

ASSESSING HEAVY METAL POLLUTION RISKS IN SOIL AND VEGETABLES FROM WASTEWATER IRRIGATION

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Abstract. Wastewater is using worldwide to meet irrigation requirements, however, it can cause serious health implications in human. The wastewater contains a significant amount of arsenic (As), chromium (Cr), cadmium (Cd), iron (Fe), copper (Cu), manganese (Mn) lead (Pb), nickel (Ni) and zinc (Zn), which can pose serious threat to humans. The present survey research was carried out to assess the impacts of sewerage and industrial wastewater on soil physio-chemical properties and heavy metals accumulation in soil and leaves of vegetable grown at Saggian, Lahore Pakistan. Results indicated that the pH of soil ranged from 6.99-7.24, soil electrical conductivity (EC) from 2.0-3.1 dSm⁻¹, organic matter content from 0.98-1.20%, bulk density (BD) of soil from 1.21-1.24 cm⁻³, sodium absorption ratio (SAR) from 6.81 to 7.33 and wet aggregate stability from 11-14%. The concentration of heavy metals in vegetable samples were recorded as followings: 4.09-5.46 mg kg⁻¹ for Pb, 12.01-13.64 mg kg⁻¹ for Cu, 0.11-0.44 mg kg⁻¹ for Zn, 12.01-13.69 mg kg⁻¹ for nickel, 0.001-0.005 mg kg⁻¹ for Cd and 2.01-2.38 mg kg⁻¹ for chromium. The concentration of heavy metals in soil samples were the followings: 37-59 mg kg⁻¹ for Ni, 103-142 mg kg⁻¹ for Cr, 84-130 mg kg⁻¹ for Zn, 37-68 mg kg⁻¹ for Cu, 84-130 mg kg⁻¹ for Pb and 0.31-0.75 mg kg⁻¹ for Cd.

Keywords: *heavy metals, soil, vegetables, water scarcity, organic matter*

Introduction

The estimated growth rate of the world population is about 0.91% that means almost 73 million people per year (Kharazi et al., 2021). Therefore, the population of the world

will go beyond 8.5 billion after 2025 due to which the resources will be depleting (Singh et al., 2024) and water scarcity will become a grave concern. Fresh water is a precious nonrenewable resource for socioeconomic development (Soleimani et al., 2023). The burgeoning population in developing nations diversified the industrialization that has led to increased water demand in domestic, municipal and industrial sectors (Ruan et al., 2023). Therefore, the freshwater contribution towards the agriculture sector is reduced. This scarcity led to the usage of wastewater to irrigate crops which results in the accumulation of toxic metals in the edible parts of food crops and pollutes the human food chain (Shainberg and Letey, 1984; Irandoust and Tabriz, 2017; Ahmadi-Jouibari et al., 2023; Ahmed et al., 2023). The developed countries treat the wastewater to meet the environmental standards and then fulfil the irrigation requirements (Guadie et al., 2021; Soleimani et al., 2023).

Soil is the basic medium for aboveground vegetation (Ali et al., 2021) and for underground microorganisms (Singh et al., 2011; Liang et al., 2011). Any disturbance to soil texture, soil organic carbon and fertility degrades soil quality (Vogeler et al., 2009; Ahmad et al., 2018). Wastewater application on agricultural land enhances productivity (Rusan et al., 2007) by providing more nutrients to soil bacteria and plants as compared to clean water (Singh et al., 2009). According to the World Health Organization (WHO) standards the use of wastewater for a longer term to irrigate agricultural lands leads towards the accumulation of heavy metals in soils as well as uptaken by plants to harm the health of humans and animals (Arora et al., 2008; Gupta et al., 2010; Othman et al., 2021; Oubane et al., 2021). These toxic metals are required in trace amounts for plant growth but their excess leads to plant intoxication (Riyazuddin et al., 2021). Intoxicated foods can result in poisoning human and animal tissues due to toxic metals build up (Cheshmazar et al., 2018). Bioavailability of Cu, Manganese (Mn), Cd and Zn in the gastrointestinal tract of humans by an edible portion of vegetables are used in vitro gastrointestinal technique of extraction. The edible portion of lettuce and radish have a greater response towards metal accumulation (Hamoud et al., 2024). Pb accumulates 0.06–0.65 mg/kg in lettuce and 0.3 mg per kg in onion, and Cd accumulates 0.30 mg per kg in spinach (Kong et al., 2024). Zn is found less in green beans, potatoes and carrots than in leafy vegetables (Saumel et al., 2016; Abou Fayssal et al., 2024).

Keeping in view all the above facts the present study was envisaged to examine the impacts of wastewater application on soil and its tendency to pollute soil and cultivated vegetables.

Materials and methods

The samples of soil and vegetables were collected from Lahore Pakistan and details are given below (*Table 1*).

Table 1. Sampling locations, and collection of soil and vegetable samples

Location	Saggian, Lahore Pakistan (31.5957° N, 74.2436° E)
Soil samples	Soil samples were collected from twenty sites irrigated with wastewater
Vegetable samples	The leaves of different vegetables including carrot, potato, spinach, and cauliflower were collected to determine concentration of heavy metals. Twenty plants of each vegetable were randomly selected from different location and homogenized to make composite samples to determine heavy metals concentration.

