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

ALI, R.[1] – SHAHZAD, H.[2] – IQBAL, M.[1] – MUHAMMAD, F.[3] – SHAFIQUE, M.[4] – LI, D.[5*] – AL-KHAYRI, J. M.[6] – AL-DOSSARY, O. M.[6*] – ALSUBAIE, B.[6] – ALDAEJ, M. I.[6] – ALMAGHASLA, M. I.[7,8] – SHEHATA, W. F.[6,9]

[1]*Institute of Soil & Environmental Science, University of Faisalabad-38000, Pakistan*

[2]*Pakistan Atomic Energy Commission, Nuclear Institute for Food and Agriculture, Peshawar*

[3]*Department of Agronomy, University of Agriculture, Faisalabad-38000, Pakistan*

[4]*Sugarcane Research institute, Ayub Research Faisalabad-38000, Pakistan*

[5]*School of Life Science, Baicheng Normal University, Baicheng 137000, Jilin, China*

[6]*Department of Agricultural Biotechnology, College of Agriculture and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia*

[7]*Department of Arid Land Agriculture, College of Agriculture and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia*

[8]*Plant Pests, and Diseases Unit, College of Agriculture and Food Sciences, King Faisal University, Al-Ahsa 31982, Saudi Arabia*

[9]*Plant Production Department, College of Environmental Agricultural Science, Arish University, PO Box 45511, North Sinai, Egypt*

[*]*Corresponding authors*
e-mail: lidaji@bcnu.edu.cn, othmand@kfu.edu.sa

(Received 1st Nov 2024; accepted 27th Feb 2025)

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

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671

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 homogonized to make composite samples to determine heavy metals concentration.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671

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*).

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

$$\rho b = Wt/\pi r^2 \quad \text{(Eq.2)}$$

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*).

$$\text{\% Oxidizable carbon} = (\text{VBlank-VSample})\ M \times 0.3 \times Wt \quad \text{(Eq.3)}$$

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

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

where,
M = Molarity of (0.5 M) $(NH_4)_2SO_4.FeSO_4.6H_2O$ solution,
V_{blank} = Vol. of $(NH_4)_2SO_4.FeSO_4.6H_2O$ solution acquired for titration of blank in (mL),
V_{sample} = Vol. of $(NH_4)_2SO_4.FeSO_4.6H_2O$ solution required to titrate the sample in (mL),
Wt = 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*).

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

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

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671

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*).

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

For estimation of heavy metals, the samples were digested using tri-acid mixture HNO_3, $HClO_4$ and H_2SO_4 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 HNO_3 and $HClO_4$ 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®.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671

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*.

