RESEARCH ARTICLE

Accumulation of Heavy Metals in the Vegetables Cultivated in the Subarnarekha River Basin of Ranchi City

Sweta, Bhaskar Singh*

DOI: 10.18811/ijpen.v11i01.19

Abstract

Heavy metal (HM) contamination in agroecosystems and edible crops is a worldwide issue. It is becoming an emerging threat to global food security. There is a huge pressure on the entire world to fulfill the increasing demand for food to nourish the burgeoning population. The periodical monitoring to assess the HM contamination in the agricultural land and the edible crops may help in tracking the HM status, thereby minimizing the risk of HM toxicity. The objective of the present study was to check the physicochemical properties of the river water used for irrigation purposes and soil for the cultivation of edible crops along with the presence of different heavy metals (HMs) viz., copper (Cu), cadmium (Cd), lead (Pb) nickel (Ni), and iron (Fe) in the Subarnarekha river water, soil and vegetables viz., coriander (*Coriandrum sativum*), cabbage (*Brassica oleracea*), beans (*Phaseolus vulgaris*), brinjal (*Solanum melongena*), chili (*Capsicum annuum*) and tomato (*Solanum lycopersicum*). The results obtained from the analysis of physicochemical characteristics of water found the temperature in the range of 19.33 to 22.45°C, pH 5.83 to 7.43, EC 197.33 to 485.138 mho/cm with iron as the highest available heavy metal with a concentration of 1.909 mgl^{-1} and cadmium was found in the least concentration (0.011 mgl^{-1}). The findings of different soil properties revealed that the soil is good for the cultivation of crops but the presence of some heavy metals like Cd and Pb in the edible parts of the vegetables especially at the sites Namkum, Sembo and Kumba Toli indicates the need for periodical evaluation of soil to assess their levels. HM accumulation in the edible parts of the vegetables was found below the permissible limits prescribed by FAO and WHO except at a few sites.

Highlights:

- Heavy metal contamination in agroecosystems is a worldwide concern.
- The physicochemical properties of the water and soil have been analyzed and found suitable for agriculture purposes.
- The accumulation of heavy metals in vegetables has been found in the edible parts of vegetables at some sites.
- Heavy metal accumulation in edible crops accelerates the global food security concern.

Keywords: Bioaccumulation, Heavy metals, Vegetables, Subarnarekha river, Soil

International Journal of Plant and Environment (2025); **ISSN:** 2454-1117 (Print), 2455-202X (Online)

Introduction

Vegetables contain several important and valuable components like vitamins and minerals, which are essential for the proper functioning of the human body (Hung *et al*., 2004; Siegel *et al*., 2014; Kumar *et al*., 2023; Mishra *et al*., 2023). Due to the increasing problem of pollution, the pollutants, especially toxic heavy metals (HMs) reach the agroecosystems and contaminate the food chain, alleviating their nutritional aspects and escalating the risk of toxicity (Hou *et al*., 2020; Kumar *et al*., 2022; Chen *et al*., 2023; Menon *et al*., 2023; Shetty *et al*., 2025). Anthropogenic activities like dumping of solid waste into the agricultural soil, discharge of wastewater either directly to the soil or through irrigating water, presence of HMs in the fertilizers especially synthetic fertilizers, etc. are the major causes of the HM contamination of the agroecosystems (Ahirwal and Maiti, 2016; Kumar *et al*., 2019; Ngo *et al*., 2024; Rahim *et al*., 2024; Sikakwe *et al*., 2024). The majority of HMs like cadmium (Cd), nickel (Ni), lead (Pb), etc. are well-known potential toxicants even at low doses (Branca *et al*., 2018; Harischandra *et al*., 2019; Balali-Mood *et al*., 2021; Mitra *et al*., 2022). Some of the HMs like iron (Fe), copper (Cu), cobalt (Co), etc. are considered micronutrients, however, their excess level may cause severe diseases in human beings (Prohaska 2000; Cai *et al*., 2005; Tanaka and Kawahara 2017; Branca *et al*., 2018). A study conducted by Singh *et al*., (2018) found the level of Cu = 10.1, Fe = 13,179, Ni = 9.3 and Pb = 10.6 mg/Kg soil collected from control sites for their study of Ranchi. Agricultural crops are generally short-height plants and therefore have a great risk of getting contaminated with HM (Xiang *et al*., 2021; Chowdhury *et al*., 2024). Vegetables are considered staple food crops having high nutritious values. Several vegetable plant species have been reported to bear the potential to accumulate HMs along with some metalloids like arsenic (As) in their roots and transfer them into the aerial parts (Chandel *et al*., 2021; Gupta *et al*., 2022; Manwani *et al*., 2023). The periodical monitoring to check the level of HMs in the agricultural soil and water used for irrigation is of pivotal importance (Zhang *et al*., 2025). Further, time-to-time estimation of different HMs in the edible parts of vegetables must be carried out to minimize the risk of consumption of toxic metals via food sources.

Department of Environmental Sciences, Central University of Jharkhand, Ranchi-835222, India.

***Corresponding author:** Bhaskar Singh, Department of Environmental Sciences, Central University of Jharkhand, Ranchi-835222, India., Email: bhaskar.singh@cuj.ac.in

How to cite this article: Sweta, Singh, B. (2025). Accumulation of Heavy Metals in the Vegetables Cultivated in the Subarnarekha River Basin of Ranchi City. International Journal of Plant and Environment. 11(1), 175-187.

Submitted: 28/12/2024 **Accepted:** 28/01/2025 **Published:** 28/03/2025

This study aimed to assess the physicochemical properties along with the contamination level of Subarnarekha River water collected from different sites passing through Ranchi City, Jharkhand, India. The agricultural soil of the Subarnarekha River basin was also characterized along with the analysis of the presence of HMs. Further, the accumulation of Cd, Pb, Ni, Cu, and Fe in six different vegetables viz coriander (*Coriandrum sativum*), cabbage (*Brassica oleracea*), beans (*Phaseolus vulgaris*), brinjal (*Solanum melongena*), chili (*Capsicum annuum*) and tomato (*Solanum lycopersicum*) grown over Subarnarekha river basin (passing through Ranchi City of Jharkhand from Piska Nagadi to Namkum) was assessed to determine the potential risk of consumption on human health.

Methodology

The site of the study was selected near the Basin of Subarnarekha River flowing in Ranchi city as shown in Fig. 1.

Collection of soil, water and vegetable samples

The samples of river water, soil and vegetables were collected from seven different sites viz. Piska Nagri, Garha Toli, Tikara Toli, Hethu, Sembo, Kumba Toli, and Namkum region are located in the vicinity of the Subarnarekha River passing through Ranchi District of Jharkhand, India. Nine samples of water, soil, and vegetables separately were collected from three different locations of each study site shown on the map in the month of February 2023. The distance between the two subsamples collected was around 200 m. The total distance of the study (starting from Piska Nagadi to Namkum) was around 35 Km. The entire plant (including fruits) was uprooted and kept the plastic bags. The samples were brought to the laboratory followed by the separation of the roots, shoots and fruits after careful washing with tap water followed by a proper rinse with the help of distilled water.

Physicochemical analysis of soil and water samples

The soil and water samples were collected from the studied sites randomly. Nine different samples of water and soil were collected from each site. Water temperature was measured on the study sites using a thermometer. pH and EC were measured using the electrode method, and total dissolved solids (TDS) of water were measured using a TDS meter. Temperature, pH, EC, and TDS of water were measured using the provided in APHA (2017). Further pH and EC of the soil were measured using the electrode method given by Jackson (1973). Soil organic carbon (SOC) was estimated using Walkley and Black (1934), available nitrogen by Subbiah, (1956), available phosphorous by (Olsen, 1954), and available potassium by (Toth and Prince, 1949). The bulk density (BD) gram per cubic centimeters (cm) (g/cm^3) of soil refers to the mass of dried soil per unit volume (V) of soil. It