Soil and vegetable samples were collected during month of February from marked sites. Soil samples were collected from 0-15 and 15-30 cm with the help of soil auger. Soil cores were also taken to determine soil bulk density. The irrigation water sample was also taken for to determine the concentration of heavy metals. Soil samples taken in cores are oven dried at 105 °C till constant weight and used for measurement of soil BD by given formula (*Eq. 1 and Eq. 2*).

$$\text{Bulk density} = \text{Oven dried weight/Core volume} \quad (\text{Eq.1})$$

$$\rho_b = W_t / \pi r^2 \quad (\text{Eq.2})$$

Soil samples were air dried, crushed and the plant roots or other debris was removed. Soil was then passed through 2 mm mesh sized sieve. One-gram soil sample was oxidized with potassium dichromate ($K_2Cr_2O_7$) and acidified using sulfuric acid (H_2SO_4) and phosphorous acid (H_3PO_3) solutions. Diphenylamine was used as indicator that turned color to violet blue. This was titrated against ferrous ammonium sulphate till green end point. The organic matter can be measured using following equations (*Eq.3, Eq.4 and Eq.5*).

$$\% \text{ Oxidizable carbon} = (V_{\text{blank}} - V_{\text{sample}}) M \times 0.3 \times W_t \quad (\text{Eq.3})$$

$$(\text{SOC}) \% = (1.334) \times \% \text{ Oxidizable carbon} \quad (\text{Eq.4})$$

$$(\text{SOM}) \% = (1.724) \times (\text{SOC}) \% \quad (\text{Eq.5})$$

where,

M = Molarity of (0.5 M) $(NH_4)_2SO_4 \cdot FeSO_4 \cdot 6H_2O$ solution,

V_{blank} = Vol. of $(NH_4)_2SO_4 \cdot FeSO_4 \cdot 6H_2O$ solution acquired for titration of blank in (mL),

V_{sample} = Vol. of $(NH_4)_2SO_4 \cdot FeSO_4 \cdot 6H_2O$ solution required to titrate the sample in (mL),

W_t = air dried Wt. of soil in grams,

0.3 = $(3 \times 10^{-3} \times 100)$ here 3 is the equivalent weight of C.

Wet stable aggregation of (0.25-2 mm) small aggregates was determined utilizing the artificial rainfall simulator (Local made). A catch pan and stacked sieves of (2 and 0.25 mm) were used. Mechanical shaker was used to shake the soil samples for 10 seconds. Small fractions of aggregates were remained. It was used to know the wet stable aggregation. Larger aggregates (2 mm) and small aggregates (0.25-2 mm) were spread in single layer on mesh sieve. Under the 0.59 m diameter rainfall simulator, four sieves were kept at same time for five minutes. This delivered 1.25 mm of water as 4 mm drops in 5 minutes and every sieve received 1.9 Joules of energy under simulated rainfall. Solid particles and stones remained on the sieves. The soil material which fell through the sieve in filter funnel were collected. After collection it was dried and weighed. Water stable aggregates fraction was calculated by these formulas (*Eq.6 and Eq.7*).

$$\text{Wet stable aggregate} = W_{\text{stable}} / (W_{\text{total}}) \quad (\text{Eq.6})$$

$$\text{Wet stable aggregate} = W_{\text{total}} - (W_{\text{slaked}} + W_{\text{stones}}) \quad (\text{Eq.7})$$

Soil saturated paste was prepared using dishes made up of Porcelain, beakers, and spatulas. Soil sample was weighed and added in a beaker. Distilled water was added and placed overnight. Next day wet soil was mixed with spatula until all the particles appear wet and placed. After one hour, paste was again checked and added more distilled water to prepare saturated soil paste having shiny appearance and non-stickiness with spatula. Soil pH was measured by using pH meter (Hanna Instruments) while reagents used were De-ionized water, pH 7.0 buffer solution and pH 4.0 buffer solution was used. Firstly, pH meter was calibrated and combine electrode was dipped in paste and reading was taken for each sample. After measuring pH of soil, the saturated paste was processed through system of vacuum extraction to extract the solution for different soil chemical analysis. EC of soil gives information about inorganic salts in soil which are soluble. It was measured by using EC meter (Cond 7310, Inolab). Conductivity bridge was used as apparatus and system of vacuum filtration was used. Reagent used for this purpose was 0.01 N Potassium Chloride solution. Amount of Na⁺ and Ca²⁺+Mg²⁺ were measured by using flame photometer and titration, respectively. SAR gave the measurement of sodium amount in relation to calcium and magnesium in the water extracted from soil paste (Eq.8).

$$\text{SAR} = \text{Na} / \sqrt{(\text{Ca} + \text{Mg}/2)} \quad (\text{Eq.8})$$

For estimation of heavy metals, the samples were digested using tri-acid mixture HNO₃, HClO₄ and H₂SO₄ 5:1:1 for soil and water. To measure concentration atomic absorption spectrophotometer (AAS) (contrAA 800, Analytik Jena made) was used that works on absorption principle. AAS has Xe-Arc Lamp specifically for elements in which atoms absorbs energy and their electrons go to higher energy state that emits light on returning to their ground state. Emitted light is passed through the suspension and concentration of elements is measure of absorbed light. The detected readings are compared with that of standards to find the original amount of metal in the sample.