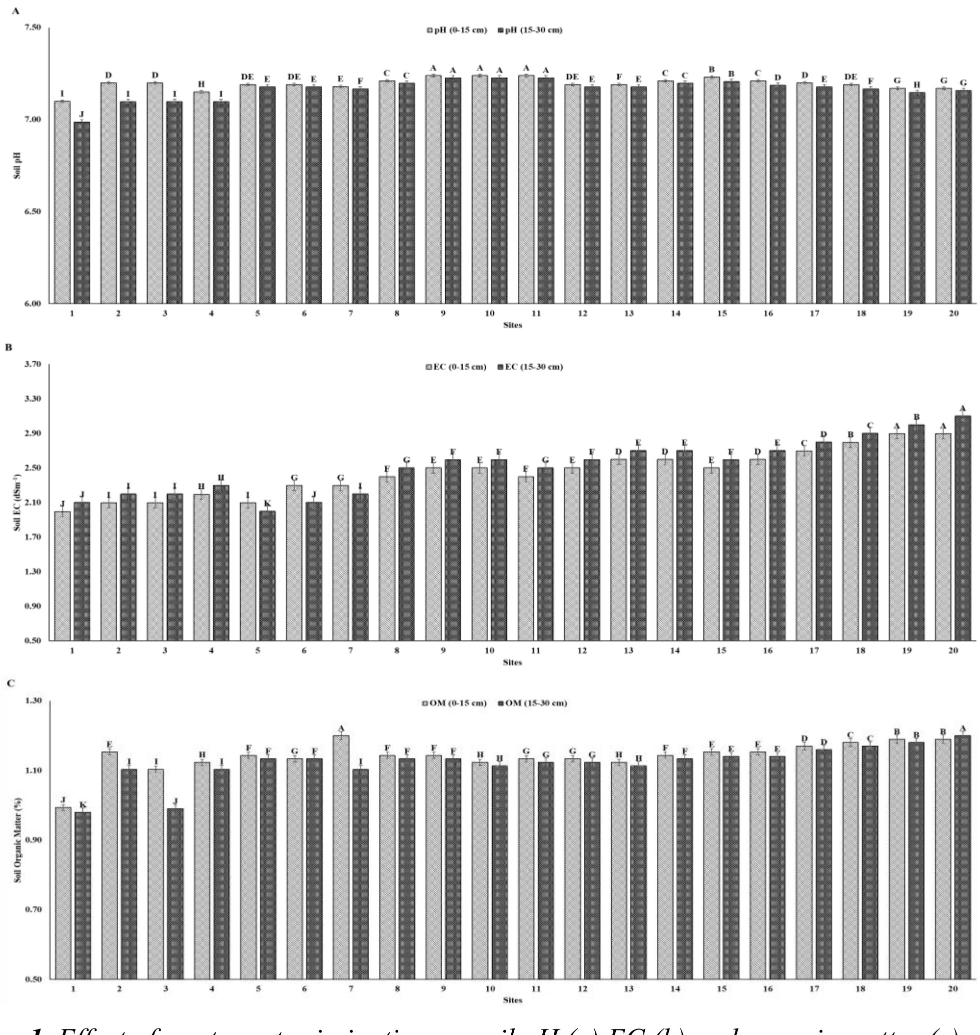

Figure 1. *Effect of waste-water irrigation on soil pH (a) EC (b) and organic matter (c) of 0-15 and 15-30 cm depth*

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 23(4):6657-6671.
http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671

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

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671

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.

