IMPACT OF WASTEWATER IRRIGATION ON HEAVY METAL CONCENTRATIONS IN VEGETABLES, WITH PRIMARY FOCUS ON Pb AND Cd

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Abstract

This review paper evaluated the impact of wastewater irrigation on heavy metal accumulation in vegetables, focusing specifically on lead (Pb) and cadmium (Cd). Rising water exploitation poses a severe risk to the environment. Heavy metal contamination, primarily driven by industrial activities such as textile manufacturing, mining, and metal processing, remains a major global concern. The application of wastewater for irrigation can significantly elevate heavy metal concentrations in both soil and crops. In many regions worldwide, vegetables that constitute a vital part of the human diet are being irrigated with untreated wastewater. Findings indicated that leafy greens, such as spinach and lettuce, along with root vegetables, exhibited high bioconcentration and transfer factors (TF > 1). Furthermore, Pb and Cd levels in wastewater-irrigated vegetables frequently exceed the Maximum Levels (MLs) set by the Codex Alimentarius 2023. This study also assessed modern treatment technologies, concluding that membrane filtration and ion exchange methods are essential for mitigating these risks. Ultimately, it was established that rigorous monitoring and efficient purification processes are critical for ensuring food safety and environmental protection.

Keywords: Wastewater irrigation, Lead (Pb), Cadmium (Cd), Bioaccumulation, Vegetables

Introduction

Water is a precious natural resource upon which the sustainability of agriculture, an adequate food *supply*, and a productive environment for all living organisms rely. Unfortunately, water is exposed to maximum exploitation and heavy metal accumulation, which is not only an ecological issue but also a global problem (Kausar *et al*., 2017; Dadebo *et al*., 2024; Kilic, 2020). Irrigation water can be defined as water used for the production of cultivated plants. Irrigation is the delivery of water to plant roots when the required amount of water cannot be met by precipitation (Ors *et al*., 2021; Shahriar *et al*., 2023). The increase in the content of toxic metals and metalloids in irrigation water is a matter of worldwide concern, as toxic metals enter the soil and, through the root system, accumulate in the edible parts of plants such as vegetables (Kausar *et al*., 2017). The use of wastewater for irrigation, especially if it has a high concentration of heavy metals and during long-term application, can significantly increase the concentration of heavy metals in the soil and, consequently, in the plants (Aboukila, 2022; Mushtaq *et al*., 2010).
Wastewater is any water that has been contaminated by human use in domestic, industrial, commercial, and agricultural activities, as well as untreated sewage water, and it is most commonly used in agriculture (Sane *et al*., 2020; Khalid *et al*., 2018). Many studies are focused on analyzing heavy metal concentrations in vegetables and plants irrigated with various types of wastewater, such as industrial wastewater (Singh *et al.*, 2024), sewage (Bao *et al*., 2014), drainage, agricultural and domestic waste (Nowwar *et al*., 2023), farms, wells, streams, and rivers (Lere *et al*., 2021), domestic wastewater (Ahmad *et al*., 2015), and others. High concentrations of heavy metals such as cadmium, lead, chromium, copper, nickel, zinc, and iron have been found in wastewater from various industries, including textiles, construction, and mechanical manufacturing, exceeding the maximum permissible concentrations for

irrigation water (Bahiru *et al*., 2020). However, if wastewater is used for irrigation in a diluted form, there is no significant increase in the concentration of heavy metals within the plants (Lente *et al*., 2014)

Presence of heavy metals in irrigation water

Environmental pollution with heavy metals is a growing ecological crisis and a matter of concern due to their non-biodegradability and long biological half-life. Heavy metals have detrimental effects on human health, and exposure to these metals is increasing, primarily through the contamination of water, soil, and air, and secondarily through their entry into the food chain (Balali-Mood *et al*., 2021; Bhatia *et al*., 2015). Heavy metals represent a group of toxic metals with a density greater than 5 g/cm^3 and an atomic mass ranging from 60 to 200. They are present in ecosystems and wastewater in various concentrations, ranging from ng/L to mg/L (Jadaa & Mohammed, 2023). Heavy metals in wastewater most commonly originate from both natural and anthropogenic factors. Natural factors include soil erosion, volcanic activities, aerosol particles, and others, while anthropogenic factors primarily stem from industry, specifically the metal processing industry such as metal finishing and electroplating as well as mining, the textile industry, and nuclear energy (Akpor *et al*., 2014). Table 1 shows the most common sources of wastewater contamination with lead (Pb) and cadmium (Cd).