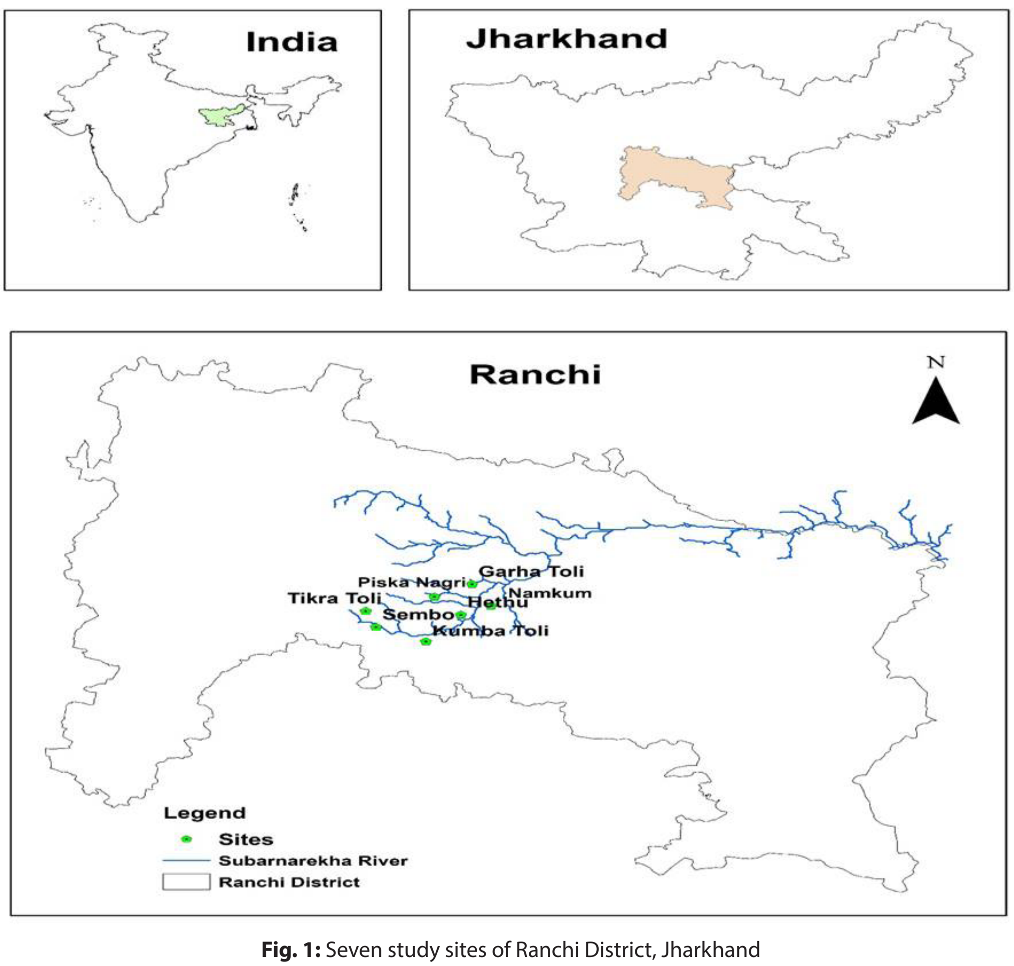

Fig. 1: Seven study sites of Ranchi District, Jharkhand

means of expressing the amount of soil and its value depends partly on the amount of pore space or soil porosity. Porosity was measured using granulometric analysis Brogowski (1990).

Estimation of metal content in soil, water and vegetables

The water samples were collected from the Subarnarekha River that was used to irrigate the vegetables cultivated in the nearby areas and samples of soil and vegetables were collected from the cultivating sites. The vegetable samples collected from the field of the river basin are as mentioned in Table 1.

Table 1: Sample of vegetables collected from different sites

S. No.	*Common name*	*Scientific name*	*Family*
1.	Coriander	*Coriandrum sativum*	Apiaceae
2.	Cabbage	*Brassica oleracea*	Brassicaceae
3.	Brinjal	*Solanum melongena*	Solanaceae
4.	Tomato	*Solanum lycopersicum*	Solanaceae
5.	Chilly	*Capsicum annuum*	Solanaceae
6.	Beans	*Phaseolus vulgaris*	Fabaceae

The estimation of metal content in water samples was performed using the wet digestion method. A 100 mL well-mixed, acid-preserved water sample was transferred to a conical flask. A 10 mL mixture of HNO_3 and HCl in a ratio of 3:1 was added to the flask and covered with watch glass. Samples were digested on a hot plate. The digested samples were allowed to become cool followed by adding 5 mL of H_2O_2. The samples were diluted with the help of 0.01 N HNO_3 (Douglas *et al*., 2022). The concentration of heavy metals in the filtrate of water will be calculated by using the equation.

$$Metal\ concentration\ in\ water\left(\frac{mg}{L}\right)=\frac{(x-y)}{v}\times V$$

Where X = the reading (in ppm) of the test sample, Y = the readings (in ppm) for the blank, V = the final volume of the digested samples (ml) and volume of sample taken (ml).

For estimation of heavy metals in soil and vegetables, the samples were digested in 15 ml of HNO_3, H_2SO_4, and $HClO_4$ (in a 5:1:1 ratio) at 80 °C till a clear/transparent solution was obtained Allen *et al*., (1986). The HM concentration in water, soil and plant parts was determined through an atomic adsorption spectrophotometer (AAS) (model-LABINDIA-AA8000).

Results and Discussion

Physicochemical characteristics of water and soil

The physicochemical properties of water used for irrigation and agricultural soil are important to determine the ability of agroecosystems to support plant growth and produce a generous amount of yield. Any change in physicochemical parameters above or below the standard limits affects crop yield both quantitatively and qualitatively. Moreover, the physiochemical attributes of soil influence the mobility and bioavailability of heavy metals in plants. Therefore, monitoring these parameters routinely is crucial to managing food production and alleviating the risk of toxicity in humans. The physical parameters like temperature, pH, EC, and TDS in water samples of Subarnarekha River collected from seven different sites viz., Piska Nagari, Tikara Toli, Sembo, Garha Toli, Kumba Toli, Hethu, and Namkum were assessed. Similarly, the soil samples collected from the vicinity of the river from the same sites were also analyzed for physical parameters viz. EC, pH, porosity, SOC, and SOM. The soil temperature that directly affects plant growth is influenced by the temperature of water used for irrigation (Liu *et al*., 2021) and it has been reported that the temperature ranging between 15 to 25℃ is optimum for the root growth of most of crops (Falah *et al*., 2010). In the present study, the temperature of onsite river water was reported to range between 19.33℃ (Namkum and Tikara Toli) to 22.45℃ (Kumba Toli) (Table 2), which can be considered suitable for irrigation (Liu *et al*., 2021). Soil pH is the most influential physical parameter that determines the availability of nutrients to plants, biological and enzyme activity (Puissant *et al*., 2019), as well as mobilization and immobilization of heavy metals in soil (Lauchli and Grattan 2017; Dipti *et al*., 2023). For most of the crops, the range of soil pH 6 to 8 is considered ideal as it ensures optimal availability of nutrients to plants (Lauchli and Grattan, 2017). Low pH of soil supports the solubilization of metals, increasing bioavailability; however, higher pH reduces the process (Dipti *et al*., 2023). The water used for irrigation also influences the soil pH and therefore the pH of water used for irrigation must be monitored as per the soil pH characteristics (Poyen *et al*., 2018). In the study undertaken, the pH of river water and soil, both were analyzed and the pH of the water was found to range between 5.83 (Piska Nagari) to 7.43 (Namkum), i.e. moderately acidic to slightly alkaline, and that of soil samples was reported to vary from 6.43 (Tikara Toli) to 7.14 (Kumba Toli) (Table 3). The pH values of the soil obtained were almost similar to the pH values of agricultural soil (6.5–8.5) reported by Dipti *et al*., (2023). The data reveal that soil pH was optimum for plant cultivation. The electrical conductivity (EC) of water can be defined as the function of its chemical composition and the EC of soil

Table 2: Physicochemical characteristics of Subarnarekha River water collected from different sites

Parameters	*Piska Nagari*	*Tikara Toli*	*Sembo*	*Garha Toli*	*Kumba Toli*	*Hethu*	*Namkum*
Temperature	21.50 ± 0.71	19.33 ± 1.15	21.33 ± 0.58	20.25 ± 1.52	22.45 ± 1.43	20.05 ± 2.11	19.33 ± 0.87
pH	5.83 ± 0.29	6.33 ± 0.29	6.17 ± 0.29	6.90 ± 0.36	7.13 ± 0.31	6.83 ± 0.40	7.43 ± 0.25
EC (mho/cm)	197.333 ± 12.32	207.091 ± 43.21	304.925 ± 12.84	318.547 ± 23.87	336.672 ± 16.72	427.078 ± 9.53	485.138 ± 22.33
TDS (mg/L))	119.092 ± 24.73	140.011 ± 28.83	159.836 ± 6.205	160.761 ± 11.91	171.600 ± 8.92	376.414 ± 19.83	409.115 ± 32.38

Data is the mean of 9 individual measurements ± SD.

Table 3: Physicochemical characteristics of soil collected from different sites

Parameters	*Piska Nagari*	*Tikara Toli*	*Sembo*	*Garha Toli*	*Kumba Toli*	*Hethu*	*Namkum*
pH	6.63 ± 0.11	6.43 ± 0.11	6.64 ± 0.26	6.60 ± 0.31	7.14 ± 0.26	6.84 ± 0.10	6.97 ± 0.13
EC (µS/cm)	127.840 ± 5.59	133.988 ± 8.46	131.640 ± 11.01	139.155 ± 13.02	138.383 ± 14.56	141.609 ± 11.63	133.684 ± 4.40
SOC (%)	0.696 ± 0.01	0.700 ± 0.03	0.752 ± 0.07	0.721 ± 0.03	0.722 ± 0.01	0.689 ± 0.04	0.675 ± 0.03
SOM (%)	1.199 ± 0.03	1.206 ± 0.05	1.296 ± 0.13	1.243 ± 0.04	1.244 ± 0.02	1.187 ± 0.07	1.163 ± 0.04
Porosity (%)	36.968 ± 1.38	37.979 ± 3.52	35.907 ± 0.56	37.560 ± 5.40	35.126 ± 2.51	32.783 ± 1.37	42.478 ± 4.38
Bulk Density (g/cm^2)	1.462 ± 0.04	1.436 ± 0.04	1.441 ± 0.01	1.423 ± 0.07	1.419 ± 0.05	1.384 ± 0.01	1.432 ± 0.05
Available N (kg/ha)	173.744 ± 13.96	182.087 ± 15.50	187.300 ± 21.34	207.767 ± 23.51	232.391 ± 8.96	201.796 ± 21.29	232.344 ± 20.81
Available P (kg/ha)	25.959 ± 3.24	26.205 ± 0.81	26.194 ± 1.94	26.133 ± 2.51	29.226 ± 1.95	29.289 ± 3.32	33.434 ± 2.59
Available K (kg/ha)	178.142 ± 8.26	168.682 ± 5.09	175.786 ± 7.88	173.482 ± 9.63	187.897 ± 3.76	177.177 ± 7.09	183.850 ± 7.09

Data is the mean of 9 individual measurement ± SD.