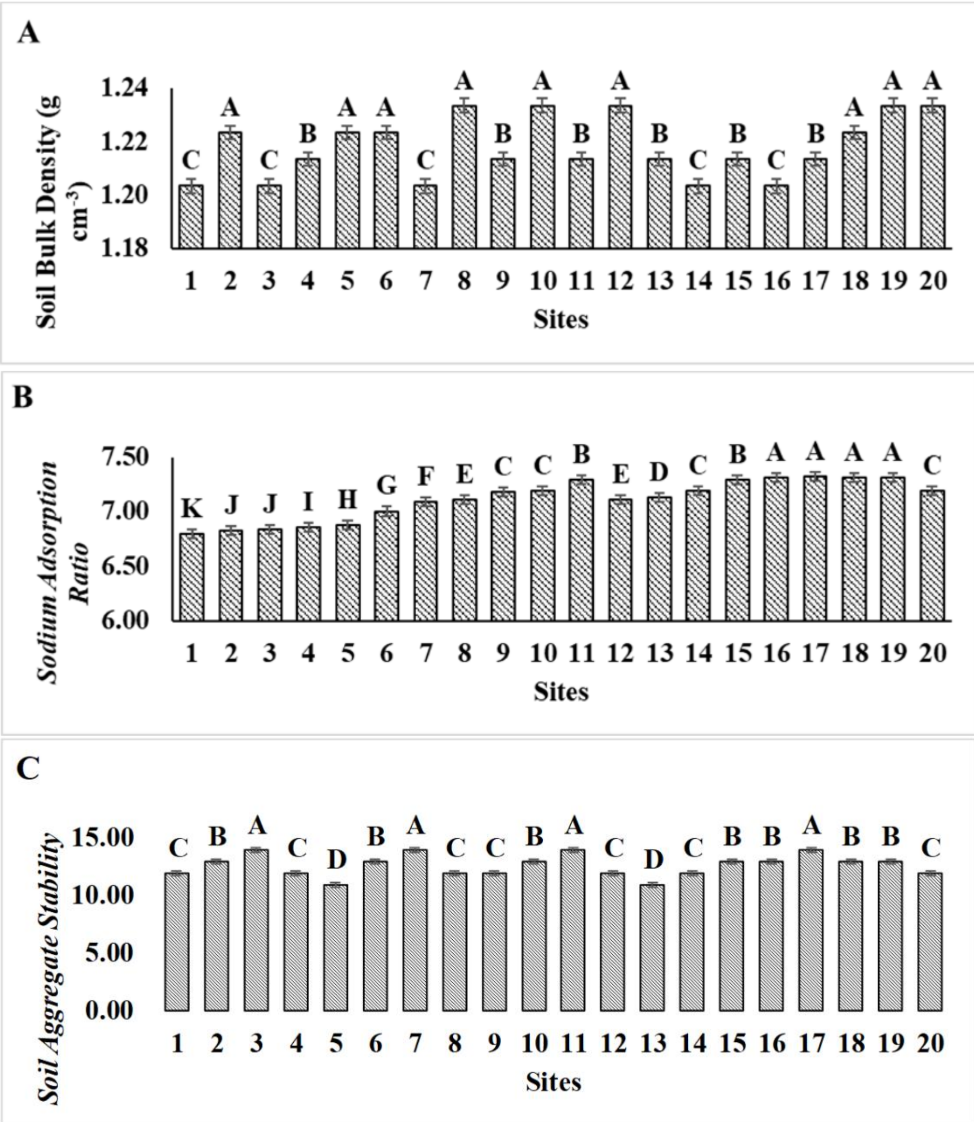

Figure 2. *Effect of waste-water irrigation on Soil bulk density (a), Sodium Adsorption Ratio (b) and Soil Aggregate Stability (c)*

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.

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 23(4):6657-6671.
http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671