Table 1. Sources of Pb and Cd in wastewater and their characteristics (adapted from Jadaa & Mohammed, 2023)

Element	Oxidation state	Stable form	Sources of metal in wastewater and the environment
Lead (Pb)	Pb^{-4} to Pb^{+4}	Pb (II), Pb (IV)	Batteries, mining, paint, pigments, steel, explosives, electroplating, smelters, inorganic fertilizers and pesticides, printing industry
Cadmium (Cd)	Cd^{-1} to Cd^{+2}	Cd (II)	Mining, metallurgy, paints, cement, plastic stabilizers, nickel-cadmium battery production, fossil fuel combustion, high-phosphate fertilizers, municipal and sewage waste

In soils irrigated with wastewater, there is a significant increase in heavy metal concentrations in residual form, followed by bound oxides and heavy metal fractions associated with carbonates, compared to soils not irrigated with wastewater (Haroon *et al*., 2018). As a result of population growth, there is an increasing demand for food production, but also an increase in wastewater generation in urban and rural areas. The reuse of wastewater (treated or untreated) in agriculture is most commonly employed for irrigation in developing countries to address the problem of water scarcity, particularly in regions with warmer climates. This wastewater can often be contaminated with heavy metals, which must be removed to reduce their accumulation in plants and, consequently, in the food chain (Kerbouna Faycal M. A., 2018; Hashem & Qu, 2021).

Vegetables are an integral part of the normal human diet because they contain nutrients that are vital for the proper functioning of the human body. However, vegetables grown in contaminated areas, as well as those irrigated with water contaminated with heavy metals, can accumulate significant concentrations of heavy metals in their edible parts (Manwani *et al*., 2022).

The absorption of heavy metals into the edible parts, resulting from high heavy metal content in irrigation water, is influenced by their solubility in the soil, soil pH, plant development characteristics, and other factors (Khan *et al*., 2023; Sarker *et al*., 2021). Wastewater can contain high levels of metals and metalloids depending on the types of industries located in the region. Nevertheless, untreated wastewater is very frequently used for irrigation. This practice contributes to an increase in the heavy metal content in the soil, which is most commonly associated with organic matter, amorphous iron oxides, and unidentified residual fractions, particularly in the surface soil layer (Rivera *et al*., 2023).

A vast amount of fresh water is consumed in the textile industry, particularly for textile dyeing along with dyes, chemicals, and energy used for wet processing. Although there are various methods for treating textile wastewater, they often involve high operational and utility costs. Consequently, in many cases, this wastewater is discharged into nearby sewers, drains, and agricultural land after the dyeing processes without adequate treatment, especially in developing countries. This wastewater may contain certain heavy metals that can accumulate in cultivated plants and enter the human body through the food chain (Hassan *et al*., 2024; Hassain *et al*., 2018). High contents of Cd, Pb, and Fe have been found in irrigation water from rivers and streams where untreated wastewater from mechanical workshops (lubricating oil, tire and fuel combustion) and other industries is discharged; these concentrations exceeded the maximum permissible concentrations for irrigation water (Lere *et al*., 2021). The maximum permissible concentrations in irrigation water according to the FAO are shown in Table 2.

Table 2. Maximum permissible concentrations of heavy metals (mg/L) in irrigation water according to FAO (1985) (Shahriar et al., 2023).

Pb	Fe	Cu	Zn	Cd	Ni	Mo	Co	Mn
5	5	0,2	2	0.02	0,2	0,01	0,05	0,2

The analysis by Fauozi *et al.* (2022) regarding heavy metal concentrations in irrigation water and soil during the rainy and dry seasons showed that during the dry season, the concentrations of heavy metals Cd, Cr, Cu, Fe, Ni, Pb, and Zn were higher in both irrigation water and soil compared to the rainy season. Furthermore, the content of all heavy metals, except zinc, was higher in the analyzed plants during the dry season. Significant concentrations of heavy metals were found in irrigation water from rivers where wastewater from hospitals, households, laundries, etc., was discharged. Higher heavy metal content was observed in the surface soil layers and lettuce leaves; moreover, the bioconcentration factor and the transfer factor were > 1 for Cd, Cu, and Zn, indicating significant bioaccumulation of heavy metals in the edible parts of the lettuce (Mewouo *et al*., 2024). Similarly, the highest heavy metal content and the highest transfer factor for Fe, Ni, Pb, and Zn were found in lettuce in the study by Aksouh *et al.* (2024). Higher concentrations of Cd, Pb, Cu, Cr, Ni, and Zn were present in wastewater for irrigation compared to groundwater, resulting in significantly higher concentrations of these heavy metals in the soil as well as in the vegetables grown on it. In carrots, spinach, and radishes, the transfer factor for cadmium, chromium, and zinc from soil to plant was above 1, indicating high bioaccumulation from the soil (Kausar *et al*., 2017). All analyzed plants showed a high transfer factor for Cd (> 1), ranging from 0.85 – 1.17, which indicates high mobility of Cd from the soil into the plants. The transfer factor was lower for Pb, ranging from 0.02 – 0.03, and for iron, ranging from 0.04 – 0.06 (Gupta *et al*., 2010). According to Parmoozeh *et al*. (2024), vegetables irrigated with synthetic effluent containing permissible concentrations of Pb, Cd, and As according to the WHO for the reuse of treated wastewater for irrigation, had high heavy metal accumulation that exceeded the permissible limits set by FAO/WHO. Consequently, vegetables irrigated with treated wastewater may pose a risk to human health.