represents the total concentration of soluble salts (Corwin and Lesch, 2003). Evaluating the EC of water and soil is crucial as it helps in determining the salinity, which plays an important role in plant growth (Othaman *et al*., 2020). Soil salinity affects the availability of water and nutrients to plants, and is responsible for causing ion toxicity in plants (Corwin and Lesch, 2003). The EC of water and soil samples collected were reported to range from 197.33 (Piska Nagari) to 485.138 (Namkum) mho/cm and 127.84 (Piska Nagari) to 141.61 (Hethu) mho/cm, respectively. The water used for irrigation having EC below 750 µS/cm does not show any harmful effects on crops (Zaman *et al*., 2018). Similarly, the soil with EC ranging between 0 to 2 dS/m or 0 to 2000 µS/cm is non-saline (Zaib *et al*., 2022). Based on EC results obtained for water and soil samples collected, it was confirmed that the water and soil are safe for irrigation and crop production. In addition to pH and EC, organic matter is a crucial attribute of soil that influences the distribution, migration, as well as transformation of heavy metals (Dipti *et al*., 2023). Additionally, soil organic matter supports plant productivity, and SOC above 2% is considered good for plant growth. However, in the present study, the percentage of organic matter in soil was below 2%. The mean values of soil organic carbon and soil organic matter in different sites soil samples were observed to vary from 0.675 to 0.752 % and 1.163 to 1.296%, respectively. The organic matter of less than 2% in agricultural soil has been reported by other researchers as well. Dipti *et al*., (2023) reported 0.254 to 0.758% organic carbon and 0.437 to 1.307% organic matter in agricultural soil. TDS was found highest in the water samples collected from the Namkum site (409.115) and it might be due to the discharge of waste and domestic water runoff. The porosity and bulk density of soil collected from Hethu was recorded to be the lowest (32.78% and 1.34 g/cm^2, respectively), whereas, soil samples of Namkum and Piska Nagari showed the highest porosity (42.48%) and bulk density (1.46 g/cm^2), respectively, among all soil samples. The analysis of soil for assessing available NPK content demonstrated that the Piska Nagari had the lowest N (173.74 ± 13.96 kg/ha) and P (25.96 ± 3.24 kg/ha) level whereas, the lowest K content (168.68 ± 5.09 kg/ha) seemed to be in Tikara Toli soil. The maximum available N, P, and K content was 232.39, 33.43, and 187.90 kg/ha in soil samples of Kumba Toli, Namkum, and Kumba Toli, respectively.

The metal analysis of water and soil samples revealed the presence of heavy metals (Tables 4 and 5). The heavy metals viz. Cu, Cd, Ni, Fe, and Pb were estimated and found to vary from site to site however; a trend in occurrence of metal concentration was reported. In water samples, iron concentration was the highest among all studied metals, followed by copper, nickel, lead and cadmium. The range of metals in different water samples was found as: Cu (0.180–0.212 mg/L), Cd (Not detected-0.013 mg/L), Ni (0.119–0.194 mg/L), Fe (1.442–1.909 mg/L), and Pb (Not detected-0.074 mg/L). The analysis revealed that the Piska Nagari had the lowest contamination level for all metals except Ni, while Namkum had the highest metal content values except for Pb. Piska Nagari is a rural area, which may be the reason for low metal contamination, while Namkum, which is an industrial site had a comparatively high metal load owing to industrial activities. As per the standard guidelines of irrigation water (Pescod, 1992), water samples collected from certain sites reported Cu (Sembo, Garha Toli, and Namkum) and Cd (Titara Toli, Sembo, Garha Toli, and Namkum) content to be near threshold level, whereas other metals viz., Ni, Fe, and Pb level were within the standard recommended level (Pescod, 1992). However, in a study, the concentration of Cd, Ni, Pb, Cr, and As in irrigation water was higher than the maximum allowable concentration in most of the samples investigated by Kumar *et al*., (2022). Analogous to water samples, in soil samples, iron content was the highest following Cu, Ni, Pb, and Cd. The Cd (0.570 mg/kg), Fe (502.667 mg/kg), and Pb (3.313 mg/kg) content in soil samples collected from Piska Nagari had the lowest values whereas least Cu (16.340 mg/kg) and Ni (6.880 mg/kg) content was reported from Tikara Toli soil samples. The maximum reported concentration of Cu (45.460 mg/kg), Cd (0.943 mg/kg), Pb (12.893 mg/kg), and Fe (714.333 mg/kg) were found in soil samples collected from Namkum and that of Ni (30.253 mg/kg) in soil from Kumba Toli.

Table 4: Presence of Cu, Cd, Ni, Fe and Pb (mg/L) in the Subarnarekha River water collected from different sites

Sites	Cu	Cd	Ni	Fe	Pb
Piska Nagari	0.186 ± 0.011	ND	0.119 ± 0.021	1.442 ± 0.200	ND
Tikara Toli	0.180 ± 0.009	0.011 ± 0.001	0.122 ± 0.011	1.510 ± 0.215	0.038 ± 0.001
Sembo	0.203 ± 0.012	0.012 ± 0.001	0.153 ± 0.009	1.464 ± 0.154	0.054 ± 0.002
Garha Toli	0.184 ± 0.014	0.009 ± 0.001	0.128 ± 0.008	1.530 ± 0.074	0.064 ± 0.002
Kumba Toli	0.193 ± 0.020	0.009 ± 0.001	0.172 ± 0.012	1.697 ± 0.168	0.064 ± 0.003
Hethu	0.204 ± 0.012	0.011 ± 0.001	0.194 ± 0.020	1.620 ± 0.122	0.074 ± 0.003
Namkum	0.212 ± 0.026	0.013 ± 0.001	0.170 ± 0.022	1.909 ± 0.134	0.059 ± 0.004
IS* (2019)	0.20	0.01	0.20	5.0	5.0

*Indian Standards. Data is the mean of 9 individual measurements ± SD; ND=Not detected

Table 5: Presence of Cu, Cd, Ni, Fe and Pb (mg/kg) in the soil collected from different sites.

Sites	*Cu*	*Cd*	*Ni*	*Fe*	*Pb*
Piska Nagari	26.653 ± 1.567	0.570 ± 0.092	8.873 ± 1.866	502.667 ± 38.156	3.313 ± 0.889
Tikara Toli	16.340 ± 4.061	0.873 ± 0.021	6.880 ± 0.758	544.633 ± 66.042	5.380 ± 0.901
Sembo	20.240 ± 0.450	0.730 ± 0.059	14.183 ± 2.873	566.600 ± 12.389	7.967 ± 1.790
Garha Toli	37.660 ± 4.503	0.724 ± 0.011	9.979 ± 2.109	629.833 ± 45.775	5.553 ± 0.439
Kumba Toli	38.353 ± 2.864	0.797 ± 0.084	30.253 ± 2.772	576.200 ± 43.585	12.360 ± 0.980
Hethu	36.360 ± 3.517	0.727 ± 0.042	23.613 ± 2.180	665.533 ± 66.911	10.527 ± 2.679
Namkum	45.460 ± 0.450	0.943 ± 0.013	27.730 ± 1.984	714.333 ± 48.858	12.893 ± 3.225
Awashthi (2000)	135-270	3-6	75-150	--	250-500
Bowen (1966)	2–100	0.01–0.7	10–1000	--	2–200

Data is the mean of 9 individual measurements ± SD

The content of metals viz., Cu, Cd, Ni, and Pb in all soil samples collected was within the safe limit as per the Indian Standard (Awasthi, 2000). However, in some studies, high concentrations of heavy metals in agricultural soil have been reported. Sharma *et al*., (2009) found the maximum concentration of Cu, Zn, and Cd in soil samples to be 19.3, 133, and 2.3 mg/kg, respectively, which was higher than the background level (Cu-15 mg/kg, Zn-100 mg/kg and Cd-1.0 mg/kg). Similarly, Dipti *et al*., (2023) reported Cd and Fe content to be 2 and 72 times more than the permissible limit given by Indian Standard, respectively, in soil samples collected from Gaughat, Lucknow, India. Gupta *et al*., (2021) reported the level of Pb, Ni and Cd were found in 14.62, 21.73 and 2.71 mg/Kg soil respectively in the soil collected from the agriculture field of Jhansi, India. Gupta *et al*., (2022) reported the level of Cd (2.02 mg/Kg soil) and Pb (19.09 mg/Kg soil) in soil higher than the permissible limits set by USEPA (2002). Through the present study, data revealed that the metal contamination in river water and soil was within the safe limit and suitable for agricultural activities, however, Cu and Cd concentration in water samples from certain sites was near the maximum permissible limit, advocating the need for continuous monitoring of water quality to avoid the risk of agro-ecosystem pollution and reducing the incidence of metal concentration build up in both soil and crop plants on long-term exposure. Along with soil samples, river water samples were analyzed to assess the heavy metal content.