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±1.94VW	42±2.30QRS	103±5.40Y	115±6.29TUV	23±1.21P	35±1.91G	38±1.99KLM	41±2.13IJKL	87±4.56TUV	94±5.14QRS	0.31±0.02U	0.33±0.02STU
S2	44±2.31OPQ	44±2.41OPQ	106±5.55XY	112±6.13VW	27±1.41LM	29±1.59K	49±2.57CDEFG	43±2.52GHIJKL	91±4.77RST	97±5.31PQ	0.66±0.03G	0.63±0.03HIJ
S3	55±2.88DEF	46±2.52MNO	112±5.87VW	119±6.51PQRSTU	25±1.31NO	24±1.31OP	37±1.94LM	44±2.74EFGHIJK	95±4.98QR	117±6.40KLM	0.62±0.03IJ	0.73±0.04EF
S4	42±2.20QRS	36±1.97W	115±6.03TUV	117±6.40RSTUV	21±1.10Q	32±1.75IJ	52±2.72BCD	50±3.01CDEF	88±4.61TUV	125±6.84DEFG	0.77±0.04BC	0.64±0.04GHI
S5	50±2.62IJK	44±2.41OPQ	138±7.23CDE	121±6.62NOPQRS	34±1.78GH	23±1.26P	66±3.46A	48±2.19CDEFGH	101±5.29OP	127±6.95CDE	0.80±0.04A	0.74±0.04DEF
S6	59±3.09A	54±2.95EFG	109±5.71WX	128±7.00HIJKL	41±2.15D	39±2.13E	40±2.10JKLM	50±3.06CDEF	114±5.97LMN	86±4.70UV	0.46±0.02NO	0.51±0.03M
S7	48±2.52KLM	52±2.84GHI	114±5.97UVW	126±6.89JKLMN	49±2.57A	29±1.59K	44±2.31FGHIJK	46±2.41DEFGHIJ	119±6.24HIJK	119±6.51HIJK	0.52±0.03LM	0.56±0.03K
S8	43±2.25PQR	57±3.12BCD	135±7.07DEFG	116±6.35STUV	42±2.20CD	32±1.75IJ	68±3.56A	51±2.09BCDE	123±6.45EFGH	122±6.67FGHIJ	0.36±0.02QR	0.38±0.02Q
S9	41±2.15RST	59±3.23AB	139±7.28CD	122±6.67MNOPQR	32±1.68IJ	42±2.30CD	58±3.04B	45±2.19DEFGHIJ	126±6.60CDEF	130±7.11BC	0.45±0.02OP	0.32±0.02TU
S10	51±2.67HIJ	37±2.02VW	124±6.50KLMNOP	120±6.56OPQRST	38±1.99EF	28±1.53KL	51±2.67CDE	48±2.09CDEFGH	130±6.81ABC	87±4.76TUV	0.55±0.03K	0.74±0.04DEF
S11	36±1.89W	48±2.63KLM	132±6.92FGHI	132±7.22FGHI	43±2.25C	33±1.81HI	44±2.31FGHIJK	45±2.35DEFGHIJ	128±6.71BCD	135±7.38A	0.65±0.03GH	0.61±0.03J
S12	39±2.04TUV	58±3.17ABC	125±6.55KLMNO	142±7.77BC	31±1.62J	21±1.15Q	49±2.57CDEFG	48±2.68CDEFGH	118±6.18IJKLM	117±6.40KLM	0.46±0.02NO	0.48±0.03N
S13	45±2.36NOP	38±2.08UVW	118±6.18QRSTU	146±7.99AB	26±1.36MN	16±0.88S	47±2.46DEFGHI	48±2.84CDEFGHI	129±6.76BCD	132±7.22AB	0.35±0.02RS	0.72±0.04F
S14	57±2.99ABCD	56±3.06CDE	127±6.65IJKLM	119±6.51PQRSTU	29±1.52K	19±1.04R	51±2.20HIJKL	54±2.95BCDE	121±6.34GHIJK	114±6.24MN	0.54±0.03KL	0.64±0.04GHI

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671

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
S15	49±2.57JKL	48±2.63KLM	129±6.76HIJK	125±6.84KLMNO	17±0.89S	27±0.93LM	58±3.04B	51±2.57CDEF	111±5.82N	129±7.06BCD	0.51±0.03M	0.78±0.04AB
S16	39±2.04TUV	36±1.97W	123±6.45LMNOPQ	133±7.28EFGH	27±1.41LM	17±0.93S	54±2.83BC	51±2.84CDEF	97±5.08OPQ	123±6.73EFGHI	0.43±0.02P	0.46±0.03NO
S17	53±2.78FGH	52±2.84GHI	119±6.24PQRSTU	148±8.10A	37±1.94F	47±2.57B	50±2.62CDEF	47±2.30DEFGHI	84±4.40V	118±6.45JKLM	0.75±0.04CDE	0.66±0.04G
S18	36±1.89W	41±2.24RST	121±6.34NOPQRS	137±7.49CDEF	47±2.46B	37±2.02F	46±2.41DEFGHIJ	48±2.79CDEFGH	89±4.66STU	102±5.58O	0.72±0.04F	0.31±0.02U
S19	43±2.25PQR	51±2.79HIJ	115±6.03TUV	139±7.60CD	38±1.99EF	48±2.63AB	34±1.78M	47±2.63DEFGHIJ	93±4.87QRS	96±5.25QR	0.63±0.03HIJ	0.44±0.02OP
S20	40±2.10STU	47±2.57LMN	117±6.13RSTUV	131±7.17GHIJ	49±2.57A	38±2.08T	48±2.52CDEFGHI	46±2.24DEFGHIJ	86±4.51UV	88±4.81TUV	0.34±0.02RST	0.76±0.04BCD