Presence of cadmium and lead in vegetables irrigated with wastewater

Cd was highly accumulated in radishes, lettuce, and spinach irrigated with wastewater compared to vegetables irrigated with well water (Khan *et al*., 2015). High concentrations of Cd and Pb were found in lettuce (0.5 and 0.27 mg/kg dry weight, respectively), spinach (0.37 and 0.06 mg/kg dry weight, respectively), kale (0.67 and 0.13 mg/kg dry weight, respectively), and cabbage (0.93 and 0.23 mg/kg dry weight, respectively) irrigated with untreated sewage wastewater (Alamnie *et al*., 2020). Table 3 shows the concentration of Cd in irrigation water and in the vegetables irrigated with that water.

Table 3. Cadmium content in irrigation water and vegetables.

Vegetable	Cd in wastewater mg/L	Cd in vegetable mg/kg	Description	References
Lettuce	0.20	0.16	Domestic wastewater and local industrial sources	Rezapour *et al*., 2024
Cabbage		0.18		
Green beans		0.12		
Peppers		0.14		
Radishes	0.054	0.33 *	River channels receiving wastewater from industrial zones and households	Khan *et al*., 2015
Cabbage		0.26 *		
Lettuce		0.51 *		
Cauliflower		0.37 *		
Spinach		0.62 *		
Radishes	0.03	0.351 *	Synthesized wastewater with Cd	Parmoozeh *et al*., 2024

			concentrations according to treated wastewater reuse standards	
Spinach	0.014	1.20	Sewage wastewater	Aftab *et al.*, 2023
Cauliflower		0.97		
Spinach	0.13	21.35 *	Wastewater	Chopra & Pathak, 2015
Cauliflower		17.51 *		
Cabbage	0.02	1.86	Wastewater from various industries (textiles, batteries, paints, plastic recycling, etc.) discharged with municipal sewage	Kumar & Thakur, 2018
Spinach		1.21		
Cauliflower		0.86		
Peppers	0.003	0.0037	Wastewater	Leblebici *et al.*, 2018
Onion		0.0010		
Cabbage	0.07	1.21	Industrial wastewater	Lere *et al.*, 2021
Cucumbers		3.55		
Radishes	0.0003	6.5 *	Industrial wastewater from integrated steel plants, thermal power plants, untreated sewage, etc.	Gupta *et al.*, 2010
Carrot	0.15	0.05	Sewage and industrial wastewater	Rehman *et al.*, 2019
Cabbage		0.03		
Spinach		0.08		
Cauliflower		0.03		

** - mg/kg on a dry weight (dw) basis*
Maximum Levels (MLs) for Cd (mg/kg) according to Codex Alimentarius (2023):
Brassica vegetables (cauliflower, cabbage, broccoli, kale) – 0.05

Leafy vegetables (lettuce, spinach, Swiss chard, etc.) – 0.2
Fruiting vegetables (cucumber, tomato, pepper, eggplant, etc.), garlic, onion – 0.05
Root and tuber vegetables (carrot, radish, beetroot, etc.) – 0.1

According to the study by Khan *et al*. (2023), the concentration of heavy metals in vegetables irrigated with industrial wastewater at three different locations was high. The concentrations of Pb and Cd were higher in all vegetables (spinach, cabbage, cauliflower, turnip, radish, carrot, and lettuce), exceeding the MLs. The average concentrations of these metals in the wastewater were 14.86, 0.331, and 8.267 mg/L for Pb, and 0.706, 0.52, and 0.773 mg/L for cadmium. The concentration of all heavy metals in the vegetables was significantly higher in those irrigated with wastewater compared to those irrigated with high-quality tap water. There was significant heavy metal contamination in vegetables irrigated with wastewater contaminated by the discharge of municipal waste, urban drainage, and effluents from various industries (dairy, paper mill, textile industry, and iron foundry). The average Cd value in all vegetables exceeded the MLs according to Codex Alimentarius (2023), with the highest concentrations found in radishes at 1.2 mg/kg, and turnips at 1.06 mg/kg (Sharma *et al*., 2016). Table 4 shows the concentration of Pb in irrigation water and in the vegetables irrigated with that water.