Heavy metals in vegetable samples

Six different leafy and fruit-bearing vegetables viz., coriander, cabbage, chili, tomato, brinjal, and beans were collected from study areas to evaluate the heavy metals content. The analysis presence of Cu, Fe, Ni, Pb and Cd in roots, shoots (fruit-bearing vegetables), and edible part of vegetable samples (above-ground part of coriander and cabbage, and fruits of chili, beans, tomato, and brinjal) done and presented in Tables 6 to 12. The range of Cu, Fe, Ni, Pb, and Cd in roots and shoots (fruit-bearing plants) of test samples collected were reported as: 27.60 to 1.69 and 18.71 to 2.02 mg/kg; 148.13 to 23.37 and 99.64 to 24.54 mg/kg; 19.90-not detected (ND) mg/kg and 19.48-ND mg/kg; 11.49-ND mg/kg and 7.5-ND mg/kg; 11.75 to 0.19 and 6.27-ND mg/kg, respectively. The level of metals studied in edible parts (including leafy, fruits or shoot parts) of vegetable samples were found in the range: Cu (ND-17.84 mg/kg), Fe (10.29–87.01 mg/kg), Ni (ND-2.21 mg/kg), Pb (ND-0.92 mg/kg), and Cd (ND-0.39 mg/kg). No trend in metal accumulation in vegetables was found, however, among the metals studied, Fe was present in the highest amount in samples from all sites. Similarly, Guadie *et al*., (2021) in their studied found that the bioaccumulation Fe in vegetable samples was maximum followed by Mn> Zn> Pb> Cu> Cd. Metals like Cu, Ni and Fe are essential for plant growth, and Cu and Fe are required by the human body for proper functioning. Nevertheless, these metals are needed in minute quantities and their accumulation above threshold level may induce toxicity. In the present study, the concentration of Cu, Ni, and Fe in edible parts of vegetables collected from seven different sites was below the permissible limit given by FAO/WHO, and thus safe for human consumption (Figs 2-6). Other metals like Pb and Cd which are non-essential metals may cause health risks to humans, even in minute concentration (Figs 4-6). The levels of Pb and Cd in edible parts of vegetable samples collected were found to range 0.0 to 0.92 mg/kg and 0.0 to 0.39 mg/kg, respectively. The mean concentration of Pb in vegetables was below the safe limit and the maximum allowable concentration (MAC) given by FAO/WHO (2001). The level of Cd was much lower than the reference value given by the Indian Standard, but certain samples reported Cd levels in edible parts higher than the value prescribed by FAO/WHO (2001). Pb and Cd are non-essential metals; hence their occurrence in food commodities is unsafe for consumers. Higher content of Pb and Cd in vegetables above the safe limit has been reported by other investigators in their studies. In particular, the study undertaken by Kumar *et al*., (2021) to evaluate the heavy metal content in vegetables sold in local markets of Lucknow, India reported Pb and Cd content to be higher than the maximum allowable concentration given by FAO/WHO in some of the samples. In a study done by Gupta *et al*., (2021) the level of heavy metals especially Pb and Cd were higher than the permissible limits in the Jhansi place of India. They reported the value of Cd 0.51 and 0.86 mg/Kg in fenugreek and spinach, respectively and the values of Pb were 1.82 and 4.52 mg/Kg in fenugreek and spinach, respectively. These levels are much higher than the permissible limits given by allowable concentrations of heavy metals (mg/kg) in vegetables according to Gebeyehu and Bayissa (2020).

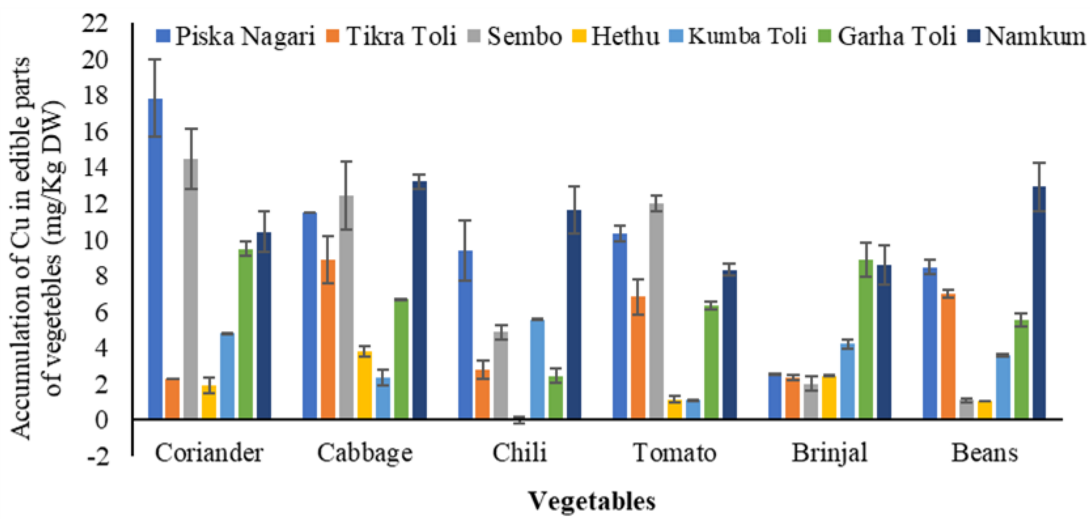

Fig. 2: Accumulation of Cu in edible parts of various vegetables at seven different sites of Ranchi District. The data is statistically analyzed to show the relations in accumulation of Cu in the edible parts of vegetables at different studied sites using least significant difference (LSD) by one-way ANOVA at *p-value* 0.000345. It is found that there is no similarity in the Cu accumulation in the edible parts of vegetables collected from different studied sites.

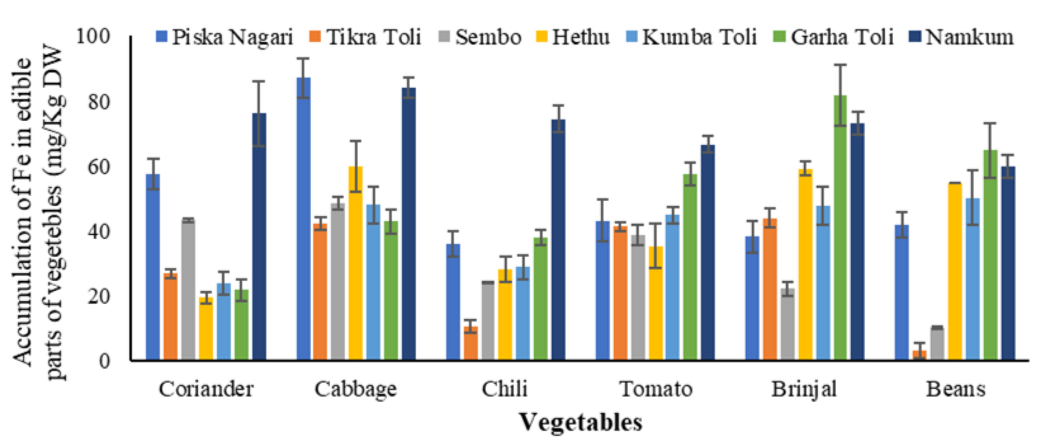

Fig. 3: Accumulation of Fe in edible parts of various vegetables at seven different sites of Ranchi District. The data is statistically analyzed to show the relations in accumulation of Fe in the edible parts of vegetables at different studied sites using least significant difference (LSD) by one-way ANOVA at *p-value* 0.000865. It is found that there is no similarity in the Fe accumulation in the edible parts of vegetables collected from different studied sites.

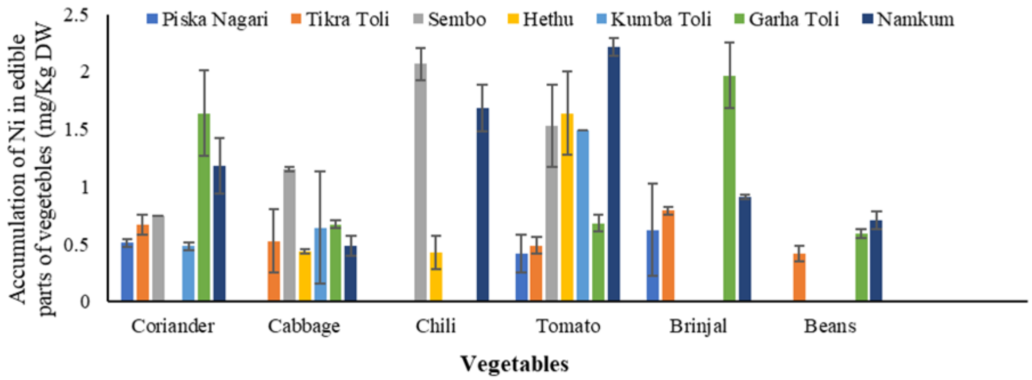

Fig. 4: Accumulation of Ni in edible parts of various vegetables at seven different sites of Ranchi District. The data is statistically analyzed to show the relations in the Ni accumulation in the edible parts of vegetables at different studied sites where it is found that the value of F-calculated is higher than the values of F-critical indicating a similar pattern in Ni accumulation in the edible parts of vegetables at collected from different studied sites.

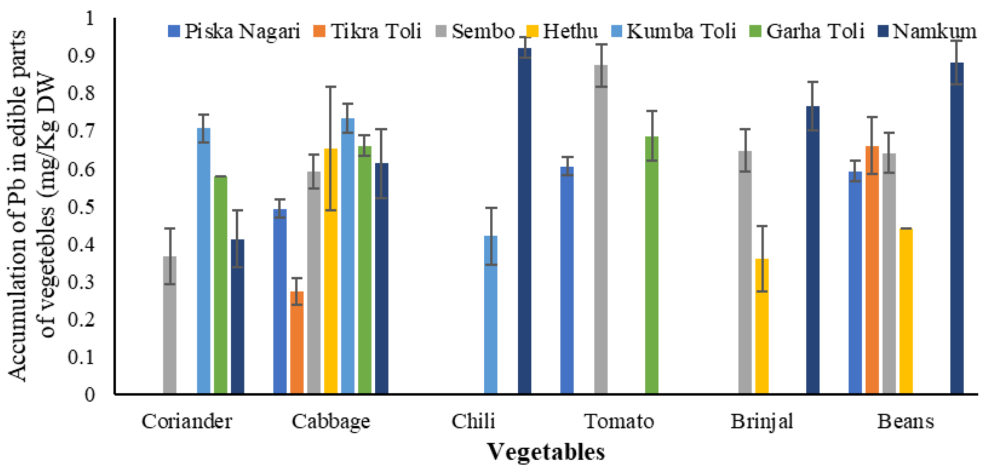

Fig. 5: Accumulation of Pb in edible parts of various vegetables at seven different sites of Ranchi District. The data is statistically analyzed to show the relations in the Pb accumulation in the edible parts of vegetables at different studied sites where it is found that the value of F-calculated is higher than the values of F-critical indicating a similar pattern in Pb accumulation in the edible parts of vegetables at collected from different studied sites.

