Sewage water use in Crop Production and its effect on Physico-chemical and Biological properties of soil: A Review

Abstract :

The availability of freshwater for irrigation is dwindling, prompting the need for innovative solutions to tackle this critical issue. This research delves into comparing sewage water with fresh water, recognizing the immense volume of wastewater generated daily due to rapid population growth and industrial expansion. The current state of sewage water in India presents a formidable challenge, highlighting the imperative for proactive management strategies moving forward. The study explores methods to harness sewage water for agricultural use, aiming to enhance productivity while acknowledging the global significance of wastewater management. Sewage water composition varies depending on local industrial activities, often containing higher levels of nutrients like nitrogen, phosphorus, potassium, organic carbon, micronutrients, and soil microbial content compared to regular water sources. Utilizing sewage water for irrigation can positively impact soil chemistry and fertility, although it may increase electrical conductivity, albeit usually within acceptable limits to mitigate soil salinity risks. However, sewage water typically contains elevated concentrations of heavy metals such as Cadmium, Chromium, Lead, and Nickel, posing potential hazards to soil and plant health if surpassing safety thresholds. Continuous use of sewage water may exacerbate the accumulation of these hazardous metals, posing risks to both soil quality and human health. Nonetheless, during periods of water scarcity crucial for crop growth, sewage water emerges as a vital resource, potentially saving agricultural productivity. In this context, sewage farming emerges as a promising approach to alleviate the demand for freshwater while addressing wastewater challenges. Embracing sewage water for irrigation holds the promise of significant advancements in curbing wastewater proliferation, underscoring its role as a sustainable solution for agricultural water requirements.

Keywords: Sewage water, soil, heavy metals, agricultural productivity, heavy metals, water scarcity

1. Introduction

The escalating global population, coupled with rapid urbanization and industrialization, has led to a surge in wastewater generation, posing significant challenges for sustainable water management. World population has been continuous increase day by day, it was observed approximately 5.3 billion in 1992 to about 7.4 billion in 2016 (World Population Data Sheet, 2016) and global population will reach over 8 billion in 2030 and 9 billion in 2050, according to United Nation projections. Effect of this rapid population growth the consumption of water increase and resulted the production of huge amount of waste water and sewage sludge (Li *et al*., 2011). In the face of dwindling freshwater resources, the utilization of sewage water for crop production has garnered increasing attention as a potential solution to address water scarcity and enhance agricultural sustainability. This review aims to explore the implications of sewage water use on crop production and its effects on soil physical and biological properties. The utilization of sewage water in agriculture presents a multifaceted opportunity to address the pressing issues of water scarcity and wastewater management. According to FAO (2013), the agriculture industry is currently the world's largest user of water resources. Agriculture sector, approximately 92% of total water with drawals in several arid and semi-arid nations, (Forouzani *et al.,* 2013). Improving water usage eficiency and finding alternative resources are essential to reducing further demand on water resources and ensuring sustainable management of irrigation water in arid and semi-arid environments. Application of treated wastewater is a suitable strategy to reduce the shortage of water in arid and semi-arid areas and preserve considerable amounts of freshwater since it is an environmentally sound technology

(Garrone *et al*., 2018). Sewage water, often treated to varying degrees, contains essential nutrients such as nitrogen, phosphorus, and potassium, along with organic matter, micronutrients, and beneficial microbial communities. These components can potentially supplement or replace conventional irrigation water and chemical fertilizers, thereby reducing dependency on freshwater resources and minimizing nutrient runoff into natural water bodies. However, the adoption of sewage water for crop irrigation raises concerns regarding its impact on soil quality and plant health. Sewage water may introduce contaminants such as heavy metals, pathogens, and organic pollutants into the soil, which could accumulate over time and compromise soil fertility and ecosystem health. Moreover, the physical properties of soil, including structure, texture, and hydraulic conductivity, may be altered by long-term irrigation with sewage water, potentially affecting water infiltration, root growth, and overall crop productivity. Understanding the complex interactions between sewage water application, soil properties, and crop responses is crucial for devising effective management strategies to optimize agricultural productivity while safeguarding environmental and human health. This review synthesizes existing literature to evaluate the benefits and challenges associated with sewage water use in crop production, with a focus on its effects on soil physical and biological properties. By elucidating the mechanisms underlying these interactions, this review aims to inform policymakers, researchers, and agricultural practitioners on the sustainable utilization of sewage water for irrigation and its implications for soil and crop management in diverse agroecosystems. This approach treating the sewage water by different methods reduces stress on freshwater resources which are primarily used for human and industrial uses, while also addressing waste disposal (Hajjami *et al*., 2012, Cheftez *et al*., 2006). Peri-urban farmers perceive wastewater as a priceless, cost-free water source that is rich in fertilizers (Tamrabet, 2011). However, the utilizing of treated wastewater may have effects, either on crops (Yadav *et al*., 2002) or on physical and chemical properties of soils (Tarchouna *et al*., 2010, Mamedov *et al*., 2000). Hydrodynamic properties of soils may change as a result of changes in soil characteristics brought on by irrigation with treated wastewater (Tarchitzky *et al*., 1999). According to Shainberg and Oster (1978), irrigation water quality is thought to affect soil properties, crop yield, and water management in agricultural activities. In sewage was irrigation improved physiochemical characteristics of soil (Antil, 2012). In Domestic wastewater contains essential plant nutrients such as N, P, K and micronutrients which are beneficial for plants growth (Kiran *et al*., 2012; Agrawal *et al*., 2014). In evaluated the changes in soil parameters after discharging domestic wastewater on soil (Yang *et al*., 2015). Irrigation with treated wastewater increased soil pH, EC, OM, major elements (N, P, K, Na, Cl and Mg), salts and heavy metals such as Mn, Zn and Fe contents compared with well water irrigation (Bedbabis *et al*., 2015). Therefore, the current research discusses the components of sewage and industrial effluents in India and their potential impact on the health of soil and plants.