Table 4. Lead content in irrigation water and vegetables.

Vegetable	Pb in wastewater (mg/L)	Pb in vegetable (mg/kg)	Description	References
Radishes	0.21	2.91*	River channels receiving wastewater from industrial zones and households	Khan *et al*., 2015
Cabbage		2.24*		
Lettuce		1.52*		
Cauliflower		1.32*		
Spinach		1.84*		
Radishes	3	12.26*	Synthesized wastewater with Pb concentrations according to standards for treated wastewater reuse.	Parmoozeh *et al*., 2024
Spinach	0.88	68.17*	Wastewater	Chopra & Pathak, 2015
Cauliflower		86.69*		
Tomatoes	0.00003	0.0247	Wastewater	Leblebici *et al*., 2018
Onion		0.0213		
Peppers		0.0263		
Cabbage	0.02	0.28	Industrial wastewater	Lere *et al*., 2021
Cucumber		0.56		
Radishes	0.0523	22 *	Industrial wastewater from integrated steel plants, thermal power plants,	Gupta *et al*., 2010

			untreated sewage, etc.	
Carrot	1.35	1.49	Sewage and industrial wastewater	Rehman *et al*., 2019
Cabbage		1.81		
Spinach		2.68		
Cauliflower		1.38		
Lettuce	0.35	0.23	Wastewater	Jalil *et al*., 2022
Cabbage		0.23		
Green beans		0.12		
Peppers		0.14		

** - mg/kg on a dry weight (dw) basis*
Maximum Levels (MLs) for Pb (mg/kg) according to Codex Alimentarius (2023):
Brassica vegetables (cauliflower, cabbage, broccoli, kale) – 0.1
Leafy vegetables (lettuce, spinach, Swiss chard, etc.) – 0.3
Fruiting vegetables (cucumber, tomato, pepper, eggplant, etc.) – 0.05
Root and tuber vegetables (carrot, radish, beetroot, etc.), garlic, onion – 0.1

According to Ali *et al*. (2022), the highest average concentration of Pb in vegetables irrigated with wastewater was found in cauliflower, followed by spinach, cabbage, tomato, and lettuce. High Pb concentrations were observed when irrigating vegetables with industrial and sewage wastewater, ranging from 35 - 93 mg/kg in spinach, 17 to 43 mg/kg in tomatoes, and 23 to 47 mg/kg in cauliflower. The concentration of Pb in the wastewater was above permissible limits, while the accumulation of Pb in the soil was lower because the soil concentration remained within permissible limits. The high concentrations in the vegetables are attributed to the direct bioaccumulation of Pb from the water into the vegetables (Aslam *et al*., 2017). From the study by Ali *et al*. (2021), an analysis of vegetables irrigated with wastewater near various industries such as leather, metal processing, paper, battery manufacturing, pharmaceuticals, etc. showed that the heavy metal concentrations in the wastewater were 0.79 mg/L for Pb and 0.02 mg/L for Cd. The concentrations of Pb and Cd in the vegetables irrigated with this wastewater ranged from 0.70 – 18.14 mg/kg and 0.02 – 3.64 mg/kg, respectively (Ali *et al*., 2021). According to the study by Aslam *et al*. (2024), the concentration of heavy metals in domestic wastewater used for vegetable irrigation exceeded the maximum permissible concentrations. The Pb concentration ranged from 0.06 to 0.37 mg/L, and Cd from 0.01 to 0.80 mg/L. The concentrations of these heavy metals were above the MLs in the vegetables irrigated with wastewater, ranging from 11.1 to 47.02 mg/kg for Pb and from 2.9 to 11.02 mg/kg for Cd. These concentrations were particularly high in radishes, cabbage, carrots, spinach, and cauliflower. According to Khan *et al*. (2023), the concentration of heavy metals in irrigation water containing industrial effluents ranges from 0.05 to 0.09 mg/L for Pb and 0.01 to 0.03 mg/L for cadmium. The concentration of heavy metals in the vegetables irrigated with this water ranged from 5 to 9 mg/kg for Pb and 0.70 to 1.90 mg/kg for cadmium. High concentrations of Cd and Pb were found in radishes, cabbage, carrots, spinach, and cauliflower.

