLUSIONS

The current study investigated heavy metal contamination in sewage water, soil, and the coriander plants (*Coriandrum sativum*) grown in that soil in the Dhuripara region of Bilaspur, India. The findings indicated that site 10 generally had lower levels of heavy metals in the sewage water from other sites. The analysis of soil from fields irrigated with sewage water compared to those irrigated with borewell water (control) suggested that sewage water introduces heavy metals into the soil. Furthermore, the study explored that manganese (Mn), zinc (Zn), and lead (Pb) accumulated more in the stems when grown with borewell water. Conversely, in plants grown with sewage water, Pb accumulated in the leaves, while Mn remained in the stems, and Zn accumulated in the seeds.

The levels of heavy metals in both the soil and the edible parts of coriander grown with sewage water fell within permissible limits. It suggests that coriander cultivation in the Dhuripara region is currently safe. Additionally, the BAF and TF of these metals indicated minimal accumulation within the plant tissues. While Pb showed the highest TF, its concentration remained within safe limits in the edible portions.

However, for a more comprehensive understanding of the contamination, future studies should specify the source and type (industrial or residential) of the sewage water used for irrigation.

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