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671

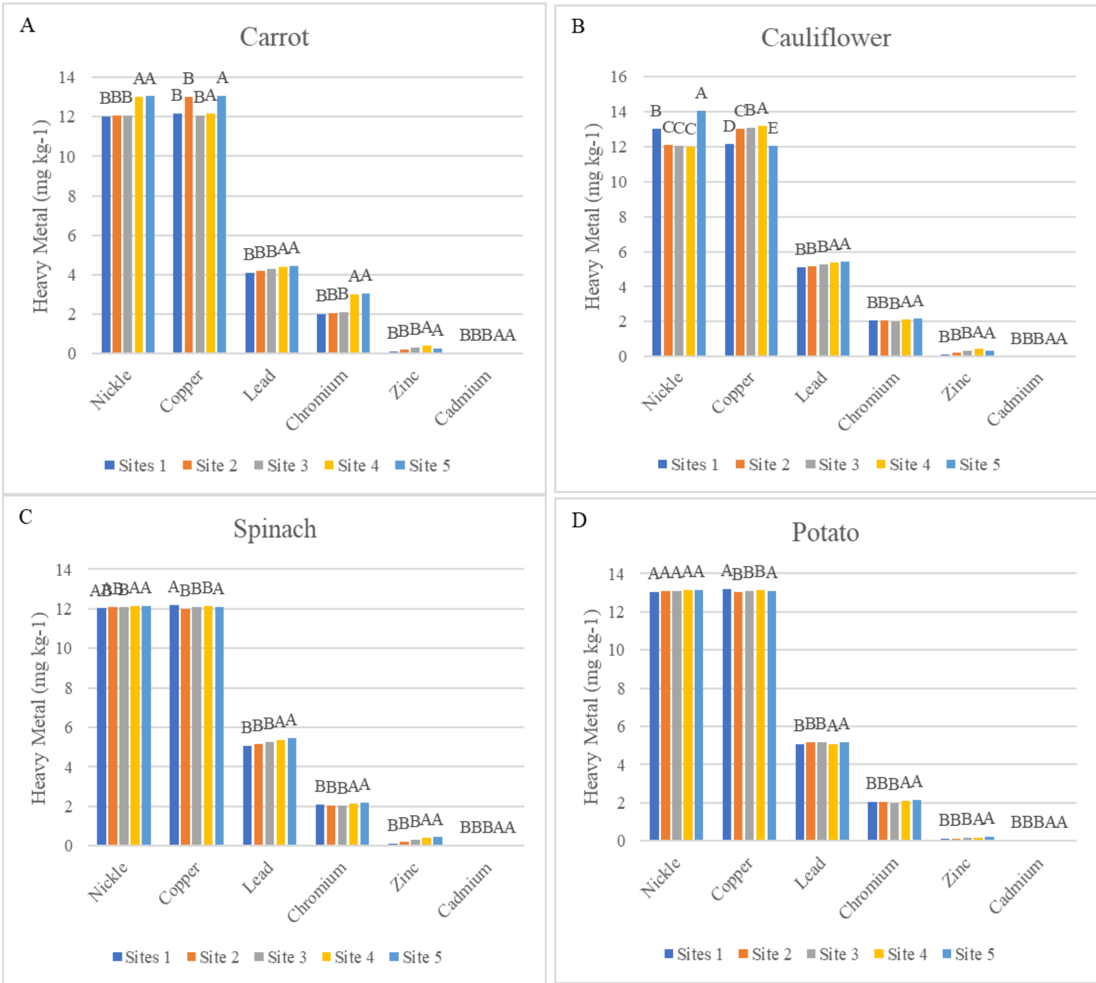

***Figure 3.** Heavy metals concentration in carrot (a), cauliflower (b), spinach (c) and potato (d)*

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

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671

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 bicorbonate ($MgHCO^{3+}$), 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

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671

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.

Funding. This work was supported by the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia [Grant No. KFU251187].

Acknowledgment. The authors extend their appreciation for the support of the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia [Grant No. KFU251187].