Treatment of heavy metals from wastewater

Heavy metal pollution is of great significance due to its pronounced toxicity, difficult degradation, and accumulation in plants and living organisms. Irrigation with wastewater raises major concerns among the population due to the high accumulation of heavy metals in vegetables. It is of vital importance to treat the water before it is discharged into rivers and streams, especially from the metal-processing industry, households, and industrial waste (Noor *et al*., 2019). Treated wastewater can be reused for irrigation. This involves physical, chemical, and biological processes to remove these pollutants and obtain environmentally safe treated wastewater. Various technologies exist for the removal of heavy metals from water, such as chemical precipitation, oxidation or reduction, filtration, ion exchange, electrochemical treatments (electrocoagulation, electroflotation, and electrodeposition), reverse osmosis, adsorption (activated carbon, carbon nanotubes, and wood sawdust), membrane filtration, as well as nanotechnology. The most commonly used methods are ion exchange and membrane filtration. However, most treatments are either ineffective or too expensive when metal concentrations exceed 100 mg/L (Nalenthiran *et al*., 2016; Zareh *et al*., 2024; Li *et al*., 2023). The membrane filtration separation method offers high efficiency, ease of operation, and low space requirements, making it a promising method for heavy metal removal (Birniwa *et al*., 2024; Xiang *et al*., 2022). Ion exchange is an advanced water treatment that can be used to remove metal ions present in low concentrations in water (Lupa & Cocheci, 2022)

Conclusions

Water is a vital natural resource essential for the sustainability of all living organisms; however, today it is subjected to intensive exploitation as well as contamination with heavy metals, primarily through the uncontrolled discharge of industrial wastewater. The data from this literature review confirm that the use of wastewater for irrigation significantly increases the concentration of heavy metals in the soil, and consequently, in the edible parts of plants, entering the human body through the food chain.
Analysis of numerous studies indicates that lead and cadmium concentrations frequently exceed the maximum levels prescribed by international standards (FAO/WHO and Codex Alimentarius 2023), both in irrigation water and in vegetables. This situation poses a serious risk to public health due to the entry of lead and cadmium from irrigation water into the food chain. As a result, it is necessary to take urgent measures to treat wastewater using modern purification technologies, such as membrane filtration and ion exchange, before its reuse in agriculture. Future focus should be directed toward strict monitoring to ensure the production of safe food and the protection of the ecosystem.

References

[1]. Aboukila, E.F. 2022. The effect of industrial activities on the heavy metals contamination of irrigation waters, soils, and plants in Kafr El-Dawar district, Egypt. *Desalination and Water Treatment*, 273, 104-113.
[2]. Aftab, K., Iqbal, S., Khan, M.R., Busquets, R., Noreen, R., Ahmad, N., Kazimi, S.G.T., Karami, A.M., Suliman, N.M.S.A. and Ouladsmane, M. 2023. Wastewater-Irrigated Vegetables Are a Significant Source of Heavy Metal Contaminants: Toxicity and Health Risks. *Molecules*, 28(3), 1371.
[3]. Ahmad, K., Khan, Z.I., Ashfaq, A., Khan, A., Shad, H.S., Sher, M., Dogar, Z.U.H., Noorka, I.R., Khan, M.A., Yasmin, S., Tufarelli, V. and Cazzato, E. 2015. Assessment of metals and metalloids in vegetable crop irrigated with domestic wastewater in peri-urban areas of Khushab City, Pakistan. *Fresenius Environmental Bulletin*, 24(10a), 3404-3408.
[4]. Akpor, O.B., Ohiobor, G.O. and Olaolu, T.D. 2014. Heavy metal pollutants in wastewater effluents: Sources, effects and remediation. *Advances in Bioscience and Bioengineering*, 2(4), 37-43.
[5]. Aksouh, M.Y., Boudieb, N., Benosmane, N., Moussaoui, Y., Michalski, R., Klyta, J. and Konczyk, 2024. Presence of Heavy Metals in Irrigation Water, Soils, Fruits, and Vegetables: Health Risk Assessment in Peri-Urban Boumerdes City, Algeria. *Molecules*, 29(17), 4187.
[6]. Alamnie, G., Kebede, A. and Menkir, S. 2020. Heavy Metal Contamination in Green Leafy Vegetables Irrigated with Wastewater Collected from Harar Town Vegetable Farm, Ethiopia. *Food Science and Quality Management*, 94, 24-28.
[7]. Ali, F., Israr, M., Rehman, S.U., Azizullah, A., Gulab, H., Idres, M., Iqbal, R., Khattak, A., Hussain, M. and 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.