Leaves of vegetables (carrot, cauliflower, spinach, and potato) were digested with di-acid HNO₃ and HClO₄ in 3:1. After digestion samples were fed in Atomic Absorption Spectrophotometer (contrAA 800, Analytik Jena made) and for each sample concentration of heavy metals was analyzed. Heavy metals found in wastewater are mentioned in results. Permissible limit of heavy metals is given in *Tables 2, 3*.

Table 2. Permissible limit of heavy metals in soil and vegetables

Heavy metals	Permissible limit in Soil (mg kg ⁻¹)	Permissible limit in Vegetables (mg kg ⁻¹)
Ni	35	10
Cu	36	10
Pb	85	2
Cr	100	1.30
Zn	50	0.60
Cd	0.8	0.02

Statistical analysis

The data collected on different traits were analyzed and differentiated by using standard errors. The results of ANOVA were significant, and figures were prepared by Microsoft excel®.

Table 3. Permissible limit of heavy metals in water

Heavy metals	Permissible limit in water (mg L ⁻¹)	Quantity in Wastewater (mg L ⁻¹)
Ni	0.20	0.337±0.015
Cu	0.20	0.373±0.020
Pb	5.0	6.240±0.017
Cr	0.05	0.008±0.001
Zn	2.0	3.030±0.012
Cd	0.01	0.005±0.001

Result and discussion

Soil pH

The variations in the pH of the soil with the application of wastewater are described in figure 1(a). A declining trend in the pH of soil can easily be observed with wastewater application. The pH of soil irrigated with canal water was 8.2 that was declined to (6.99) at the site (1), while pH ranged between (7.10 to 7.24) and (6.99 to 7.23) at 0-15 cm and 15-30 cm depth of the soils of all the 20 sites as elaborated in *Figure 1a*.

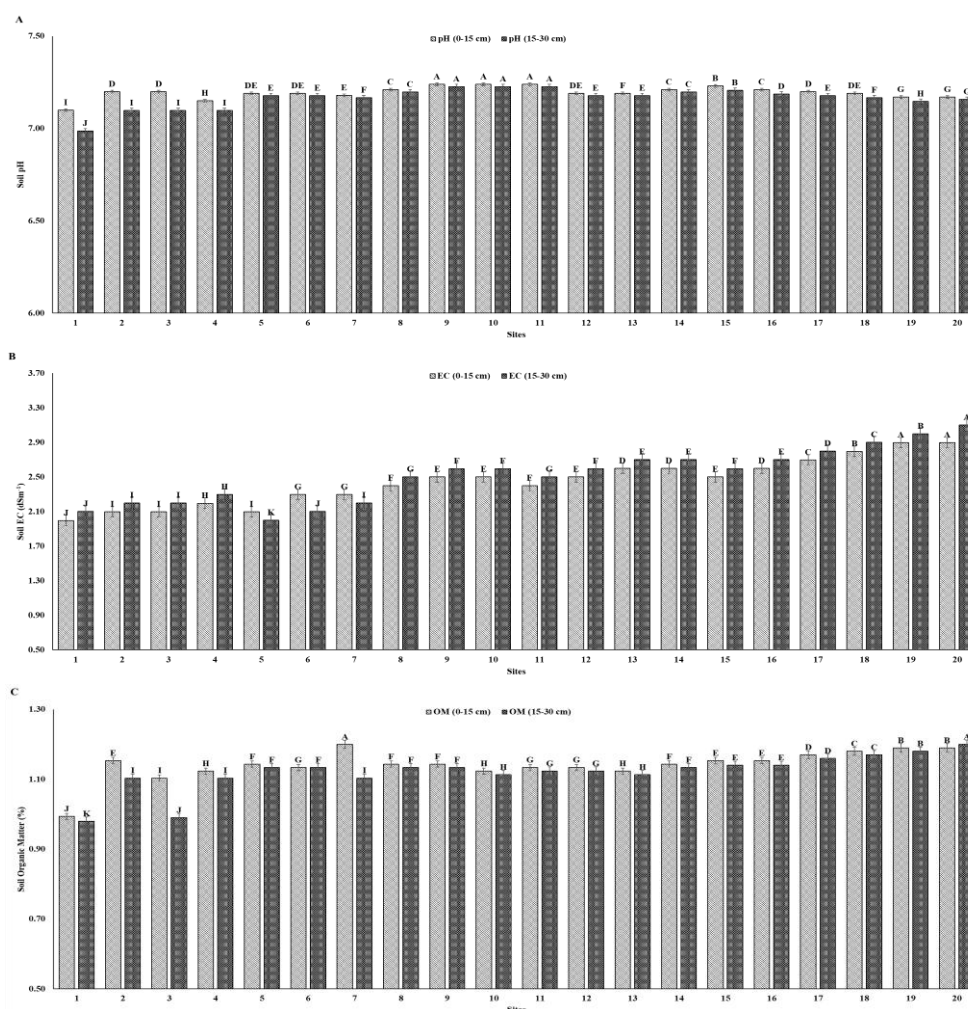


Figure 1. Effect of waste-water irrigation on soil pH (a) EC (b) and organic matter (c) of 0-15 and 15-30 cm depth

