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Effect of Sewage Irrigation on Agriculture Soil Nutrients and Metal Built-Up: A Case Study

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Abstract

This study demonstrates the effect of long-term sewage irrigation on soil physiochemical properties: pH, electrical conductivity (EC), organic carbon (OC), total nitrogen (TN), total phosphorous (TP), potassium (K), sodium (Na) and heavy metal (Zn, Pb, Ni, Cu and Cd) built-up in an agroecosystem in the periphery of Sri Ganganagar city. To achieve the goal, a comprehensive survey was conducted in such areas and top-soil (0-20 cm) samples were collected and analysed for various physicochemical parameters. Results revealed the respective range of pH, EC, OC, TN, TP, K and Na in the ranges of 7.76 – 7.89, 4.24 – 5.03 mS cm^{-1}, 15.20 – 15.88 g kg^{-1}, 5.75 – 5.77 g kg^{-1}, 0.95 – 1.09 g kg^{-1}, 0.73 – 0.85 g kg^{-1} and 0.89 – 1.03 g kg^{-1} in soils of sewage-irrigated crop setups. High NPK and OC load in such soils than that of control soils (freshwater irrigated plots) suggested the positive impact of sewage irrigation on soil nutrient profile and organic matter depositions. The respective concentration (mg kg^{-1}) of Zn, Pb, Ni, Cu and Cd 16.0 – 22.42, 16.60 – 23.55, 21.15 – 25.63, 18.12 – 26.86 and 2.04 – 4.73 also indicates the metal load built-up during such practices. In summary, sewage irrigation can be promoted to solve two issues simultaneously soil fertility management and safe disposal of untreated sewage in the urban periphery. However, the transfer of metal in standing crops from soil metal sink needs to be investigated in such cases to check the bioaccumulation of metals in food crops and human health safety.

***Keywords*:**Crop production, Urban wastewater irrigation, Soil contamination, Heavy metals

Introduction

The disposal of treated and untreated wastewater is one of the alarming issues in the majority of urban settlements in developing countries which cause several issues such as freshwater pollution, soil contamination, disease in human and quality of natural resources (Singh et al., 2010; Sridhara; Abeed et al., 2022). In India, domestic wastewater management has become a big challenge for city managers as infrastructural development and regulations have not kept pace with the ever-growing human population growth and rapid urbanization.The generation of human waste through the urban sewage system is constant and unmanaged in many parts of the countries which poses a serious risk to environmental resource management and the availability of fresh water supplies. At the same time, the urban return flow (wastewater) is also increasing day by day, which contributes to about 80% of the total water supply in urban centres. Small towns are still not connected with sewer network systems and lack proper sewage disposal and treatment system like sewage treatment plants (STPs). In this condition in the majority of areas, the untreated or partially treated (through septic tank system) wastewater flows through wastewater collection networks of '*Nala*" and is finally collected outside of the city in lowland areas as a stagnant water body or natural wetlands/ponds. In rural and peri-urban areas, decentralized wastewater treatment systems have appeared as more economically viable options for the safe disposal of wastewater(Parihar et al., 2022). Currently, even in urban and peri-urban areas of India, about 70% of the population is assisted by the operation of onsite sanitation systems. The advantages of the decentralized system are that it's a low-cost (operational and maintenance costs), energy-saving and simple-technology-based process to tackle wastewater issues with low inputs.

Untreated sewage water poses serious issues of environmental pollution and resource contamination. Sewage water is used water from urban settlements mainly comes from toilets, sinks, showers, washing and agricultural activities.Urban sewage water utilities in the agriculture system have been becoming more shared and extensive practice due to the collective water scarcity and the threat to food security, especially among the peri-urban resource-restricted farmers.In both developed and developing countries, the most predominant application of treated and untreated wastewater is its utilities for land irrigation purposes. In developed countries, where environmental standards are more confined and followed by compulsions, abundant wastewater is treated before use for soil irrigation (Hussain et al., 2002). The treated water from urban and peri-urban areas could be used for various operations like groundwater recharging, gardening and landscaping, industrial applications, construction business, wildlife habitat development, aquaculture and other farming systems, etc. In developing countries, although environmental standards are set, not followed effectively due to a lack of awareness level of people and lenient Govt. actions. Wastewater has been widely used for agriculture and aquaculture for centuries in countries like China, India and Mexico (Abeed et al., 2022; W. Meng et al., 2016a; P. K. Singh et al., 2012). Reuse of wastewater can deliver positive benefits to the farming community, society and municipalities as a part of sustainable resource consumption. But, wastewater reuse also causes adverse externality impacts on humans and ecological systems, which need to be identified and assessed before it applies for long-term irrigation purposes(Meena et al., 2016).

This study investigates the effect of long-term sewage irrigation on soil properties (pH, EC, OC, TN, TP, K and Na) and heavy metals (Fe, Zn, Pb, Ni, Cu, Cd and Cr) built-up in some selected sites of peri-urban areas of Sri Ganganagar City, Rajasthan, India. Farmers of this area have been utilizing sewage for vegetable and other commercial crop cultivation forthe last 20 years and there is no comprehensive report on the impact of sewage irrigation on soil chemical quality is available in the published literature. Therefore, the results of this study may be beneficial for policymakers and local farmers to see the overall impact of long-term sewage irrigation on local soil qualities in agricultural areas.