[8]. Aslam, A., Jabeen, F. and Salman, M. 2017. Concentration level of lead (Pb) in plants and soil of Faisalabad irrigated with waste water. *Applied Science Reports*, 20(3), 92-98.
[9]. Aslam, M.A., Abbas, M.S., Mustaqeem, M., Bashir, M., Shabbie, A., Saeed, M.T. and Irfan, R.M. 2024. Comprehensive assessment of heavy metal contamination in soil-plant system and health risk from wastewater-irrigated vegetables. *Colloids and Surfaces C: Environmental Aspects*, 2, 100044.
[10]. Bahiru, D.B. 2020. Determination of Heavy Metals in Wastewater and Their Toxicological Implications around Eastern Industrial Zone, Central Ethiopia. *Journal of Environmental Chemistry and Ecotoxicology*, 12(2), 72-79.
[11]. Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M.R. and Sadeghi, M. 2021. Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium and Arsenic. *Frontiers in Pharmacology*, 12, 643972.
[12]. Bao, Z., Wu, W., Liu, H., Chen, H. and Yin, S. 2014. Impact of Long-Term Irrigation with Sewage on Heavy Metals in Soils, Crops, and Groundwater – a Case Study in Beijing. *Polish Journal of Environmental Studies*, 23(2), 309-318.
[13]. Bhatia, A., Singh, S. and Kumar, A. 2015. Heavy metal contamination of Soil, Irrigation Water and Vegetables in Peri-Urban Agricultural Areas and Markets of Delhi. *Water Environment Research*, 87(11), 2027-2034.
[14]. Birniwa, A.H., Habibu, S., Abdullahi, S.S., Mohammad, R.E.A., Hussaini, A., Magaji, H., Al-dhawi, B.N.S., Noor, A. and Jagaba, A.H. 2024. Membrane technologies for heavy metals removal from water and wastewater: A mini review. *Case Studies in Chemical and Environmental Engineering*, 9, 100538.
[15]. Chopra, A.K. and Pathak, C. 2015. Accumulation of heavy metals in the vegetables grown in wastewater irrigated areas of Dehradun, India with reference to human health risk. *Environmental Monitoring and Assessment*, 187, 445.
[16]. Codex Alimentarius Commission. 2023. *General Standard for Contaminants and Toxins in Food and Feed*. Joint FAO/WHO Food Standards Programme.
[17]. Dadebo, T.T. and Gelaw, G.T. 2024. Determination of metals in water samples within the irrigation area in Telo District, Kaffa Zone, South Western Ethiopia. *Heliyon*, 10(7), e29003.
[18]. Faouzi, J., Kaioua, S., Allali, A., Eloutassi, N. and Lahkimi, A. 2022. Impact of Irrigation Water on Heavy Metal Content in Irrigated Soils and Plants – Spatial and Vertical Distribution. *Ecological Engineering & Environmental Technology*, 23(5), 91-98.
[19]. Gupta, S., Satpati, S., Nayek, S. and 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.
[20]. Haroon, B., Ping, A., Pervez, A., Faridullah and Irshad, M. 2018. Characterization of heavy metals in soils as affected by long-term irrigation with industrial wastewater. *Journal of Soil Science and Plant Nutrition*, 9(1), 47-56.
[21]. Hashem, M.S. and Qi, X.B. 2021. Treated Wastewater Irrigation – A review. *Water*, 13(11), 1527.
[22]. Hassain, M.S., Das, S.C., Islam, J.M.M., Mamun, M.A.A. and Khan, M.A. 2018. Reuse of textile mill ETP sludge in environmental friendly bricks – effect of gamma radiation. *Radiation Physics and Chemistry*, 151, 77-83.
[23]. Hassan, J., Rajib, M.M.R., Khan, M.N.E.A., Khandaker, S., Zubayer, M., Ashab, K.R., Kuba, T., Marwani, H.M., Asiri, A.M., Hasan, M., Islam, A., Rahman, M.M. and Awual, M.R. 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.
[24]. Jadaa, W. and Mohammed, H. 2023. Heavy Metals – Definition, Natural and Anthropogenic Sources of Releasing into Ecosystems, Toxicity, and Removal Methods – An Overview Study. *Journal of Ecological Engineering*, 24(6), 249-271.
[25]. Jalil, H.M., Rezapour, S., Nouri, A. and Joshi, N. 2022. Assessing the ecological and health implications of soil heavy metals in vegetable irrigated with wastewater in calcareous environments. *Agricultural Water Management*, 272, 107848.
[26]. Kausar, S., Faizan, S. and Haneef, I. 2017. Effect of Wastewater Irrigation on Heavy Metal Accumulation, Growth and Yield of Vegetables. *International Journal of Plant and Environment*, 3(1), 65-76.
[27]. Kerboua Faycal, M.A. 2018. The Use of Wastewater in the Irrigation of Agricultural Soil and its Contamination Effect by Trace Elements: A Review. *Journal of Applied Sciences*, 14(18), 273-287.
[28]. Khalid, S., Shahid, M., Natasha, Bibi, I., Sarwar, T., Shah, A.H. and Niazi, N.K. 2018. A Review of Environmental Contamination and Health Risk Assessment of Wastewater Use for Crop Irrigation with a Focus on Low and High-Income Countries. *International Journal of Environmental Research and Public Health*, 15, 895.