REFERENCES

[1] Abou Fayssal, S., Kumar, P., Popescu, S. M., Sardar, H., Ahmad, R., Gupta, D., Gaur, S. K., Alharby, H. F., Al-Ghamdi, A. G. (2024): Health risk assessment of heavy metals in saffron (*Crocus sativus* L.) cultivated in domestic wastewater and lake water irrigated soils. – Heliyon 10: 13-15.

[2] Abu-Elela, A., Elbehairy, U., Abou-Hadid, A. (2021): Accumulation and risk assessment of heavy metals in vegetables irrigated with wastewater in Giza governorate, Egypt. – Arab Universities Journal of Agricultural Sciences 29: 723-737.

[3] Ahmad, A., Lopulisa, C., Imran, A. M., Baja, S. (2018): Soil physicochemical properties to evaluate soil degradation under different land use types in a high rainfall tropical region: A case study from South Sulawesi, Indonesia. – In IOP Conference Series: Earth and Environmental Science 157: 012005.

[4] Ahmadi-Jouibari, T., Ahmadi Jouybari, H., Sharafi, K., Heydari, M., Fattahi, N. (2023): Assessment of potentially toxic elements in vegetables and soil samples irrigated with treated sewage and human health risk assessment. – International Journal of Environmental Analytical Chemistry 103: 2351-2367.

[5] Ahmed, D. A. E. A., Slima, D. F., Al-Yasi, H. M., Hassan, L. M., Galal, T. M. (2023): Risk assessment of trace metals in *Solanum lycopersicum* L.(tomato) grown under wastewater irrigation conditions. – Environmental Science and Pollution Research 30: 42255-42266.

[6] Ali, F., Israr, M., Ur Rehman, S., Azizullah, A., Gulab, H., Idrees, M., Iqbal, R., Khattak, A., Hussain, M., Al-Zuaibr, F. M. (2021): Health risk assessment of heavy metals via consumption of dietary vegetables using wastewater for irrigation in Swabi, Khyber Pakhtunkhwa, Pakistan. – Plos One 16(8): e0255853.

[7] Arora, M., Kiran, B., Rani, S., Rani, A., Kaur, B., Mittal, N. (2008): Heavy metal accumulation in vegetables irrigated with water from different sources. – Food Chemistry 111: 811-815.

[8] Atta, M. I., Zehra, S. S., Dai, D. Q., Ali, H., Naveed, K., Ali, I., Sarwar, M., Ali, B., Iqbal, R., Bawazeer, S., Abdel-Hameed, U. K. (2023): Amassing of heavy metals in soils, vegetables and crop plants irrigated with wastewater: Health risk assessment of heavy metals in Dera Ghazi Khan, Punjab, Pakistan. – Frontiers in Plant Science 13: 1080635.

[9] Ayers, R. S., Westcot, D. W. (1976): Water quality for agriculture. – FAO, Rome.

[10] Balkhair, K. S., Ashraf, M. A. (2016): Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of Saudi Arabia. – Saudi Journal of Biological Sciences 23: 32-44.

[11] Cheshmazar, E., Arfaeinia, H., Karimyan, K., Sharafi, H., Hashemi, S. E. (2018): Dataset for effect comparison of irrigation by wastewater and ground water on amount of heavy metals in soil and vegetables: Accumulation, transfer factor and health risk assessment. – Data in Brief 18: 1702-1710.

[12] Despland, L. M., Clark, M. W., Vancov, T., Erler, D., Aragno, M. (2011): Nutrient and trace-metal removal by Bauxsol pellets in wastewater treatment. – Environmental Science and Technology 45: 5746-5753.