Materials and methods

Study site

The current study was performed in three villages namely 2E Chhoti, village Chak 3A and village Sobha Singh Wala which are located on the periphery of the city (2 -3 km far from the city settlements). The major crops in these areas are wheat, mustard, barley, cotton and seasonal vegetables. The region is considered a dry and canal-irrigated belt and farmers mainly rely on canal water and groundwater for crop irrigation. Sewage water is disposed from urban settlements of the city through untapped channels which directly open to the nearby agricultural fields.

Soil and plant sampling

The topsoil (20 cm depth) samples were collected from some of the selected agriculture plots for physiochemical analysis. From each village, three sites were identified for possible soil sampling. Three sets of soil samples were collected from each marked agriculture plot. Soil sampling was done up to 20 cm depth using soil samples and soil was mixed thoroughly to create a homogenised representative soil sample (100 g) for the analysis. The soil was stored in polythene zip bags and stored at 4 °C in the lab.

Physicochemical analysis of soil

For analytical work soil was divided into two parts. The first part (fresh soil) was used for the analysis of pH and EC. Soil pH and EC were measured in soil extract (prepared in distilled water 1:10 w/v) through pH and conductivity meter, respectively. The second soil part was dried in a hot-air oven at 80°C for 24 hours and then grounded in powder and then used for other parameter analysis. Soil OC, TN, TP, K and Na were measured by following the standard methods as described in (APHA, 2005).

For soil metal content, the dried and sieved soil was digested in a di-acid solution (HNO_3+ $HClO_4$) in a microwave digester and then filtered through Whatman no.42 filter paper and then the filtrate was used for the analysis of heavy metals using Atomic Absorption Spectrophotometer (AAS).

Statistical analysis

Data were analysed for descriptive statistical results using SPSS software (Windows version 17.0). The difference among sampling sites was measured through One-way ANOVA and homogenous sub-sets were analysed using Post-Hoc test.

Results and discussion

Sewage chemical characteristics

The pH of sewage water was in the range of 7.76 – 7.81 at different sampling points.The slight variation among different sampling sites for pH could be attributed to the interference of other edaphic factors. EC indicates the overall load of salts in soils mainly contributed by geological as well as anthropogenic sources mainly through irrigation practices. EC values vary from 4.24 to 5.03 mS cm^{-1} at different sampling locations. The direct relationship between EC and pH was noted in this study indicating that H^+ ions releasing cations contributed to the EC load of the soil that mainly comes from the sewage inorganic substances (Balkhair and Ashraf, 2016). BOD in sewage water was in the ranges of 272.00 – 281.33 mg L^{-1}.BOD in sewage is mainly due to the presence of biodegradable organic substances. The variations in BOD could be due to factors like dilution of sewage at the point and non-point sources, precipitation rate, the flow rate of sewage and mixing of another freshwater with sewage water during irrigation practices (Pandey et al., 2016; Singh, 2021). COD in sewage water ranged between 370.67 mg L^{-1} and 374.33 mg L^{-1} at different sampling sites in the studied area. COD indicates a total load of oxidation process whether through chemical reactions or by active microbial communities involved in organic matter aerobic degradation in wastewater (Chung et al., 2011; Singh et al., 2020). The NO_3^-, SO_4^{-2} and PO_4^{-3} content in sewage water showed slight variation among the different sampling periods during vegetable cropping cycles (Fig. 1). NO_3^-, SO_4^{-2} and PO_4^{-3} content in sewage water ranged between 30.95 and 33.37 mg L^{-1}, 139.79 and 149.77 mg L^{-1} and 74.33 and 83.95 mg L^{-1}. NO_3^- and PO_4^{-3} content in sewage mainly comes from faecal sludge mixing in sewage water and also acts as a source of nitrogen for cropping systems. SO_4^{-2} is directly contributed by surfactants, detergents and chemical fertilizers in soil but wastewater disposal could be a main source of SO_4^{-2} in urban runoff waters (Sridhara Chary et al., 2008; Pandey et al., 2016).