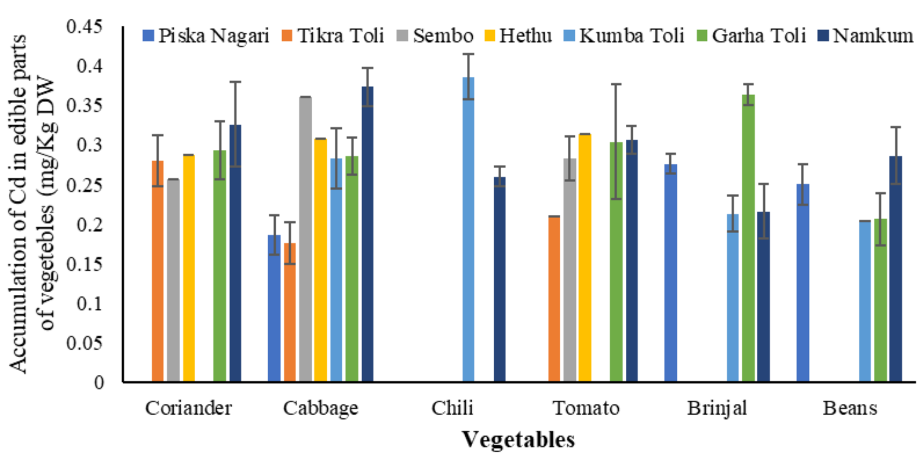

Fig. 6: Accumulation of Cd in edible parts of various vegetables at seven different sites of Ranchi District. The data is statistically analyzed to show the relations in the Cd accumulation in the edible parts of vegetables at different studied sites where it is found that the value of F-calculated is higher than the values of F-critical indicating a similar pattern in Cd accumulation in the edible parts of vegetables at collected from different studied sites.

Table 6: Accumulation of heavy metals in the roots, shoots and fruits of the vegetables (mg/Kg DW) collected from Piska Nagari (Site-1)

Vegetables	Cu			Fe			Ni			Pb			Cd		
	Root	Shoot	Fruit	Root	Shoot	Fruit	Root	Shoot	Fruit	Root	Shoot	Fruit	Root	Shoot	**Fruit**
Coriander	22.053 ± 2.33	17.840 ± 2.14	NA	90.540 ± 7.864	57.500 ± 4.670	NA	9.047 ± 3.155	0.513 ± 0.034	NA	ND	ND	NA	1.24 ± 0.161	ND	NA
Cabbage	17.760 ± 1.246	11.487 ± 0.829	NA	133.667 ± 10.372	87.013 ± 6.023	NA	5.927 ± 0.875	ND	NA	3.567 ± 0.460	0.493 ± 0.023	NA	1.56 ± 0.460	0.186 ± 0.053	NA
Chilly	17.160 ± 1.864	13.807 ± 1.975	9.413 ± 0.626	31.125 ± 2.976	35.080 ± 2.356	36.073 ± 4.0	9.927 ± 1.019	7.033 ± 1.155	ND	11.487 ± 0.181	6.813 ± 0.281	ND	0.567 ± 0.181	0.283 ± 0.081	ND
Tomato	19.220 ± 1.393	18.707 ± 2.042	10.353 ± 1.624	70.547 ± 9.211	49.947 ± 0.935	43.24 ± 6.303	16.153 ± 2.522	10.380 ± 2.0	0.420 ± 0.164	8.70 ± 1.250	4.653 ± 0.121	0.606 ± 0.023	0.283 ± 0.050	ND	ND
Brinjal	15.867 ± 2.548	13.373 ± 2.656	2.540 ± 0.26	72.247 ± 8.865	40.473 ± 5.162	38.207 ± 4.965	10.927 ± 1.536	8.813 ± 1.536	0.622 ± 0.40	2.36 ± 0.312	0.880 ± 0.124	ND	3.733 ± 0.32	1.943 ± 0.224	0.276 ± 0.012
Bean	9.240 ± 1.935	10.100 ± 1.781	8.473 ± 1.982	63.4477 ± 5.455	39.053 ± 3.388	42.033 ± 3.926	12.820 ± 1.832	5.927 ± 1.672	ND	.96 ± 0.0481	3.567 ± 0.460	0.593 ± 0.026	2.566 ± 0.081	1.270 ± 0.160	0.250 ± 0.026
Permissible limits*			40			425.5			4.0			5			0.2

Where NA= Not applicable, ND= Not detected, *FAO/WHO Standard (Codex Alimentarius Commission, 2017)

Table 7: Accumulation of heavy metals in the roots, shoots and fruits of the vegetables (mg/Kg DW) collected from Tikra Toli (Site-2)

Vegetables	Cu			Fe			Ni			Pb			Cd		
	Root	Shoot	Fruit	Root	Shoot	Fruit	Root	Shoot	Fruit	Root	Shoot	Fruit	Root	Shoot	Fruit
Coriander	2.367 ± 0.150	2.280 ± 0.00	NA	45.853 ± 0.00	26.853 ± 1.212	NA	8.820 ± 1.140	0.667 ± 0.085	NA	ND	ND	NA	2.666 ± 0.352	0.28 ± 0.032	NA
Cabbage	13.027 ± 1.189	8.900 ± 1.307	NA	31.393 ± 2.307	42.313 ± 2.095	NA	9.933 ± 0.698	0.527 ± 0.274	NA	0.566 ± 0.081	0.273 ± 0.035	NA	3.093 ± 0.057	0.176 ± 0.086	NA
Chilly	11.480 ± 1.121	11.907 ± 1.028	2.793 ± 0.510	31.253 ± 7.497	24.54 ± 0.510	10.473 ± 1.960	11.707 ± 1.818	10.153 ± 1.928	ND	9.487 ± 1.059	6.813 ± 0.476	ND	4.96 ± 0.074	2.583 ± 0.201	ND
Tomato	7.867 ± 0.817	5.973 ± 0.530	6.833 ± 0.966	95.653 ± 8.120	49.273 ± 3.539	41.327 ± 1.362	13.487 ± 1.385	10.820 ± 1.393	0.487 ± 0.074	4.213 ± 0.00	0.686 ± 0.140	ND	3.65 ± 0.018	1.19 ± 0.352	0.210
Brinjal	2.627 ± 0.150	2.540 ± 0.00	2.367 ± 0.150	30.260 ± 3.095	43.880 ± 2.120	43.880 ± 2.974	14.593 ± 1.385	7.487 ± 1.385	0.793 ± 0.034	9.986 ± 0.867	ND	ND	2.01 ± 0.097	ND	ND
Bean	15.267 ± 1.268	12.853 ± 2.357	7.007 ± 0.231	124.307 ± 27.023	45.153 ± 3.326	43.167 ± 2.336	14.600 ± 1.083	15.047 ± 2.309	0.420 ± 0.067	5.960 ± 0.00	0.567 ± 0.021	0.66 ± 0.076	3.566 ± 0.250	2.79 ± 0.085	ND
Permissible limits*			40			425.5			4.0			5			0.2

Where NA= Not applicable, ND= Not detected, *FAO/WHO Standard (Codex Alimentarius Commission, 2017)

Table 8: Accumulation of heavy metals in the roots, shoots and fruits of the vegetables (mg/Kg DW) collected from Sembo (Site-3)

Vegetables	Cu			Fe			Ni			Pb			Cd		
	Root	Shoot	Fruit	Root	Shoot	Fruit	Root	Shoot	Fruit	Root	Shoot	Fruit	Root	Shoot	Fruit
Coriander	19.213 ± 1.173	14.493 ± 1.660	NA	53.953 ± 1.613	43.300 ± 0.520	NA	10.820 ± 0.381	0.747 ± 0.076	NA	0.967 ± 0.098	0.367 ± 0.075	NA	3.3363 ± 0.209	0.256 ± 0.057	NA
Cabbage	13.373 ± 2.719	12.427 ± 1.863	NA	60.473 ± 4.771	48.560 ± 1.944	NA	11.927 ± 3.676	1.153 ± 0.019	NA	4.540 ± 0.491	0.593 ± 0.045	NA	4.83 ± 0.219	0.360 ± 0.028	NA
Chilly	6.067 ± 1.869	4.627 ± 0.150	4.860 ± 0.395	99.060 ± 5.110	51.113 ± 3.212	24.160 ± 0.277	17.487 ± 1.017	9.933 ± 3.352	2.067 ± 0.341	ND	ND	ND	2.543 ± 0.351	1.230 ± 0.258	ND
Tomato	27.140 ± 3.069	18.193 ± 0.284	11.993 ± 0.459	99.340 ± 11.463	52.387 ± 1.478	38.800 ± 3.221	18.820 ± 2.338	8.373 ± 1.330	1.527 ± 0.360	3.120 ± 0.276	5.960 ± 0.057	0.873 ± 0.057	6.48 ± 0.736	6.270 ± 0.443	0.283 ± 0.014
Brinjal	7.187 ± 0.497	3.793 ± 0.345	2.020 ± 0.391	68.847 ± 8.627	28.173 ± 2.760	22.227 ± 2.231	0.426 ± 0.024	ND	ND	4.787 ± 0.359	3.220 ± 0.011	0.647 ± 0.057	1.140 ± 0.575	ND	ND
Bean	5.827 ± 0.278	2.873 ± 0.755	1.087 ± 0.077	38.087 ± 3.668	52.327 ± 7.000	10.287 ± 0.277	6.540 ± 0.393	0.427 ± 0.00	ND	1.660 ± 0.901	1.140 ± 0.175	0.64 ± 0.053	3.573 ± 0.404	1.16 ± 0.231	ND
Permissible limits*			40			425.5			4.0			5			0.2