[13] 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.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671

[14] Gupta, S., Satpati, S., Nayek, S., Garai, D. (2010): Effect of wastewater irrigation on vegetables in relation to bioaccumulation of heavy metals and biochemical changes. – Environmental Monitoring and Assessment 165: 169-177.
[15] Habu, M. A., Bawa, U., Musa, S. I. (2021): Health risk assessment and heavy metal bioaccumulation in vegetables irrigated with waste water in Kano State, Nigeria. – Notulae Scientia Biologicae 13: 10890-10890.
[16] Hamoud, Y. A., Shaghaleh, H., Zia-ur-Rehman, M., Rizwan, M., Umair, M., Usman, M., Ayub, M. A., Riaz, U., Alnusairi, G. S., Alghanem, S. M. S. (2024): Cadmium and lead accumulation in important food crops due to wastewater irrigation: Pollution index and health risks assessment. – Heliyon 10: 3.
[17] Hassan, J., Rajib, M. R., Khan, N.-E.-A., Khandaker, S., Zubayer, M., Ashab, K. R., Kuba, T., Marwani, H. M., Asiri, A. M., Hasan, M. M., Islam, A. (2024): Assessment of heavy metals accumulation by vegetables irrigated with different stages of textile wastewater for evaluation of food and health risk. – Journal of Environmental Management 353: 120206.
[18] Hough, M. (2002): Cities and natural process. – Routledge.
[19] Irandoust, M., Tabriz, A. S. (2017): The effect of municipal wastewater on soil chemical properties. – Solid Earth Discussions 1: 1-13.
[20] Jabeen, F., Aslam, A., Salman, M. (2020): Heavy metal contamination in vegetables and soil irrigated with sewage water and associated health risks assessment. – Journal of Environment and Agriculture Sciences 22: 23-31.
[21] Kemper, W. D., Koch, E. J. (1966): Aggregate stability of soils from Western United States and Canada: Measurement procedure, correlations with soil constituents (No. 1355). – Agricultural Research Service, US Department of Agriculture.
[22] Kemper, W. D., Rosenau, R. C. (1986): Aggregate stability and size distribution. – Methods of soil analysis: Part 1 Physical and Mineralogical Methods 5: 425-442.
[23] Khan, Z. I., Ahmad, K., Ashraf, M., Parveen, R., Bibi, Z., Mustafa, I., Noorka, I. R., Tahir, H. M., Akram, N. A., Ullah, M. F., Yaqoob, R. (2016): Risk assessment of heavy metal and metalloid toxicity through a contaminated vegetable (*Cucurbita maxima*) from wastewater irrigated area: A case study for a site-specific risk assessment in Jhang, Pakistan. – Human and Ecological Risk Assessment: An International Journal 22: 86-98.
[24] Kharazi, A., Leili, M., Khazaei, M., Alikhani, M. Y., Shokoohi, R. (2021): Human health risk assessment of heavy metals in agricultural soil and food crops in Hamadan, Iran. – Journal of Food Composition and Analysis 100: 103890.
[25] Kong, Y., Liu, J., Chen, M., Zheng, W., Liu, Y., Wang, Y., Ruan, X., Wang, Y. (2024): Accumulation and risk assessment of heavy metals in different varieties of leafy vegetables. – Environmental Geochemistry and Health 46: 527.
[26] Levy, G. J. (2011): Irrigation with treated waste water, effects on soil structure. – Encyclopedia of Agrophysics 402: 11-19.
[27] Liang, J., Chen, C., Song, X., Han, Y., Liang, Z. (2011): Assessment of heavy metal pollution in soil and plants from Dunhua sewage irrigation area. – International Journal of Electrochemical Science 6: 5314-5324.
[28] Osman, H. E. M., Abdel-Hamed, E. M. W., Al-Juhani, W. S. M., Al-Maroai, Y. A. O., El-Metwally El-Morsy, M. H. (2021): Bioaccumulation and human health risk assessment of heavy metals in food crops irrigated with freshwater and treated wastewater: A case study in Southern Cairo, Egypt. – Environmental Science and Pollution Research 28: 50217-50229.
[29] Othman, Y. A., Al-Assaf, A., Tadros, M. J., Albalawneh, A. (2021): Heavy metals and microbes accumulation in soil and food crops irrigated with wastewater and the potential human health risk: A metadata analysis. – Water 13(23): 3405.
[30] Oubane, M., Khadra, A., Ezzariai, A., Kouisni, L., Hafidi, M. (2021): Heavy metal accumulation and genotoxic effect of long-term wastewater irrigated peri-urban agricultural soils in semiarid climate. – Science of the Total Environment 794: 148611.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671