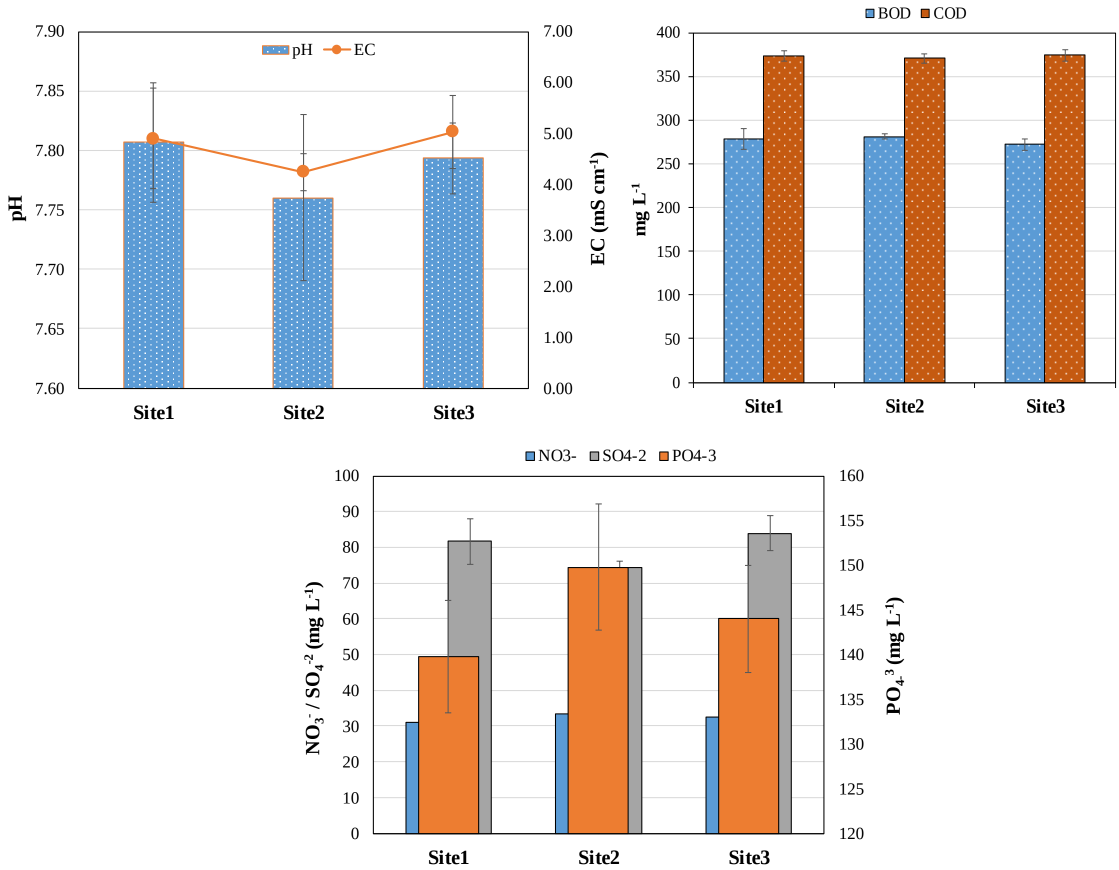

Fig. 1 - pH, EC, BOD, COD and nutrient contents in sewage being used for crop irrigation.

Sewage water also acts as a major source of heavy metals for soil and freshwater resource contamination and we found a significant load of heavy metals at different sampling sites. The average concertation of Fe, Zn, Pb, Ni, Cu, Cd and Cr was recorded in the ranges of 59.27 – 69.36 mg L^{-1}, 1.66 – 2.60 mg L^{-1}, 5.36 – 7.99 mg L^{-1}, 3.52 – 4.20 mg L^{-1}, 1.51 – 1.86 mg L^{-1}, 1.92 – 2.82 mg L^{-1} and 0.72 – 0.88 mg L^{-1}, respectively (Table 1). Fe and Zn are beneficial for crops if wastewater contains such elements in sufficient amounts. Organic matter decomposition and soil mixing could be possible sources of Zn and Fe in wastewater. Small-scale industrial ventures like washing stations, auto-repair shops and leachate from waste dump sites are considered a prime source of such metal in wastewater (Kiziloglu et al., 2008; Christou et al., 2014; Ahmed and Slima, 2018). Ni in sewage water mainly comes from washing stations and automobile washing stations in sewage water. Pb mainly originated from household pains and industrial pigments and also disposal of e-waste in open sites contributes to the Pb accumulation in wastewater (Nag & Cummins, 2022). The source and content of Pb in wastewater depend on various factors such as mining activities in the local areas, waste dumping practices, vehicle pollution and transportation load in the city, e-waste dumping and dismantling practices, pain and pigments used in buildings and farms, etc. (Kiziloglu et al., 2008; Nag & Cummins, 2022). Cu mainly comes from industrial waste disposal and pesticide application in the field. Urban runoff water from different sectors contributes to the Cu contamination of sewage water. The common sources of Cu in the environment could be mining, fossil fuel combustion, waste disposals, phosphate fertilizer, and metallurgical processing (Rehman et al., 2019). Cu is an important soil mineral required for plant metabolic activities such as oxidative processes, photosynthesis, protein metabolism and N_2 fixation, etc. Apart from that Cu also acts as an important factor in affecting the enzymatic activities and respiration in plants (Quartacci et al., 2000; Chaffai et al., 2007;). Cd is a rare element found in soil and acts as a plant growth substance if occurs in a low concentration. Industrial activities are the prime source of Cd in the environment and apart from that other human activities like aquaculture, wastewater disposals, waste dumping sites, pigments, and agro-chemicals also contribute significantly to Cd accumulation in wastewater and soil resources (Yuan et al., 2019). Cr is an anthropogenic element in wastewater and mainly comes from paint and other industrial products. Low Cr concentration suggested that no industrial effluent is mixed with sewage water in this area. (Verma & Suthar, 2015). Cr is a toxic substance in the environment especially Cr(VI) which cause direct toxicity in plant and other biota. Cr is contributed by anthropogenic activities in the environment which include mining metal works, paint and pigments manufacturing, timber industries, clothes dyeing, etc. (Kazakis et al., 2017; Jones et al., 2019). The lack of industrial settlements in Sri Ganganagar would be a reason for the low Cr load in the sewage water of the studied area. A consistent load of heavy metal in sewage indicates that metals are coming from point and non-point sources and also suggest the mixing of wastewater from some small-scale industrial units, mechanical workshops and chemical-related shops (Rattan et al., 2005; Anita Singh et al., 2010). Drainage water from such places could be responsible for the heavy metal load in the sewage water of Sri Ganganagar city.