Where NA= Not applicable, ND= Not detected, *FAO/WHO Standard (Codex Alimentarius Commission, 2017)

Table 9: Accumulation of heavy metals in the roots, shoots and fruits of the vegetables (mg/Kg DW) at Hethu (site-4)

Vegetables	Cu			Fe			Ni			Pb			Cd		
	Root	Shoot	Fruit	Root	Shoot	Fruit	Root	Shoot	Fruit	Root	Shoot	Fruit	Root	Shoot	Fruit
Coriander	4.053 ± 0.306	1.900 ± 0.432	NA	23.373 ± 3.199	19.467 ± 1.744	NA	0.973 ± 0.150	ND	NA	0.620 ± 0.035	ND	NA	2.330 ± 0.359	0.287 ± 0.011	NA
Cabbage	6.507 ± 0.466	3.800 ± 0.2943	NA	72.747 ± 8.690	59.833 ± 7.866	NA	9.920 ± 1.111	0.440 ± 0.034	NA	2.333 ± 0.043	0.653 ± 0.164	NA	1.156 ± 0.658	0.307 ± 0.00	NA
Chilly	5.493 ± 0.2567	4.900 ± 0.546	ND	41.667 ± 6.008	50.220 ± 0.774	28.153 ± 0.393	11.220 ± 0.242	0.807 ± 0.077	0.427 ± 0.039	4.833 ± 0.043	ND	ND	0.186 ± 0.064	ND	ND
Tomato	1.687 ± 0.150	2.020 ± 0.883	1.127 ± 0.195	121.840 ± 8.455	78.300 ± 3.427	35.433 ± 3.977	8.920 ± 1.593	1.253 ± 0.180	1.640 ± 0.485	1.833 ± 0.254	1.147 ± 0.095	ND	11.753 ± 2.865	3.263 ± 0.573	0.313 ± 0.066
Brinjal	7.093 ± 0.397	4.813 ± 0.634	2.447 ± 0.180	59.380 ± 4.854	58.033 ± 6.54	59.227 ± 6.808	ND	ND	ND	2.940 ± 0.264	1.840 ± 0.597	0.360 ± 0.075	1.830 ± 0.437	0.950 ± 0.046	ND
Bean	3.547 ± 0.274	5.487 ± 0.634	1.053 ± 0.046	117.787 ± 18.757	52.627 ± 3.972	54.873 ± 2.275	0.533 ± 0.046	0.400 ± 0.0242	ND	3.820 ± 0.860	1.040 ± 0.86	0.440 ± 0.086	1.216 ± 0.362	0.426 ± 0.073	ND
Permissible limits*			40			425.5			4.0			5			0.2

Where NA= Not applicable, ND= Not detected, *FAO/WHO Standard (Codex Alimentarius Commission, 1984)

Table 10: Accumulation of heavy metals in the roots, shoots and fruits of the vegetables (mg/Kg DW) collected from Kumba Toli (Site-5)

Vegetables	*Cu*			*Fe*			*Ni*			*Pb*			*Cd*		
	Root	*Shoot*	*Fruit*	*Root*	*Shoot*	*Fruit*	*Root*	*Shoot*	*Fruit*	*Root*	*Shoot*	*Fruit*	*Root*	*Shoot*	*Fruit*
Coriander	8.267 ± 0.364	4.787 ± 0.037	NA	60.733 ± 5.37	23.800 ± 3.584	NA	6.813 ± 0.460	0.484 ± 0.028	NA	4.393 ± 0.739	0.706 ± 0.037	NA	ND	ND	NA
Cabbage	6.167 ± 0.372	2.333 ± 0.4 c48	NA	105.180 ± 18.573	47.967 ± 5.743	NA	10.087 ± 1.374	0.643 ± 0.037	NA	3.639 ± 0.175	0.733 ± 0.038	NA	5.676 ± 0.372	0.283 ± 0.038	NA
Chilly	5.913 ± 0.473	4.473 ± 0.573	5.560 ± 0.047	34.907 ± 5.373	33.613 ± 2.485	28.927 ± 3.743	0.513 ± 0.083	ND	ND	5.353 ± 0.083	2.457 ± 0.193	0.420 ± 0.076	2.696 ± 0.037	0.696 ± 0.482	0.386 ± 0.089
Tomato	4.813 ± 0.736	3.040 ± 0.864	1.093 ± 0.057	44.940 ± 7.483	33.160 ± 1.684	44.840 ± 2.485	10.173 ± 1.585	6.173 ± 0.873	1.486 ± 0.079	0.833 ± 0.094	ND	ND	0.856 ± 0.047	0.643 ± 0.094	ND
Brinjal	11.153 ± 0.203	7.433 ± 0.472	4.220 ± 0.249	72.747 ± 11.753	34.453 ± 5.473	47.700 ± 5.955	7.473 ± 1.484	2.733 ± 0.273	ND	1.747 ± 0.043	0.780 ± 0.037	ND	7.026 ± 0.492	5.223 ± 0.028	0.213 ± 0.023
Bean	10.487 ± 0.047	5.740 ± 0.362	3.580 ± 0.047	38.667 ± 2.493	39.740 ± 4.373	50.220 ± 8.462	3.247 ± 0.274	0.840 ±	ND	ND	ND	ND	0.433 ± 0.047	0.260 ± 0.028	0.203 ± 0.001
Permissible limits*			40			425.5			4.0			5			0.2

Where NA= Not applicable, ND= Not detected, *FAO/WHO Standard (Codex Alimentarius Commission, 1984)

Table 11: Accumulation of heavy metals in the roots, shoots and fruits of the vegetables (mg/Kg DW) collected from Garha Toli (Site-6)

Vegetables	*Cu*			*Fe*			*Ni*			*Pb*			*Cd*		
	Root	*Shoot*	*Fruit*	*Root*	*Shoot*	*Fruit*	*Root*	*Shoot*	*Fruit*	*Root*	*Shoot*	*Fruit*	*Root*	*Shoot*	*Fruit*
Coriander	14.387 ± 0.272	9.493 ± 0.382	NA	34.907 ± 4.374	21.847 ± 3.282	NA	12.060 ± 1.383	1.640 ± 0.373	NA	7.233 ± 0.937	0.580 ± 0.027	NA	1.450 ± 0.382	0.293 ± 0.037	NA
Cabbage	6.253 ± 0.831	6.673 ± 0.032	NA	62.987 ± 9.372	42.867 ± 3.583	NA	6.660 ± 0.832	0.673 ± 0.037	NA	2.793 ± 0.372	0.660 ± 0.037	NA	4.723 ± 0.232	0.286 ± 0.083	NA
Chilly	4.900 ± 0.547	3.707 ± 0.251	2.447 ± 0.387	95.747 ± 6.237	47.793 ± 5.735	37.987 ± 2.483	ND	ND	ND	5.670 ± 0.074	2.853 ± 0.832	ND	1.100 ± 0.027	ND	ND
Tomato	12.600 ± 0.372	8.620 ± 0.228	6.333 ± 0.237	76.800 ± 9.393	51.280 ± 2.373	57.580 ± 3.585	5.113 ± 0.837	4.147 ± 0.836	0.680 ± 0.073	4.927 ± 0.563	1.843 ± 0.073	0.686 ± 0.036	3.210 ± 0.232	1.070 ± 0.236	0.304 ± 0.072
Brinjal	21.700 ± 3.287	9.880 ± 0.392	8.867 ± 0.943	137.220 ± 8.383	99.640 ± 8.383	81.867 ± 9.383	18.660 ± 2.473	15.140 ± 1.233	1.967 ± 0.283	3.940 ± 0.982	1.087 ± 0.073	ND	4.910 ± 0.337	0.913 ± 0.072	0.363 ± 0.013
Bean	7.480 ± 0.372	10.427 ± 0.181	5.540 ± 0.372	72.300 ± 5.484	69.340 ± 8.383	64.893 ± 8.383	7.667 ± 0.783	3.233 ± 0.732	0.593 ± 0.038	ND	ND	ND	4.023 ± 0.063	3.813 ± 0.2510	0.206 ± 0.073
Permissible limits*			40			425.5			4.0			5			0.2

Where NA= Not applicable, ND= Not detected, *FAO/WHO Standard (Codex Alimentarius Commission, 1984)

Table 12: Accumulation of heavy metals in the roots, shoots and fruits of the vegetables (mg/Kg DW) collected from Namkum (Site-7)