Electrical conductivity

The variations in the EC of soil with the application of wastewater is described in *Figure 1b*. An increasing trend in the EC of soil can easily be observed with wastewater application. The EC of soil irrigated with wastewater was increased to (2.0) at site (1), while EC was ranged between (2.0 to 2.9) and (2.0 to 3.1) at 0-15 cm and 15-30 cm depth of the soils of all the 20 sites as elaborated in *Figure 1b*.

Soil organic matter

The variations in the organic matter (OM) of soil with the application of wastewater is described in *Figure 1c*. An increasing trend in the OM of soil can easily be observed with wastewater application. The OM of soil irrigated with wastewater was enhanced to (1.20) at site (20), while OM was ranged between (0.99 to 1.20) and (0.98 to 1.20) at 0-15 cm and 15-30 cm depth of the soils of all the 20 sites as elaborated in *Figure 1c*.

Soil bulk density

The variations in the BD of soil with the application of wastewater is described in *Figure 2a*. A declining trend in the BD of soil can easily be observed with wastewater application. The BD of soil irrigated with wastewater was declined to (1.21) at site (1), while BD was ranged between (1.21 to 1.24) of the soils of all the 20 sites as elaborated in *Figure 2a*.

Sodium adsorption ratio

The variations in the SAR of soil with the application of wastewater is described in *Figure 2b*. A declining trend in the SAR of soil can easily be observed with wastewater application. The SAR of soil irrigated with wastewater was declined to (6.81) at site (1), while SAR was ranged between (6.81 to 7.33) of the soils of all the 20 sites as elaborated in *Figure 2b*.

Soil aggregate stability

The variations in the soil aggregate stability (SAS) of soil with the application of wastewater is described in *Figure 2c*. A declining trend in the SAS of soil can easily be observed with wastewater application. The SAS of soil irrigated with wastewater was declined to (11) at site (5), while SAS was ranged between (14 to 11) of the soils of all the 20 sites as elaborated in *Figure 2c*.

Heavy metals contents of vegetables

Heavy metal concentration in vegetables by applying wastewater tends to increase to some extent. The concentration of heavy metals in all vegetables was higher than their permissible limits. The permissible limit of heavy metals found in vegetables is mentioned in *Table 2*.

The wastewater application causes changes in the physicochemical characters of the soil system and subsequently heavy metal uptake by vegetables. The concentration of heavy metals in Carrot is given in *Figure 3a*, the concentration of heavy metals in Cauliflower is given in *Figure 3b*, the concentration of heavy metals in Spinach is given in *Figure 3c* and the concentration of heavy metals in Potato is given in *Figure 3d*. Concentration of Cd and Zn in our study was under a safer limit as compared to other

heavy metals. This align with study findings of Khan et al. (2016) they also observed the same results. Concentration of heavy metals in leaves of vegetables ranges from Ni, 12.01-13.69 mg/kg; Cu, 12.01-13.64 mg/kg; Pb, 4.09-5.46 mg/kg; Cr, 2.01-2.38 mg/kg; Zn, 0.11-0.44 mg/kg; Cd, 0.001-0.005 mg/kg.