Table 1 – Heavy metal concentration in sewage water being used for soil irrigation practices at different sampling sites.

Metal		Site-I	Site-II	Site-III
Fe (mg L^{-1})	Mean	63.79	69.36	59.27
	Std. Deviation	12.41	5.49	8.19
Zn (mg L^{-1})	Mean	2.33	2.60	1.66
	Std. Deviation	0.26	0.49	0.17
Pb(mg L^{-1})	Mean	7.99	5.96	5.36
	Std. Deviation	1.81	0.68	0.57
Ni (mg L^{-1})	Mean	4.20	3.52	4.11

	Std. Deviation	0.68	0.08	0.18
Cu (mg L^{-1})	Mean	1.51	1.86	1.79
	Std. Deviation	0.10	0.10	0.12
Cd (mg L^{-1})	Mean	2.82	2.16	1.92
	Std. Deviation	0.58	0.18	0.27
Cr (mg L^{-1})	Mean	0.88	0.72	0.88
	Std. Deviation	0.25	0.24	0.18

Soil physicochemical properties

The soils of sewage irrigated water showed drastic variation in terms of major physicochemical parameters (Fig. 2). Long-term irrigation by sewage water cause the sinking of several organic and inorganic chemical substances in soils some of them could be beneficial for plant and microbial growth in soils but some show direct toxicity to biota (Tomar and Suthar, 2011; Pandey et al., 2016). The pH of the soil varied from 7.76 to 7.89 at different study sites and the maximum pH of the soil was recorded at Site-1 (7.89 ± 0.01) followed by Site-3 (7.79 ± 0.03) and Site-2 (7.76 ± 0.07). Soil pH was not in the higher range possibly due to the anaerobic degradation of sewage organic substances that lead to the formation of several intermediate metabolites of acidic nature that shifts the pH towards acidic ranges. Soil pH variation in studied sampling sites could be attributed to the factors like soil salt contents, organic matter decomposition rates, soil microbial properties, tillage practices and frequency of sol irrigations (Rattan et al., 2005; Meng et al., 2016; Rezapour et al., 2019). The average EC content in soil varied from 4.24 to 5.03 mS cm^{-1} in different field soils. EC in soil mainly indicates a load of cations and anions in soil setups mainly contributed by geological sources and sewage irrigation water as well. EC is an indicator of soil salt accumulation rate and soil health status. The results of this study are in line with previous studies that reported the effect of wastewater irrigation on soil pH and EC values. For example, a study by Hati et al. (2007) found in their study the changed soil chemical properties after the long-term application of wastewater originating from a distillery industry. Carbon content in soil is directly related to the organic matter degradation rate in soils through microbial communities, soil organic matter input rates and surface disposal of wastewater (Meng et al., 2016; Pandey et al., 2016). OC in soil ranged between 15.20 – 15.88 g kg^{-1}, significantly higher than normal soils irrigated with freshwater sources. The high OC indicates that long-term irrigation of soils by sewage sludge has contributed a significant amount of OC in such soils. Raw sewage contains a large amount of organic matter that is further degraded through the aerobic degradation process and during this mineralization process, microbial communities play an important role in organic carbon pool buildup wastewater irrigated soils (Suthar, 2008; Meng et al., 2016;

Singh et al., 2020). Wastewater contains a high load of organic substances in the form of BOD and total solid which directly contribute as carbon sources in soil for soil fertility enhancement and microbial biomass increases. A close relationship between wastewater irrigation and microbial biomass carbon and soil organic matter contents was also reported suggesting the positive impact of wastewater irrigation on soil chemical properties. TKN is an important element required for normal plant growth and crop productivity. In sewage, several organic substances contain N-based organic stuff which is further mineralized through the nitrification process under an aerobic environment. TKN ranged between 5.75 – 5.77 g kg^{-1} at different sampling sites in the studied area. The impact of sewage irrigation on soil N building has been reported by various previous researchers (Meng et al., 2016, 2019). TP load in soil was comparatively higher (0.95 – 1.09 g kg^{-1}) possibly due to the sewage inputs in soils. The K content in soil is also taken as an important soil parameter indicating the soil fertility and cation exchange capacity and K content in soil ranges between 0.73 and 0.85 g kg^{-1}. K in soil mainly comes from surface discharges, sewage disposal practices and chemical fertilizer applications (Rattan et al., 2005; SouDakouré et al., 2013). But it hardly accumulates in soil due to its high solubility, leaching potential and plant uptake rates. Na content in soils varied in the ranges of 0.89 – 1.03 g kg^{-1} among different sampling sites. Na is an indicator of soil solidity and accumulation of salts under long-term soil irrigation practices (Ganjegunte et al., 2017). Results indicate that long-term sewage irrigation plays a vital role in soil nutrient pool development which acts as a soil reserve for supporting plant growth and soil microbial enrichments for better rhizosphere physiology without affecting plant productivity. Such a soil nutrient pool may also help in reducing the dependency on chemical fertilizers for sustainable crop production in a water defiant environment. The adverse impact in terms of soil toxic substance accumulation under long-term irrigation practices also required close monitoring to ensure food quality and human health safety.