[29]. Khan, M.N., Aslam, M.A., Muhsinah, A.B. and Uddin, J. 2023. Heavy Metals in Vegetables: Screening Health Risk of Irrigation with Wastewater in Peri-Urban Areas of Bhakkar, Pakistan. *Toxics*, 11(5), 460.
[30]. Khan, M.N., Aslam, M.A., Zada, I. and Albekairi, T.H. 2023. Statistical Analysis and Health Risk Assessment: Vegetables Irrigated with Wastewater in Kirri Shamozai, Pakistan. *Toxics*, 11(11), 899.
[31]. Khan, S.A., Liu, X., Shah, B.R., Fan, W., Li, H., Khan, S.B. and Ahmad, Z. 2015. Metals uptake by wastewater irrigated vegetables and their daily dietary intake in Peshawar, Pakistan. *Ecological Chemistry and Engineering*, 22(1), 125-139.
[32]. Khan, Z., Elahi, A., Bukhari, D.A. and Rehman, A. 2022. Cadmium sources, toxicity, resistance and removal by microorganisms – A potential strategy for cadmium eradication. *Journal of Saudi Chemical Society*, 26(6), 101569.
[33]. Kilic, Z. 2020. The importance of water and conscious use of water. *International Journal of Hydrology*, 4(5), 239-241.
[34]. Kumar, V. and Thakur, R.K. 2018. Health risk assessment of heavy metals via dietary intake of vegetables grown in wastewater irrigated areas of Jagjeetpur, Haridwar India. *Archives of Agricultural and Environmental Science*, 3(1), 73-80.
[35]. Leblebici, Z. and Kar, M. 2018. Heavy Metals Accumulation in Vegetables Irrigated with Different Water Sources and Their Human Daily Intake in Nevsehir. *Journal of Agricultural Science and Technology*, 20(2), 404-415.
[36]. Lente, I., Ofosu-Anim, J., Brimah, A.K. and Atiemo, S. 2014. Heavy Metal Pollution of Vegetable Crops Irrigated with Wastewater in Accra, Ghana. *West African Journal of Applied Ecology*, 22(1), 41-58.
[37]. Lere, B.K., Basira, I., Abdulkadir, S., Tahir, S.M., Ari, H.A. and Ugya, Y. 2021. Health risk assessment of heavy metals in irrigated fruits and vegetables cultivated in selected farms around Kaduna metropolis, Nigeria. *Egyptian Journal of Basic and Applied Sciences*, 8(1), 317-329.
[38]. Li, Y., Huang, Z., Lyu, C., Yan, Y. and Zhu, S. 2023. Exploration of treatment technology for heavy metal wastewater. *E3S Web of Conferences*, 393, 03031.
[39]. Lupa, L. and Cocheci, L. 2022. Heavy Metals Removal from Water and Wastewater. In book: *Heavy Metals – Recent Advances*, 1-29.
[40]. Manwani, S., Vanisree, C.R., Jamen, V. and Awasthi, K.K. 2022. Heavy Metal Contamination in Vegetables and Their Toxic Effects on Human Health. In book: *Sustainable Crop Production - Recent Advances*, 1-17.
[41]. Mewouo, Y.C.M., Traore, M., Zing, B.Z., Aboubakar, A., Oyono, S.O., Nzeket, A.B., Begoude, D., Ngoupayou, J.R.N., Gnankambary, Z. and Nacro, H.B. 2024. Evidence of heavy metals in soil, irrigation water and vegetables cultivated in peri-urban area of Yaounde-Cameroon. *Scientific African*, 25, e02280.
[42]. Mushtaq, N. and Khan, K.S. 2010. Heavy metals contamination of soils in response to wastewater irrigation in Rawalpindi region. *Pakistan Journal of Agricultural Research*, 47(3), 215-224.
[43]. Nalenthiran, P., Sambandam, A. and Ashokkumar, M. 2016. Removal of Heavy Metal from Wastewater. In book: *Handbook of Ultrasonics and Sonochemistry*, 813-839.
[44]. Noor, S.F.M., Khattak, M.A., Mukhtar, A., Badshah, S. and Khan, R.U. 2019. Removal of Heavy Metal from Wastewater: A review of Current Treatment Processes. *Journal of Advanced Research in Materials Science*, 58(1), 1-9.
[45]. Nowwar, A., Farghal, I.I., Ismail, M.A. and Amin, M.A. 2023. Impact of Irrigation with Wastewater on Accumulation of Heavy Metals in Phaseolus vulgaris L. and Its Remediation. *Journal of Soil Science and Plant Nutrition*, 23, 761-777.
[46]. Ors, S., Sahin, U., Ekinci, M. and Turan, M. 2021. Principles of Irrigation Management for Vegetables. In book: *Vegetable Growing*, 1-14.
[47]. Parmoozeh, Z., Mostafaii, G.R., Rabbani, D., Akbara, H., Salem, A. and Miranzadeh, M.B. 2024. Investigation of heavy metal concentrations (lead, cadmium and arsenic) in vegetables irrigated with synthetic effluent and well water: Risk assessment of carcinogenicity and non-carcinogenicity. *Environmental Health Engineering and Management Journal*, 11(3), 327-336.
[48]. Rehman, K., Bakhari, S.M., Andleeb, S., Mahmood, A., Erinle, K.O., Naeem, M.M. and 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.
[49]. Rezapour, S., Nouri, A., Alamdari, P. and Akhlaghi, M. 2024. Cadmium accumulation in wastewater irrigated vegetables: Exploring factors, thresholds, health implications, and transfer modeling. *Journal of Agriculture and Food Research*, 16, 101070.
[50]. Rivera, F.R.A.Z., Pano, B.P., Guedron, S., Palomino, L.M., Hill, C.P.L. and Grabach, C.S. 2023. Impact of the change in irrigation practices from untreated to treated wastewater on the mobility of potentially toxic elements (PTEs) in soil irrigated for decades. *Journal of Soils and Sediments*, 23, 2726-2743.
[51]. Sane, G.G., Nagarkar, S.S. and Shinde, S.S. 2020. Wastewater Reuse for Agricultural Irrigation – A Review. *International Journal of Current Microbiology and Applied Sciences*, 9(12), 1144-1149.