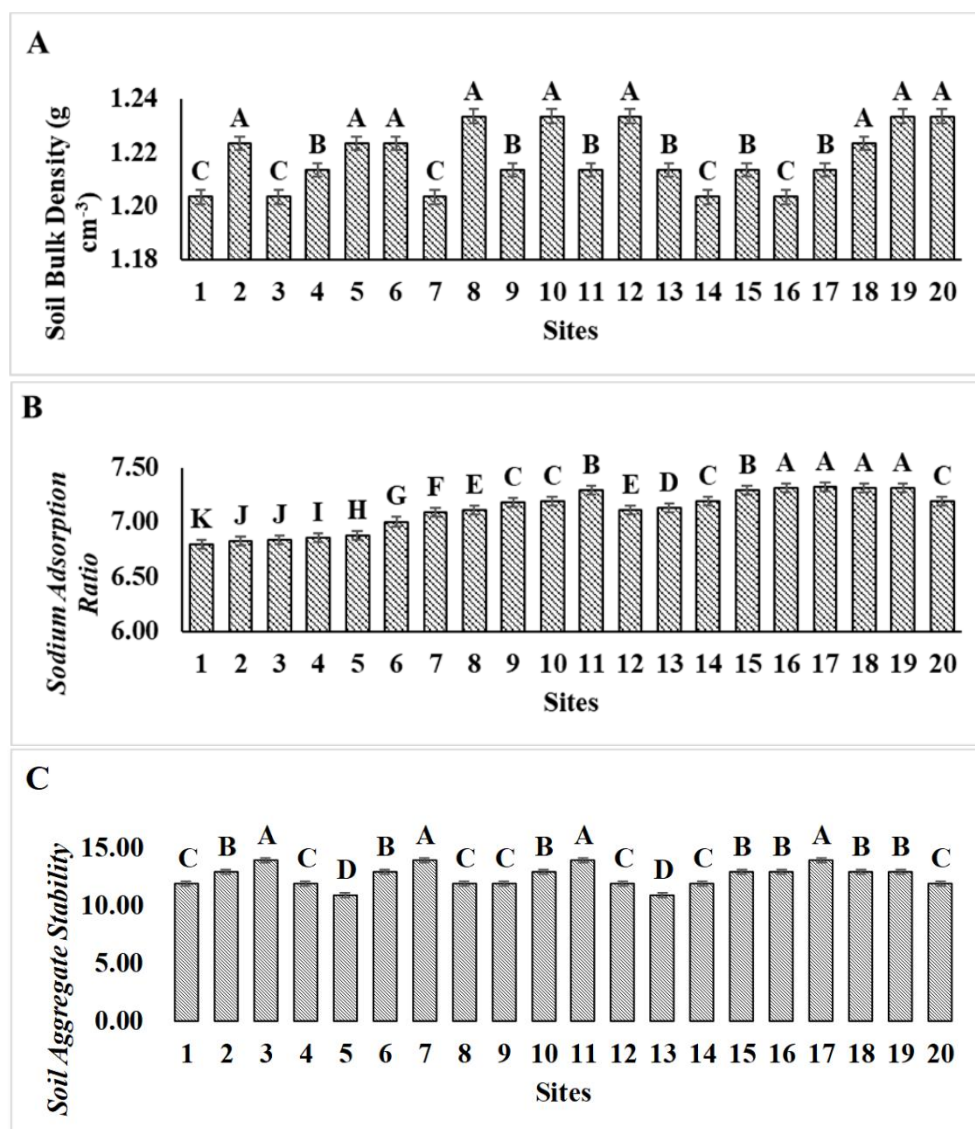


Figure 2. Effect of waste-water irrigation on Soil bulk density (a), Sodium Adsorption Ratio (b) and Soil Aggregate Stability (c)

Heavy metal contents of soil

The variations in the heavy metal concentration of soil irrigated by wastewater are described in Table 4. An increasing trend in the concentration of heavy metals present in soil irrigated by wastewater can easily be observed. Data indicates that Cd and Zn were under a safer limit as compared to other heavy metals. The concentration of NI ranges from 37-59 mg/kg, Cr ranges from 103-142 mg/kg, Zn ranges from 84-130 mg/kg, Cu ranges from 37-68 mg/kg, Pb ranges from 84-130 mg/kg and Cd ranges from 0.31-0.75 mg/kg.

Table 4. Heavy metals in soil irrigated by wastewater

Sites	Heavy Metals in Soil (mg kg ⁻¹)											
	Nickle		Chromium		Zinc		Copper		Lead		Cadmium	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
S1	37±1.94 VW	42±2.30Q RS	103±5.40Y	115±6.29 TUV	23±1.2 1P	35±1.91 G	38±1.99KL M	41±2.13IJK L	87±4.56T UV	94±5.14Q RS	0.31±0.0 2U	0.33±0.0 2STU
S2	44±2.31 OPQ	44±2.41OP Q	106±5.55X Y	112±6.13 VW	27±1.4 1LM	29±1.59 K	49±2.57CD EFG	43±2.52GH IJKL	91±4.77R ST	97±5.31P Q	0.66±0.0 3G	0.63±0.0 3HIJ
S3	55±2.88 DEF	46±2.52M NO	112±5.87V W	119±6.51 PQRSTU	25±1.3 1NO	24±1.31 OP	37±1.94L M	44±2.74EF GHIJK	95±4.98Q R	117±6.40 KLM	0.62±0.0 3IJ	0.73±0.0 4EF
S4	42±2.20 QRS	36±1.97W	115±6.03T UV	117±6.40 RSTUV	21±1.1 0Q	32±1.75 IJ	52±2.72BC D	50±3.01CD EF	88±4.61T UV	125±6.84 DEFG	0.77±0.0 4BC	0.64±0.0 4GHI
S5	50±2.62I JK	44±2.41OP Q	138±7.23C DE	121±6.62 NOPQRS	34±1.7 8GH	23±1.26 P	66±3.46A	48±2.19CD EFGH	101±5.29 OP	127±6.95 CDE	0.80±0.0 4A	0.74±0.0 4DEF
S6	59±3.09 A	54±2.95EF G	109±5.71 WX	128±7.00 HIJKL	41±2.1 5D	39±2.13 E	40±2.10JK LM	50±3.06CD EF	114±5.97L MN	86±4.70U V	0.46±0.0 2NO	0.51±0.0 3M
S7	48±2.52 KLM	52±2.84G HI	114±5.97U VW	126±6.89J KLMN	49±2.5 7A	29±1.59 K	44±2.31FG HIJK	46±2.41DE FGHIJ	119±6.24 HIJK	119±6.51 HIJK	0.52±0.0 3LM	0.56±0.0 3K
S8	43±2.25P QR	57±3.12B CD	135±7.07D EFG	116±6.35 STUV	42±2.2 0CD	32±1.75 IJ	68±3.56A	51±2.09BC DE	123±6.45E FGH	122±6.67F GHIJ	0.36±0.0 2QR	0.38±0.0 2Q
S9	41±2.15 RST	59±3.23A B	139±7.28C D	122±6.67 MNOPQ R	32±1.6 8IJ	42±2.30 CD	58±3.04B	45±2.19DE FGHIJ	126±6.60 CDEF	130±7.11 BC	0.45±0.0 2OP	0.32±0.0 2TU
S10	51±2.67 HIJ	37±2.02V W	124±6.50K LMNOP	120±6.56 OPQRST	38±1.9 9EF	28±1.53 KL	51±2.67CD E	48±2.09CD EFGH	130±6.81 ABC	87±4.76T UV	0.55±0.0 3K	0.74±0.0 4DEF
S11	36±1.89 W	48±2.63K LM	132±6.92F GHI	132±7.22 FGHI	43±2.2 5C	33±1.81 HI	44±2.31FG HIJK	45±2.35DE FGHIJ	128±6.71 BCD	135±7.38 A	0.65±0.0 3GH	0.61±0.0 3J
S12	39±2.04 TUV	58±3.17A BC	125±6.55K LMNO	142±7.77 BC	31±1.6 2J	21±1.15 Q	49±2.57CD EFG	48±2.68CD EFGH	118±6.18I JKLM	117±6.40 KLM	0.46±0.0 2NO	0.48±0.0 3N
S13	45±2.36 NOP	38±2.08U VW	118±6.18Q RSTU	146±7.99 AB	26±1.3 6MN	16±0.88 S	47±2.46DE FGHI	48±2.84CD EFGHI	129±6.76 BCD	132±7.22 AB	0.35±0.0 2RS	0.72±0.0 4F
S14	57±2.99 ABCD	56±3.06C DE	127±6.65IJ KLM	119±6.51 PQRSTU	29±1.5 2K	19±1.04 R	51±2.20HI JKL	54±2.95BC DE	121±6.34 GHIJK	114±6.24 MN	0.54±0.0 3KL	0.64±0.0 4GHI