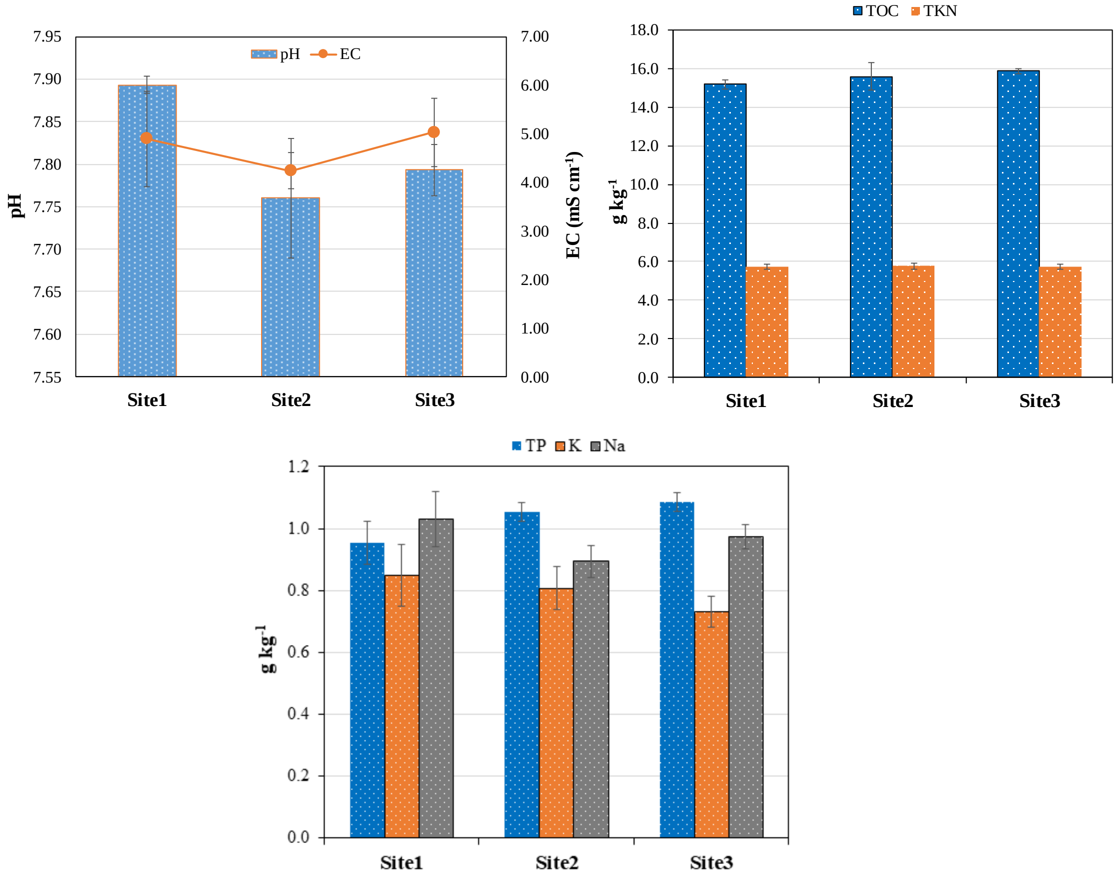

Fig. 2 Soil physicochemical properties at different sampling sites.

Heavy metal load in soils irrigated with sewage water showed significant variations among different sampling periods (Fig. 3) at different sampling stations. Fe was found in the highest concentration in soils and the order of metal in soil was as follows: Fe > Ni > Cu >Zn >Pb> Cr > Cd, based on average values of the heavy metal load in soils. The safe limit for the heavy metal load (mg kg^{-1}) in the soil is described as 2.5 for Pb, 50 for Zn, 1.5 for Cd, 20 for Cr, 30 for Cu and 1.5 for Ni as per the standard limit described in the literature (Anita Singh et al., 2010). Results of heavy metal analysis of soil indicate that the respective average content of Cr, Cd, Ni, Fe, Zn, Pb and Cu in soils of this area was found 16.60 – 24.36 mg kg^{-1}, 2.04 – 4.73 mg kg^{-1}, 21.15 – 25.63 mg kg^{-1}, 60.36 – 88.54 mg kg^{-1}, 16.0 – 22.42 mg kg^{-1},16.60 – 23.55 mg kg^{-1} and 18.12 – 26.86 mg kg^{-1}, significantly higher in cropping soils (Fig. 3).