[52]. Sarker, B., Keya, K.N., Mahir, F.I., Nahiun, K.M., Shahida, S. and Khan, R.A. 2021. Surface and Ground Water Pollution: Causes and Effects of Urbanization and Industrialization in South Asia. *Scientific Review*, 7(3), 32-41.
[53]. Shahriar, S.M.S., Munshi, M., Zakir, H.M., Islam, M.J., Mollah, M.M.A. and Salam, S.M.A. 2023. Assessment of Heavy Metal Pollution in Irrigation Water of Rajshahi City, Bangladesh. *Environmental and Earth Sciences Research Journal*, 10(3), 100-110.
[54]. Sharma, A., Katnoria, J.K. and Nagpal, A.K. 2016. Heavy metals in vegetables: screening health risk involved in cultivation along wastewater drain and irrigating with wastewater. *SpringerPlus*, 5, 488.
[55]. Singh, R., Singh, P.K., Madheshiya, P., Khare, A.K. and 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.
[56]. Xiang, H., Min, X., Tang, C.J., Sillanpaa, M. and Zhao, F. 2022. Recent advances in membrane filtration for heavy metal removal from wastewater: A mini review. *Journal of Water Process Engineering*, 49, 103023.
[57]. Zareh, M.M., Metwally, N. and Abdel-Tawwab, M. 2024. Review of Methods of Removal of Heavy Metals from Wastewater. *Bulletin of Faculty of Science, Zagazig University*, 1, 51-58.