Sites	Heavy Metals in Soil (mg kg ⁻¹)											
	Nickel		Chromium		Zinc		Copper		Lead		Cadmium	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
S15	49±2.57J KL	48±2.63K LM	129±6.76H IJK	125±6.84 KLMNO	17±0.8 9S	27±0.93 LM	58±3.04B	51±2.57CD EF	111±5.82 N	129±7.06 BCD	0.51±0.0 3M	0.78±0.0 4AB
S16	39±2.04 TUV	36±1.97W	123±6.45L MNOPQ	133±7.28 EFGH	27±1.4 1LM	17±0.93 S	54±2.83BC	51±2.84CD EF	97±5.08O PQ	123±6.73E FGHI	0.43±0.0 2P	0.46±0.0 3NO
S17	53±2.78F GH	52±2.84G HI	119±6.24P QRSTU	148±8.10 A	37±1.9 4F	47±2.57 B	50±2.62CD EF	47±2.30DE FGHI	84±4.40V	118±6.45J KLM	0.75±0.0 4CDE	0.66±0.0 4G
S18	36±1.89 W	41±2.24RS T	121±6.34N OPQRS	137±7.49 CDEF	47±2.4 6B	37±2.02 F	46±2.41DE FGHIJ	48±2.79CD EFGH	89±4.66S TU	102±5.58 O	0.72±0.0 4F	0.31±0.0 2U
S19	43±2.25P QR	51±2.79HI J	115±6.03T UV	139±7.60 CD	38±1.9 9EF	48±2.63 AB	34±1.78M	47±2.63DE FGHIJ	93±4.87Q RS	96±5.25Q R	0.63±0.0 3HIJ	0.44±0.0 2OP
S20	40±2.10S TU	47±2.57L MN	117±6.13R STUV	131±7.17 GHIJ	49±2.5 7A	38±2.08 T	48±2.52CD EFGHI	46±2.24DE FGHIJ	86±4.51U V	88±4.81T UV	0.34±0.0 2RST	0.76±0.0 4BCD