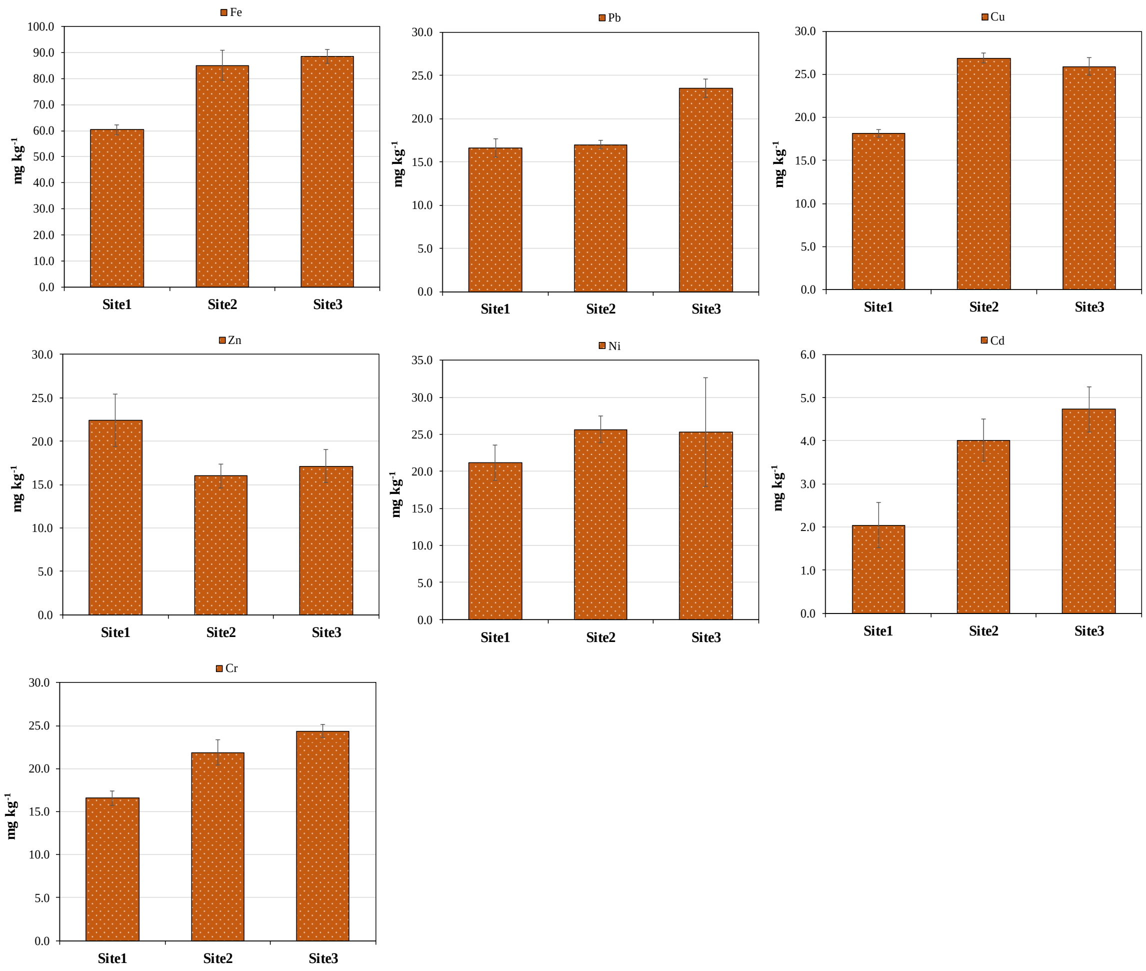

Fig. 3 – Soil heavy metal contents in the soil at different sampling sites.

The Ni in the environment mainly comes from anthropogenic sources and sewage water mixed with wastewater from mechanical shops, metal plating, washing stations, etc. could be the major source of Ni in the sewage water. It is suggested that such point sources in the city are contributing to the Ni load in soils irrigated with the untreated sewage water. Cr is also a toxic metal and it shows a high bio-accumulative property a high load in the soil further leads to the transfer of such Cr substances to standing crops and other biotas. The results of the heavy metal load of this study are in line with some previous researchers who have reported a significant concentration of elements in soils being irrigated with wastewater under long-term crop irrigation practices. For example, a study by (Sayo et al., 2020) demonstrated the accumulation of heavy metals in soils after sewage water irrigation in agriculture practices in Kenya. They found a high load (mg/L) of Cu (0.484–1.834), Zn (1.432–4.612), Cd (0.015–0.353) and Pb (0.011–2.123) than that of setups with clean water irrigations. The soils showed the overall metal load in soils above the safe limit decided by the pollution monitoring agencies. They concluded that sewage water irrigation needs to be monitored from time to time to ensure the quality of field crops under such irrigation practices.

Conclusion

Sewage water has been considered as alternative source of water for crop irrigation in many parts of the world. But such practices also need to be evaluated in terms of adverse impact on soil environment. In this study we investigated the effect of long-term irrigation on soil nutrient and metal built-up in agriculture soils as a result of sewage irrigation. Results suggested that sewerage irrigation enriched the soils with valuable soil nutrients, required for soil fertility, but at the same time also promotes soil heavy metal build-up which need close monitoring to ensure the food quality in such systems. Heavy metal content in sewage irrigated setups was found to be higher and that may pose serious risk of food contamination and human health safety.

References

Abeed, A. H. A., Ali, M., Eissa, M. A., & Tammam, S. A. (2022). Impact of sewage water irrigation on Datura innoxia grown in sandy loam soil. *BMC Plant Biology*, *22*(1), 559. https://doi.org/10.1186/s12870-022-03935-9

Ahmed, D. A., & Slima, D. F. (2018). Heavy metal accumulation by Corchorus olitorius L. irrigated with wastewater. *Environmental Science and Pollution Research*, *25*(15), 14996–15005. https://doi.org/10.1007/s11356-018-1675-1

APHA. (2005). Standard Methods for the Examination of Water and Wastewater, twenty-first ed. In *American Public Health Association, Washington, DC*.