[31] Rehman, K., Bukhari, S. M., Andleeb, S., Mahmood, A., Erinle, K. O., Naeem, M. M., Imran, Q. (2019): Ecological risk assessment of heavy metals in vegetables irrigated with groundwater and wastewater: the particular case of Sahiwal district in Pakistan. – Agricultural Water Management 226: 105816.
[32] Rengasamy, P., Olsson, K. A. (1993): Irrigation and sodicity. – Soil Research 31: 821-837.
[33] Riyazuddin, R., Nisha, N., Ejaz, B., Khan, M. I. R., Kumar, M., Ramteke, P. W., Gupta, R. (2021): A comprehensive review on the heavy metal toxicity and sequestration in plants. – Biomolecules 12: 43.
[34] Rohoskova, M., Valla, M. (2004): Comparison of two methods for aggregate stability measurement–a review. – Plant Soil Environment 50: 379-382.
[35] Ruan, X., Ge, S., Jiao, Z., Zhan, W., Wang, Y. (2023): Bioaccumulation and risk assessment of potential toxic elements in the soil-vegetable system as influenced by historical wastewater irrigation. – Agricultural Water Management 279: 108197.
[36] Rusan, M. J. M., Hinnawi, S., Rousan, L. (2007): Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. – Desalination 215: 143-152.
[37] Sarwar, T., Shahid, M., Natasha, Khalid, S., Shah, A. H., Ahmad, N., Naeem, M. A., ul Haq, Z., Murtaza, B., Bakhat, H. F. (2020): Quantification and risk assessment of heavy metal build-up in soil–plant system after irrigation with untreated city wastewater in Vehari, Pakistan. – Environmental Geochemistry and Health 42: 4281-4297.
[38] Saumel, I., Weber, F., Kowarik, I. (2016): Toward livable and healthy urban streets: Roadside vegetation provides ecosystem services where people live and move. – Environmental Science & Policy 62: 24-33.
[39] Shainberg, I., Letey, J. (1984): Response of soils to sodic and saline conditions. – UC Agriculture and Natural Resources.
[40] Singh, A., Sharma, R. K., Agrawal, M., Marshall, F. (2009): Effects of wastewater irrigation on physicochemical properties of soil and availability of heavy metals in soil and vegetables. – Communications in Soil Science and Plant Analysis 40: 3469-3490.
[41] Singh, S. S. (2011): Soil fertility and nutrient management. – Kalyani publishers.
[42] Singh, R., Singh, P. K., Madheshiya, P., Khare, A. K., Tiwari, S. (2024): Heavy metal contamination in the wastewater irrigated soil and bioaccumulation in cultivated vegetables: Assessment of human health risk. – Journal of Food Composition and Analysis 128: 106054.
[43] Soleimani, H., Mansouri, B., Kiani, A., Omer, A. K., Tazik, M., Ebrahimzadeh, G., Sharafi, K. (2023): Ecological risk assessment and heavy metals accumulation in agriculture soils irrigated with treated wastewater effluent, river water, and well water combined with chemical fertilizers. – Heliyon 9: 3.
[44] Vogeler, I., Rogasik, J., Funder, U., Panten, K., Schnug, E. (2009): Effect of tillage systems and P-fertilization on soil physical and chemical properties, crop yield and nutrient uptake. – Soil and Tillage Research 103: 137-143.
[45] Zhang, T., Wang, T., Liu, K. S., Wang, L., Wang, K., Zhou, Y. (2015): Effects of different amendments for the reclamation of coastal saline soil on soil nutrient dynamics and electrical conductivity responses. – Agricultural Water Management 159: 115-122.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_66576671