Vegetables	Cu			Fe			Ni			Pb			Cd		
	Root	*Shoot*	*Fruit*	*Root*	*Shoot*	*Fruit*	*Root*	*Shoot*	*Fruit*	*Root*	*Shoot*	*Fruit*	*Root*	*Shoot*	*Fruit*
Coriander	13.667 ± 0.150	10.433 ± 1.123	NA	103.547 ± 13.515	76.127 ± 9.848	NA	5.553 ± 0.754	1.180 ± 0.640	NA	6.040 ± 0.340	0.413 ± 0.075	NA	1.540 ± 0.270	0.326 ± 0.053	NA
Cabbage	17.360 ± 1.041	13.207 ± 0.428	NA	148.127 ± 12.423	84.120 ± 3.159	NA	5.240 ± 0.754	0.487 ± 0.086	NA	2.293 ± 0.112	0.613 ± 0.091	NA	5.243 ± 0.750	0.373 ± 0.064	NA
Chilly	18.367 ± 0.973	13.760 ± 0.797	11.627 ± 1.317	120.107 ± 20.362	80.653 ± 7.358	74.453 ± 4.043	13.160 ± 0.967	8.933 ± 0.900	1.687 ± 0.203	5.420 ± 0.649	7.500 ± 0.543	0.920 ± 0.027	6.57 ± 0.435	3.330 ± 0.383	0.260 ± 0.012
Tomato	16.707 ± 1.754	13.300 ± 2.402	8.307 ± 0.325	119.167 ± 7.514	88.460 ± 2.563	66.640 ± 2.594	19.900 ± 1.671	19.480 ± 0.233	2.213 ± 0.446	ND	ND	ND	7.823 ± 0.458	4.326 ± 0.195	0.306 ± 0.018
Brinjal	27.600 ± 1.571	18.193 ± 1.570	8.587 ± 1.087	137.887 ± 12.751	83.073 ± 5.397	73.113 ± 3.389	7.033 ± 0.630	6.827 ± 0.478	0.913 ± 0.019	7.500 ± 0.560	7.087 ± 0.376	0.766 ± 0.064	4.326 ± 0.165	3.706 ± 0.074	0.216 ± 0.035
Bean	17.453 ± 2.647	16.340 ± 0.840	12.920 ± 1.359	101.253 ± 11.267	83.347 ± 0.611	59.907 ± 3.525	11.667 ± 0.253	1.547 ± 0.370	0.707 ± 0.075	7.706 ± 0.187	5.266 ± 0.758	0.880 ± 0.058	6.450 ± 0.783	3.453 ± 0.152	0.286 ± 0.036
Permissible limits*			40			425.5			4.0			5			0.2

Where NA= Not applicable, ND= Not detected, *FAO/WHO Standard (Codex Alimentarius Commission, 1984)

Analogously, the mean contamination level of Pb and Cd in shoots of leafy vegetables and roots analyzed by Shakya and Khwarunjoo (2013) was above the maximum permissible limit set by FAO/WHO for human consumption. Investigation undertaken by Chowdhury *et al*., (2024) to assess the heavy metals viz. Ni, Pb, Fe, Cd, and Cr content in vegetables collected from local market of Noakhali district, Bangladesh reported that the mean concentration of all metals was above the safe limit set by FAO/WHO, whereas Jalali and Meyari (2022) reported that the metals viz, Cu, Mn, Fe, Ni, and Zn were within the safe limit but in certain vegetable samples, Cd (coriander and basil) and Pb (parsley and basil) were exceeding maximum permissible limit. Gupta *et al*., (2022) reported the level of Cd (0.23 mg/Kg soil) and Pb (2.12 mg/Kg soil) in coriander which is higher than the permissible limits set by Gebeyehu and Bayissa (2020). The level of Ni, Cd, and Pb was found in higher concentrations in wheat and rice grains cultivated near the Sutlej River, India (Setia *et al*., 2021). The use of chemical fertilizers, contaminated water for irrigation, atmospheric deposition, and industrial activities in nearby areas could be the probable reasons for the contamination of vegetable samples with heavy metals (Kumar *et al*., 2021). The occurrence of metals in soil and irrigating water allows their continuous uptake by plants that in the long term can become a probable source of human health hazards (Kumar *et al*., 2021). Therefore, it is crucial to monitor and manage the contamination of heavy metals in agricultural ecosystems and food commodities.

Conclusion

The present study depicts that the water quality of the Subarnarekha is suitable for the cultivation of agricultural crops subject to periodical monitoring of the water quality. There is no significant HM contamination in the studied soils. The presence of HMs in the water may be due to the release of urban discharge, and agricultural runoff. The physicochemical characteristics analyzed for the soil are also good resembling the test parameters in previous studies. The level of Cu, Fe, and Ni in studied vegetables is below the permissible limits comparing them to the safety limits established by WHO/FAO. The findings of Cd and Pb are also below the permissible limits given by WHO/FAO (2001) however, in some places, the levels of Cd are found slightly higher which indicates that there are some possible sources of Cd in the soil. It can be recommended from this study that there is a need for regular monitoring of Cd levels in the Subarnarekha River water, the soil of this river basin and the vegetables cultivated in this region.

Acknowledgment

The authors acknowledge the Department of Science and Technology for providing equipment support under the FIST program (SR/FST/ ES-I/2019/55(C).

References

Ahirwal, J., & Maiti, S.K. (2016). Assessment of soil properties of different land uses generated due to surface coal mining activities in tropical Sal (Shorea robusta) forest, India. Catena, 140, 155–163.

Allen, S.E., Grimshaw, H.M., & Rowland, A.P. (1986) Chemical Analysis. In: Moore, P.D. and Chapman, S.B., Eds., Methods of Plant Ecology,

Blackwell, Oxford. 285-344.
APHA (2017). Standard Methods for the Examination of Water and Wastewater (23rd ed.). Washington DC: American Public Health Association.
Awasthi, S.K. (2000) Prevention of Food Adulteration Act no 37 of 1954. Central and State Rules as Amended for 1999, third ed. Ashoka Law House, New Delhi.
Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M.R., & Sadeghi, M. (2021) Toxic Mechanisms of five heavy metals: mercury, lead, chromium, cadmium, and arsenic. Frontiers in Pharmacology. 13; 12:643972. doi: 10.3389/fphar.2021.643972.
Bowen, H.J.M. (1966) Trace Elements in Biochemistry. Academic Press, New York.
Branca, J.J.V., Morucci, G., & Pacini, A. (2018). Cadmium-induced neurotoxicity: Still much ado. Neural Regeneration Research, 13, 1879-1882, 10.4103/1673-5374.239434.
Brogowski Z., 1990. Próba obliczenia niektórych w³aœciwoœci fizycznych gleb na podstawie analizy ziarnowej (Attempt to calculate certain physical parameters of soils based on the granulometric analysis). Roczniki Gleboznawcze – Soil Scien ce Annual, 31(3-4), 17–28.
Cai, L.U., X.-K. Li, Y.E. Song, & Cherian, M.G. (2005). Essentiality, toxicology and chelation therapy of zinc and copper. Current Medical Chemistry 12(23), 2753-2763, https://doi.org/10.2174/092986705774462950.
Chandel, S.S., Rana, A.S., & Ibrahim, M., (2021). Physiological Analysis and Evaluation of Heavy Metal Contents in Leafy Vegetables and Fruits Collected from the Local Market of Prayagraj. International Journal of Statistical Distributions and Applications, 7(1), 7-12., http://doi: 10.11648/j.ijsd.20210701.12.
Chen, L., Zhou, S., Tang, C., Luo, G., *et al*., (2023). A novel methodological framework for risk zonation and source–sink response concerning heavy-metal contamination in agroecosystems, Science of The Total Environment, 868, 161610, https://doi.org/10.1016/j.scitotenv.2023.161610.
Chowdhury, A. I., Shill, L. C., Raihan, M. M., Rashid, R., Bhuiyan, M. N. H., Reza, S., & Alam, M. R. (2024). Human health risk assessment of heavy metals in vegetables of Bangladesh. Scientific Reports, 14(1), 15616.
Corwin, D. L., & Lesch, S. M. (2003). Application of soil electrical conductivity to precision agriculture: theory, principles, and guidelines. Agronomy Journal, 95(3), 455-471.
Dipti, K. P., Sanjay, D., & Pratap, S. R. (2023). Assessment of Heavy metal contaminations in agro-ecosystems around distinct pollution sources, its spatial distribution and principal component analysis. Research Journal of Chemistry and Environment, 27, 7.
Douglas, R., Albert, G., Reuben, O., Paul, O., Hellen, N., Boniface, G., *et al*., (2022). Assessment of heavy metal concentrations (Cu, Cd, Pb, and Zn) in wastewater from Gusii treatment plant in Kisii county, Kenya. Pan African Medical Journal, 1(02):122–38. doi: 10.47787/pasj. v1i02.12
Falah, M. A. F., Wajima, T., Yasutake, D., Sago, Y., & Kitano, M. (2010). Responses of root uptake to high temperature of tomato plants (Lycopersicon esculentum Mill.) in soil-less culture. Journal of Agricultural Technology, 6(3), 543-558.
FAO/WHO. (2001). Codex alimentarius commission. Food Additives and Contaminants. Joint FAO/WHO Food Standards Programme. Who. https:// www. fao. org/3/ x8723e/ x8723e. pdf.
Gebeyehu, H.R., Bayissa, L.D. (2020). Levels of heavy metals in soil and vegetables and associated health risks in Mojo area. Ethiopia. PloS One 15 (1), e0227883.
Guadie, A., Yesigat, A., Gatew, S., Worku, A., Liu, W., Ajibade, F. O., & Wang, A. (2021). Evaluating the health risks of heavy metals from vegetables grown on soil irrigated with untreated and treated wastewater in Arba Minch, Ethiopia. Science of the Total Environment, 761, 143302.
Gupta, N., Kumar, K., Zahra, Y. *et al*., (2021). Evaluating heavy metals contamination in soil and vegetables in the region of North India: Levels, transfer and potential human health risk analysis. Environmental Toxicology & Pharmacology, 82, 103563. https://doi.org/10.1016/j.etap.2020.103563
Gupta, N., Yadav, K.K., Kumar, Vinit, Prasad, S., Cabral-Pinto, M.M.S., Jeon, B.H. *et al*. (2022). Investigation of heavy metal accumulation in vegetables and health risk to humans from their consumption. Frontiers in Environmental Science, doi: 10.3389/fenvs.2022.791052.
Harischandra, D.S. S., Ghaisas, G., Zenitsky, H., Jin, A., Kanthasamy, V., Anantharam, A. G., & Kanthasamy, (2019). Manganese-induced neurotoxicity: New insights into the triad of protein misfolding, mitochondrial impairment, and neuroinflammation. Frontiers in Neuroscience, 13, https://doi.org/10.3389/fnins.2019.00654.
Hou, D., O'Connor, D., Igalavithana, A.D. *et al*., (2020). Metal contamination and bioremediation of agricultural soils for food safety and sustainability. Nature Reviews Earth and Environment 1**,** 366–381 https://doi.org/10.1038/s43017-020-0061-y.
Hung, H.C., Joshipura, K.J., Jiang, R.H., Hunter, D. & Smith, S.A., (2004). Fruits and Vegetable intake and the risk of major chronic disease. Journal of National Cancer Institute, 95,157- 164.
IS 11624: (2019) Indian Standard. Quality of Irrigation Water — Guidelines. Manak Bhavan, 9 Bahadur Shah Zafar Marg New Delhi-110002
Jackson, M., (1973). Soil chemical analysis, pentice hall of India Pvt. Ltd., New Delhi, India, 498, 151–154.
Jalali, M., & Meyari, A. (2022). Heavy metal contents, soil-to-plant transfer factors, and associated health risks in vegetables grown in western Iran. Journal of Food Composition and Analysis, 106, 104316.
Kumar, D., Kumar, S., Bhadana, N.K., Singh, B., Shekhar, C. (2023). Vegetables: source of adequate health benefits. Annals of Horticulture 13(2), 124-130.
Kumar, P., Dipti, Kumar, S., & Singh, R.P., (2022) Severe contamination of carcinogenic heavy metals and metalloid in agroecosystems and their associated health risk assessment. Environmental Pollution, 301, 118953, https://doi.org/10.1016/j.envpol.2022.118953.
Kumar, P., Kumar, S., & Singh, R.P. (2021). High contamination of toxic heavy metals in vegetables and their associated health risk assessment from different vegetable markets of the metropolitan city, Lucknow, India. International Journal of Environmental Research, 15, 837-847.
Kumar, V., Sharma, A., Kaur, P., Sidhu, G.P.S., Bhardwaj, A.S.B.R., Thukral, A.K., & Cerda, A. (2019). Pollution assessment of heavy metals in soils of India and ecological risk assessment: A state-of-the-art. Chemosphere, 216, 449-462.
Läuchli, A., & Grattan, S.R., (2017). Plant stress under non-optimal soil pH. In Plant stress physiology (Eds: Shabala, S.) (pp. 201-216). Wallingford UK: CABI.
Liu, L., Fei, L., Zhu, H., Hao, K., & Li, J. (2021). Effects of water temperature on soil water infiltration characteristics under film-mulched drip irrigation. Journal of Soil Science and Plant Nutrition, 21(4), 2837-2846.
Manwani, S., Devi, P., Singh, T., *et al*. (2023). Heavy metals in vegetables: a review of status, human health concerns, and management options. Environmental Science and Pollution Research, 30, 71940–71956. https://doi.org/10.1007/s11356-022-22210-w
Menon, M., Mohanraj, R., Divya, K.R. *et al*., (2023) Assessment of Heavy Metals in Agroecosystems of the Cauvery Delta Region, South India Using a Focal Species: The Pavo cristatus. Proceedings of Zoological Society, https://doi.org/10.1007/s12595-023-00494-1
Mishra, A., Prusty, A.K., Tamang, A., Manoj, S.G. (2023). A review on health benefits and nutritive value of vegetables. Plant Archives 23(1), 403-411. Doi: https://doi.org/10.51470/PLANTARCHIVES.2023.v23.no1.066
Mitra, S., Chakraborty, A.J., Tareq, A.M., *et al*., (2022). Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. Journal of King Saud University - Science, 34(3). https://doi.org/10.1016/j.jksus.2022.101865.
Ngo, H.T.T., Hang, N.T.T., Nguyen, X.C., Nguyen, N.T.M., Truong, H.B., Liu, C., La, D.D., Kim, S.S., Nguyen, D.D. (2024). Toxic metals in rice among Asian countries: A review of occurrence and potential human health risks. Food Chemistry, 460, 140479. https://doi.org/10.1016/J.FOODCHEM.2024.140479.
Olsen, S.R. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate (Issue 939). US Department of Agriculture.
Othaman, N.N., Isa, M.N., Ismail, R.C., Ahmad, M.I., & Hui, C.K., (2020). Factors that affect soil electrical conductivity (EC) based system for smart farming application. In AIP conference proceedings (Vol. 2203, No. 1). AIP Publishing.
Pescod, M.B. (1992) Wastewater Treatment and Use in Agriculture. FAO Irrigation and Drainage Paper 47, Food and Agriculture Organization