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*(1), S32–S44. https://doi.org/10.1016/j.sjbs.2015.09.023

Chaffai, R., Elhammadi, M. A., Seybou, T. N., Tekitek, A., Marzouk, B., & El Ferjani, E. (2007). Altered Fatty Acid Profile of Polar Lipids in Maize Seedlings in Response to Excess Copper. *Journal of Agronomy and Crop Science*, *193*(3), 207–217. https://doi.org/https://doi.org/10.1111/j.1439-037X.2007.00252.x

Christou, A., Maratheftis, G., Eliadou, E., Michael, C., Hapeshi, E., & Fatta-Kassinos, D. (2014). Impact assessment of the reuse of two discrete treated wastewaters for the irrigation of tomato crop on the soil geochemical properties, fruit safety and crop productivity. *Agriculture, Ecosystems and Environment*, *192*, 105–114. https://doi.org/10.1016/j.agee.2014.04.007

Chung, B. Y., Song, C. H., Park, B. J., & Cho, J. Y. (2011). Heavy Metals in Brown Rice (Oryza sativa L.) and Soil After Long-Term Irrigation of Wastewater Discharged from Domestic Sewage Treatment Plants. *Pedosphere*, *21*(5), 621–627. https://doi.org/10.1016/S1002-0160(11)60164-1

Ganjegunte, G., Ulery, A., Niu, G., & Wu, Y. (2017). Effects of treated municipal wastewater irrigation on soil properties, switchgrass biomass production and quality under arid climate. *Industrial Crops and Products*, *99*, 60–69. https://doi.org/10.1016/j.indcrop.2017.01.038

Hati, K. M., Biswas, A. K., Bandyopadhyay, K. K., & Misra, A. K. (2007). Soil properties and crop yields on a vertisol in India with application of distillery effluent. *Soil and Tillage Research*, *92*(1–2), 60–68. https://doi.org/10.1016/J.STILL.2006.01.011

Hussain, I., Raschid, L., Hanjra, M.A., Marikar, F.& van der Hoek, W. (2002). Wastewater use in agriculture: Review of impacts and methodological issues in valuing impacts. (With an extended list of bibliographical references). Working Paper 37. Colombo, Sri Lanka: International Water Management Institute.

Jones, A. S., Marini, J., Solo-Gabriele, H. M., Robey, N. M., & Townsend, T. G. (2019). Arsenic, copper, and chromium from treated wood products in the U.S. disposal sector. *Waste Management (New York, N.Y.)*, *87*, 731–740. https://doi.org/10.1016/j.wasman.2019.03.004

Kazakis, N., Kantiranis, N., Kalaitzidou, K., Kaprara, E., Mitrakas, M., Frei, R., Vargemezis, G., Tsourlos, P., Zouboulis, A., & Filippidis, A. (2017). Origin of hexavalent chromium in groundwater: The example of Sarigkiol Basin, Northern Greece. *The Science of the Total Environment*, *593–594*, 552–566. https://doi.org/10.1016/j.scitotenv.2017.03.128

Kiziloglu, F. M., Turan, M., Sahin, U., Kuslu, Y., & Dursun, A. (2008). Effects of untreated and treated wastewater irrigation on some chemical properties of cauliflower (Brassica olerecea L. var. botrytis) and red cabbage (Brassica olerecea L. var. rubra) grown on calcareous soil in Turkey. *Agricultural Water Management*, *95*(6), 716–724. https://doi.org/10.1016/J.AGWAT.2008.01.008

Meena, R., Datta, S. P., Golui, D., Dwivedi, B. S., & Meena, M. C. (2016). Long-term impact of sewage irrigation on soil properties and assessing risk in relation to transfer of metals to human food chain. *Environmental Science and Pollution Research*, *23*(14), 14269–14283. https://doi.org/10.1007/s11356-016-6556-x

Meng, F., Feng, L., Yin, H., Chen, K., Hu, G., Yang, G., & Zhou, J. (2019). Assessment of nutrient removal and microbial population dynamics in a non-aerated vertical baffled flow constructed wetland for contaminated water treatment with composite biochar addition. *Journal of Environmental Management*, *246*. https://doi.org/10.1016/j.jenvman.2019.06.011

Meng, W., Wang, Z., Hu, B., Wang, Z., Li, H., & Goodman, R. C. (2016a). Heavy metals in soil and plants after long-term sewage irrigation at Tianjin China: A case study assessment. *Agricultural Water*

Management, *171*, 153–161. https://doi.org/10.1016/J.AGWAT.2016.03.013

Meng, W., Wang, Z., Hu, B., Wang, Z., Li, H., & Goodman, R. C. (2016b). Heavy metals in soil and plants after long-term sewage irrigation at Tianjin China: A case study assessment. *Agricultural Water Management*, *171*, 153–161. https://doi.org/10.1016/j.agwat.2016.03.013

Nag, R., & Cummins, E. (2022). Human health risk assessment of lead (Pb) through the environmental-food pathway. *Science of the Total Environment*, *810*, 151168. https://doi.org/10.1016/j.scitotenv.2021.151168