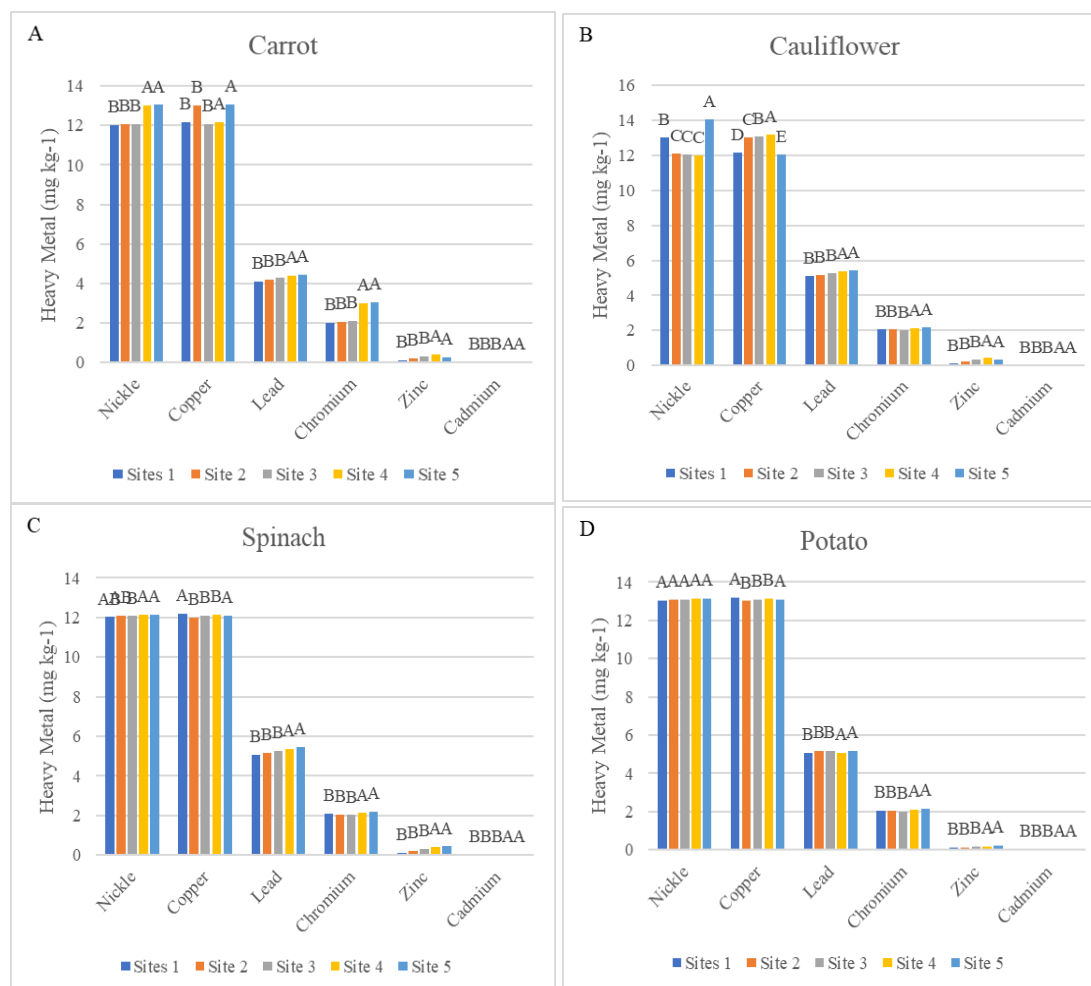


Figure 3. Heavy metals concentration in carrot (a), cauliflower (b), spinach (c) and potato (d)

Discussion

The research findings highlight the impact of wastewater application on various soil properties, including pH, EC, OM, BD, SAR, and heavy metals i.e., nickel, chromium, Zn, Pb, Cu and Cd accumulation in soil and uptake by vegetables. The application of wastewater resulted in a declining trend in soil pH. At site (1), the pH decreased from 8.2 (with canal water irrigation) to 6.99 with wastewater irrigation. Across all sites, the pH ranged between 6.99 and 7.24, indicating a consistent decrease in soil pH with wastewater irrigation. Zhang et al. (2015) explained that pH value decreases to some extent by applying wastewater in soil. The pH of Pakistani soil is 8 or 8.5, which shows that Pakistani soil is alkaline. But by applying wastewater pH value decreased to some extent.

Wastewater application led to an increase in soil EC. At site (1), the EC increased to 2.0 dSm⁻¹, and across all sites, it ranged between 2.0 and 3.1 dSm⁻¹. This rise in EC suggests an accumulation of soluble salts in the soil due to wastewater irrigation. The EC of soil by application of wastewater was lower in soil that is irrigated with water from a canal and water from a tube well also, due to wastewater implementation plants grow better by absorbing an excess quantity of salts. Salinity in soil and EC enhanced because soil absorbs more salts from water especially wastewater which was used for irrigation purposes. Wastewater irrigation causes an increase in soil EC. The value of EC of

Pakistani soil is 1.2-1.8. But applying wastewater it changes. After analysis of soil samples, it is shown that the value of EC varies from 2-3.

The OM content in soil exhibited an increasing trend with wastewater application. At site (20), OM was enhanced to 1.20% while it averaged between 0.98 and 1.20% across all sites. This increase in OM indicates the addition of organic nutrients from the wastewater, potentially enriching the soil fertility (Zhang et al., 2015). Organic matter present in soil has many elements that are necessary for better growth of plants, and it is involved in the fertility of soil. Degradation of soil OM causes the release of substances such as plant hormones, vitamins, and amino acids for better growth of plants and also increases microorganism count. The activity of the urease enzyme with the application of wastewater has no common difference to soil that is irrigated with processed water. Phosphatase enzyme activity in soil irrigated with wastewater was not found distinct from soil irrigated with the help of tap water and processed wastewater. The result indicates many changes in nitrogen and phosphorus fertilizer caused an increase in activity of phosphatase activity and phosphorus was required by plants in higher amounts. The organic matter content of Pakistani soil is less than 1%. After applying wastewater organic matter content increases to some extent.