of the United Nations, Rome, 125pp.

Poyen, F.B., Kundu, P.K., & Ghosh, A.K., (2018). pH control of untreated water for irrigation. Journal of the Institution of Engineers (India): Series A, 99, 539-546.

Prohaska, J.R., (2000). Long-term functional consequences of malnutrition during brain development: copper. Nutrition, 16 (7-8), 502-504, 10.1016/S0899-9007(00)00308-7.

Puissant, J., Jones, B., Goodall, T., Mang, D., Blaud, A., Gweon, H. S., ... & Griffiths, R. (2019). The pH optimum of soil exoenzymes adapt to long term changes in soil pH. Soil Biology and Biochemistry, 138, 107601.

Rahim, N., Noor, A., Kanwal, A., Tahir, M. M., Yaqub, A. (2024). Assessment of heavy metal contamination in leafy vegetables: Implications for public health and regulatory measures. Environmental Monitoring & Assessment, 196(8). https://doi.org/10.1007/s10661-024-12855-0

Setia, R. Dhaliwal, S.S., Singh, R., Kumar, V., Taneja, S., Kukal, S.S., Pateriya, B. (2021). Phytoavailability and human risk assessment of heavy metals in soils and food crops around Sutlej River, India, Chemosphere, 263, 128321, https://doi.org/10.1016/j.chemosphere.2020.128321.

Shakya, P.R., Khwaounjoo, N.M. (2013) Heavy metal contamination in green leafy vegetables collected from different market sites of Kathmandu and their associated health risks. Scientific World, 11, 37-42. https://doi.org/10.3126/sw.v11i11.8550.

Sharma, R.K., Agrawal, M., & Marshall, F.M., (2009). Heavy metals in vegetables collected from production and market sites of a tropical urban area of India. Food and chemical toxicology, 47(3), 583-591.

Shetty, B. R., Jagadeesha, P. B., & Salmataj, S. A. (2025). Heavy metal contamination and its impact on the food chain: exposure, bioaccumulation, and risk assessment. CyTA- Journal of Food, 23(1). https://doi.org/10.1080/19476337.2024.2438726

Siegel, K.R., Ali, M.K., Srinivasiah, A., Nugent, R.A. & Narayan, K.M.V., (2014). Do we produce enough fruits and vegetables to meet global health need? PloS One, 9, e104059.

Sikakwe, G.U., Ojo, S.A., Uzosike, P.C. (2024). Assessment of human health risk concerning edible plants contamination with toxic elements around functional and derelict mines. Food & Chemical Toxicology, 189, 114760, https://doi.org/10.1016/j.fct.2024.114760.

Singh, M., Verma, M., Naresh, R.K. (2018). Effects of open dumping of MSW on metal contamination of soil, plants, and earthworms in Ranchi, Jharkhand, India. Environmental Monitoring & Assessment, 190, 139 https://doi.org/10.1007/s10661-018-6492-y

Subbiah, B., (1956). A rapid procedure for the determination of available nitrogen in soils. Current Science, 25, 259–260.

Tanaka, K.I., & Kawahara, M., (2017). Copper enhances zinc-induced neurotoxicity and the endoplasmic reticulum stress response in a neuronal model of vascular dementia. Frontiers in Neuroscience, 11, 10.3389/fnins.2017.00058

Toth, S., & Prince, A. (1949). Estimation of cation-exchange capacity and exchangeable Ca, K, and Na contents of soils by flame photometer techniques. Soil Science, 67(6), 439–446.

USEPA (US Environmental Protection Agency), 2002. Region 9, Preliminary Remediation Goals. www.epa.Gov/region09/waste/sfund/prg.

Walkley, A., & Black, I.A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science, 37(1), 29–38.

WHO/FAO. (2001). Report on the 32nd Session of the Codex Committee on Food Additives and Contaminants, ALINORM 01/12, Beijing, China, 20-24 March 2000. Joint FAO/WHO Food Standard Programme, Codex Alimentarius Commission, 24th Session, 2-7 July, Geneva, Switzerland.

Xiang, M., Li, Y., Yang, J., Lei, K., Li, Y., *et al*. (2021). Heavy metal contamination risk assessment and correlation analysis of heavy metal contents in soil and crops, Environmental Pollution, 278, 116911, https://doi.org/10.1016/j.envpol.2021.116911.

Zaib, M., Farooq, U., Adnan, M., Sajjad, S., Abbas, Z., Haider, K., ... & Muhay-Ul-Din, M. F. (2022). Remediation of Saline Soils by Application of Biochar: A Review. Journal of Environmental & Agricultural Sciences, 24(3&4), 29-36.

Zaman, M., Shahid, S. A., Heng, L., Zaman, M., Shahid, S. A., & Heng, L. (2018). Irrigation water quality. Guideline for salinity assessment, mitigation and adaptation using nuclear and related techniques, 113-131.

Zhang, X., Yang, X., Hu, X. *et al*. (2025) Biomonitoring and food surveillance on heavy metals reveal need for food safety in a coastal region. Food Research International, 15858, https://doi.org/10.1016/j.foodres.2025.115858.