Pandey, B., Suthar, S., & Singh, V. (2016). Accumulation and health risk of heavy metals in sugarcane irrigated with industrial effluent in some rural areas of Uttarakhand, India. *Process Safety and Environmental Protection*, *102*, 655–666. https://doi.org/10.1016/j.psep.2016.05.024

Parihar, P., Chand, N., & Suthar, S. (2022). Septage effluent treatment using floating constructed wetland with Spirodela polyrhiza: Response of biochar addition in the support matrix. *Nature-Based Solutions*, *2*, 100020. https://doi.org/https://doi.org/10.1016/j.nbsj.2022.100020

Quartacci, M. F., Pinzino, C., Sgherri, C. L. M., Dalla Vecchia, F., & Navari-Izzo, F. (2000). Growth in excess copper induces changes in the lipid composition and fluidity of PSII-enriched membranes in wheat. *Physiologia Plantarum*, *108*(1), 87–93. https://doi.org/https://doi.org/10.1034/j.1399-3054.2000.108001087.x

Rattan, R. K., Datta, S. P., Chhonkar, P. K., Suribabu, K., & Singh, A. K. (2005). Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater - A case study. *Agriculture, Ecosystems and Environment*, *109*(3–4), 310–322. https://doi.org/10.1016/j.agee.2005.02.025

Rehman, M., Liu, L., Wang, Q., Saleem, M. H., Bashir, S., Ullah, S., & Peng, D. (2019). Copper environmental toxicology, recent advances, and future outlook: a review. *Environmental Science and Pollution Research*, *26*(18), 18003–18016. https://doi.org/10.1007/s11356-019-05073-6

Rezapour, S., Atashpaz, B., Moghaddam, S. S., & Damalas, C. A. (2019). Heavy metal bioavailability and accumulation in winter wheat (Triticum aestivum L.) irrigated with treated wastewater in calcareous soils. *Science of the Total Environment*, *656*, 261–269. https://doi.org/10.1016/j.scitotenv.2018.11.288

Sayo, S., Kiratu, J. M., & Nyamato, G. S. (2020). Heavy metal concentrations in soil and vegetables irrigated with sewage effluent: A case study of Embu sewage treatment plant, Kenya. *Scientific African*, *8*, e00337. https://doi.org/10.1016/j.sciaf.2020.e00337

Singh, Ajay. (2021). A review of wastewater irrigation: Environmental implications. *Resources,* *Conservation and Recycling*, *168*, 105454. https://doi.org/10.1016/j.resconrec.2021.105454

Singh, Anita, Sharma, R. K., Agrawal, M., & Marshall, F. M. (2010). Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. *Food and Chemical Toxicology*, *48*(2), 611–619. https://doi.org/10.1016/j.fct.2009.11.041

Singh, P. K., Deshbhratar, P. B., & Ramteke, D. S. (2012). Effects of sewage wastewater irrigation on soil properties, crop yield and environment. *Agricultural Water Management*, *103*, 100–104. https://doi.org/10.1016/j.agwat.2011.10.022

Singh, P., Purakayastha, T. J., Mitra, S., Bhowmik, A., & Tsang, D. C. W. (2020). River water irrigation with heavy metal load influences soil biological activities and risk factors. *Journal of Environmental Management*, *270*, 110517. https://doi.org/10.1016/j.jenvman.2020.110517

SouDakouré, M. Y., Mermoud, A., Yacouba, H., & Boivin, P. (2013). Impacts of irrigation with industrial treated wastewater on soil properties. *Geoderma*, *200–201*, 31–39. https://doi.org/10.1016/j.geoderma.2013.02.008

Sridhara Chary, N., Kamala, C. T., & Samuel Suman Raj, D. (2008). Assessing risk of heavy metals from consuming food grown on sewage irrigated soils and food chain transfer. *Ecotoxicology and Environmental Safety*, *69*(3), 513–524. https://doi.org/10.1016/j.ecoenv.2007.04.013

Suthar, S., Sharma, J., Chabukdhara, M., & Nema, A. K. (2010). Water quality assessment of river Hindon at Ghaziabad, India: Impact of industrial and urban wastewater. *Environmental Monitoring and Assessment*, *165*(1–4). https://doi.org/10.1007/s10661-009-0930-9

Suthar, Surendra. (2008). Bioremediation of aerobically treated distillery sludge mixed with cow dung by using an epigeic earthworm Eisenia fetida. In *The Environmentalist* (Vol. 28, Issue 2, pp. 76–84). https://doi.org/10.1007/s10669-007-9031-x

Tomar, P., & Suthar, S. (2011). Urban wastewater treatment using vermi-biofiltration system. *Desalination*, *282*. https://doi.org/10.1016/j.desal.2011.09.007

Verma, R., & Suthar, S. (2015). Lead and cadmium removal from water using duckweed - Lemna gibba L.: Impa ct of pH and initial metal load. *Alexandria Engineering Journal*, *54*(4). https://doi.org/10.1016/j.aej.2015.09.014

Yuan, Z., Luo, T., Liu, X., Hua, H., Zhuang, Y., Zhang, X., Zhang, L., Zhang, Y., Xu, W., & Ren, J. (2019). Tracing anthropogenic cadmium emissions: From sources to pollution. *Science of The Total Environment*, *676*, 87–96. https://doi.org/10.1016/J.SCITOTENV.2019.04.250