Wastewater application resulted in a declining trend in soil BD. At site (1), the BD decreased to 1.21 Mg m^{-3} which went maximum up to 1.24 Mg m^{-3} . This decrease in BD suggests improved soil structure and porosity, likely due to organic matter incorporation from the wastewater.

The SAR had a declining trend as the site (1), SAR decreased to 6.81, and across all sites, it ranged between 6.81 and 7.33 with wastewater application. Change of cations in soil cause replacement of sodium with cations present in that soil especially magnesium and calcium present in soil. These cations cause enhancement in the ratio of exchangeable sodium adsorption (Jabeen et al., 2020). SAR of water utilized for irrigation purposes is estimated by concentration of cation (Rengasamy and Olsson, 1993). This is the concentration of cations present for adsorption or effective activity than absolute cation concentration which determines the exchangeable sodium percentage of soils which was irrigated. Rengasamy and Olsson (1993) have clarified sodium (Na^+), sodium sulfate (Na_2SO_4), sodium bicarbonate (NaHCO_3), magnesium (Mg^{2+}), magnesium bicarbonate (MgHCO_3^+), magnesium sulfate (MgSO_4), calcium (Ca^{2+}), calcium carbonate (CaHCO_3^+) and calcium sulfate (CaSO_4) as principal species which alter SAR of soil from water input. Their role is well explained by Rengasamy and Olsson (1993) and the SAR has determined impacts on soil properties (Ayers and Westcot, 1976). Effective SAR is considered critical for the implementation of wastewater because of organic polymers that form a complex of magnesium and calcium. It is observed almost 8-26% is bound by organic ligands. Hydraulic conductivity is decreased by the binding of magnesium and calcium (Despland et al., 2011). The following findings were given by Levy (2011) who describe the difference between practical SAR and effective SAR at 48%.

Wastewater application led to a sheer decrease in SAS. At site (5), SAS decreased to 11% which was the lowest and SAS of other sites was found 11 and 14%. This decrease in SAS suggests a weakening of soil structure, potentially due to the breakdown of aggregates from the impact of wastewater components. Aggregate stability is an important property because it affects water infiltration and flow through soils. Sodium in wastewater below critical coagulation concentration can cause a reduction in aggregate stability, a decrease in infiltration rate, and an increase in the risk of runoff. The result of the method obtaining water stability of aggregates is explained by using single sieves

which were highly correlated with results from multiple sieve methods for measuring the size of aggregates distribution and with field (Kemper and Rosenau, 1986). Single-sieve methods are preferred by researchers due to their simplicity. The improved wet sieving method introduced by Kemper and Koch (1966) became a standard and common method for determining the stability of macro-aggregates (> 0.25 mm) (Rohoskova and Valla, 2004). According to Balkhair and Ashraf (2016) single sieve method is enough as complex methods are justified due to their arbitrary nature. As there are different methods to determine aggregate stability producing empirical structural stability indices, comparisons can only be done where similar procedures were used (Osman et al., 2021).

The findings suggest that while wastewater irrigation has positive effects on certain soil properties such as OM content and soil structure (as indicated by BD), it also has negative impacts on soil pH, EC, SAR, and SAS. Proper management strategies are crucial to mitigate the adverse effects and maximize the benefits of wastewater application in agricultural practices.

Heavy metals application in agricultural soil causes many changes in soil properties. Heavy metals concentration increases in agricultural soil by applying wastewater (Habu and Usman, 2021). *Table 1* shows the permissible limit for heavy metals in soil. *Table 2* shows heavy metals for all the collected samples of soil from the fields during the growing season of the selected vegetables. Heavy metals concentration was found to be higher than standards in some of the samples of soil collected from the fields (Sarwar et al., 2020). This is due to the heavy application of municipal wastewater as irrigation water to grow vegetables in the fields (Rehman et al., 2019). Heavy metal contents of the soil were found higher. This might be due to continual wastewater application and heavy metals build up in the soil (Abu-Elela et al., 2021). Higher levels of heavy metals in Pakistani soils are also reported by Hassan et al. (2024). Heavy metal concentration in vegetables by applying wastewater tends to increase to some extent. The concentration of heavy metals in all vegetables was higher than their permissible limits. Results were consistent with findings Atta et al. (2023); and Balkhair and Ashraf (2016) that accumulation concentrations were much higher than their permissible levels.

Conclusion

The research concludes that wastewater irrigation leads to an increase in heavy metal concentrations in soil, with Ni, Cr, Cu, and Pb exceeding safe limits. Although Cd and Zn remain within acceptable levels, other heavy metals pose risks to soil and environmental health. The application of wastewater positively impacts soil as it decreases the pH and BD of soil and increases organic matter and aggregate stability. Vegetable crops show significant accumulation of these contaminants, raising concerns about food safety. Therefore, the accumulation of heavy metals in soil that enter the food chain through cultivation is a grave risk and can be carcinogenic. Effective management practices and further research are needed to mitigate contamination risks and ensure agricultural sustainability and food safety.

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