2. Review of Literature

Due to continuous industrialization and urbanization, the sewer system has become the most important aspect of wastewater disposal in societies. Sewage water has the potential to improve soil fertility due to its heavy loads of macro and micro-nutrients. In agriculture practices, the quality of irrigation water can influence the soil characteristics, which in turn contribute to the potential yield of the crops.

Raw sewage water is said to be rich in organic matter and essential nutrients. Urban waste water is mainly comprised of 99 per-cent water along with moderately low concentration of suspended and dissolved organic and inorganic solids (Antil and Narwal, 2008). However, some city sewage water where industrial waste is discharged into sewer systems may contain a high amount of toxic metals. The composition of sewage may vary from hour to hour, day to day, season to season depending on the intensity and nature of activities of the people of the area as well as the methods of collection and treatment procedure in place.

2.1 Chemical composition of sewage water

According to Maheshwari *et al*. (2008) Cd, Cr, Pb and Ni were found in the industrial waste, sludge and sewage samples of Karnal, Panipat and Sonepat. The soluble heavy metals ranged from Cd (0.015 - 0.451 mg L^{-1}), Cr (0.015 - 0.248 mg L^{-1}), Pb (0.014 - 0.351 mg L^{-1}) and Ni (0.023 - 0.624 mg L^{-1}). Likewise total heavy metals ranged from Cd (0.2 - 6.5 mg L^{-1}), Cr (0.1 - 180 mg L^{-1}), Pb (0.1 - 180 mg L^{-1}) and Ni (0.3 – 125 mg L^{-1}).

Dash *et al.* (2009) carried out a study to characterize sewage water (SW) and its impact on soil properties, essential nutrients and heavy metal content in the leaf of crop plants. The results revealed that SW samples were non-saline, acidic in reaction (pH 6.5 to 6.89) and had an optimal level of BOD (48 to 55 mg L^{-1}) and COD (90 to 105 mg L^{-1}). Concentration of NH_4-N, NO_3-N, PO_4, Zn and B ranged from 48.3 to 52.6, 8.1 to 8.3, 2.4 to 2.5, 1.5 to 2.5 and 0.7 to 0.75 mg L^{-1}, respectively. The heavy metals concentration in sewage water was in the order of As > Pb >Hg >Ni >Co > Cd >Se.

Glbq et al. (2020) revealed that sewage sludge was characterized by higher P, Ca, Mg, Na and ash and lower K content than the other two feedstocks, maize straw and biochar.

Jumasheva *et al.* (2023) while analyzing sewage sludge characteristics, observed concentrations of various elements exceeding permissible limits. Specifically, chromium levels were 1.18 times higher than the maximum permissible concentration (MPC), copper exceeded MPC by 1.1 times, zinc exceeded MPC by 1.18 times, lead exceeded MPC by 1.07 times, cobalt exceeded MPC by 1.28 times, and molybdenum exceeded MPC by 1.3 times.

Lokhande *et al*. (2011) conducted an assessment of pollution due to toxic heavy metals in the industrial waste water effluents collected from Taloja industrial belt of Mumbai. The results revealed that paint manufacturing industries are the major contributors of toxic Cr, Zn and Pb amounting to 35.2, 33.1 and 31.4 mg L^{-1}, respectively. It was also observed that the major contribution of Cu (33.3 mg L^{-1}) was from dye manufacturing units, while maximum Fe concentration of 12.8 mg L^{-1} was found in effluent samples released from textile industries.

Singh *et al*. (2012) experimented on the agriculture farm by using crops such as wheat (AKW-1071), Gram (Jacky-9218), Palak (Pusa-Jyoti), Methi (Kasuri) and Berseem (Multicut). All these crops were irrigated with groundwater and domestic waste water and applied recommended dose of NPK fertilizers in the treatment. The use of domestic waste water with fertilizers has revealed improvement in the physic-chemical properties of the soil, crop yield as well as in nutrient status as compared to that which was irrigated with groundwater and applied fertilizer.

The work of Asgharipour (2012) revealed that the pH of municipal sewage effluent (7.6) was lower compared to that of the well water (7.7), where as the salt content (EC-1.65 dSm^{-1}) was considerably higher compared to that of the well-waters (0.34 dSm^{-1}), indicating that the sewage effluent was saline in nature. The sewage effluent (BOD and COD) were rated as suitable for irrigation purposes compared with the prescribed limits of 100 and 250 mg L^{-1} for BOD and COD, respectively (ISI, 1982). The concentrations of heavy metals and nutrients (N, P, K, Ca, Mg, Na, Fe, Cu, Mn, Zn, Cd, Ni and Pb) were higher in the municipal sewage effluent when compared with the well water. Furthermore, the concentrations of metals in the source of irrigation water were well within the tolerable limits for their use as irrigation water, except for Cd.

Yadav *et al*. (2013) assess the levels of different heavy metals like Fe, Cu, Zn, Cd, Ni and Pb in vegetables irrigated with water from different sources at the industrial area of Naini, Allahabad. The concentrations (mg L^{-1}) of heavy metals in irrigated water ranged from 0.249 to 0.257 for Fe, 0.049 to 0.056 for Zn, 0.028 to 0.036 for Cd, 0.015 to 0.019 for Cu, 0.035 to 0.042 for Pb and 0.031 to 0.038 for Ni which was lower than the recommended maximum tolerable levels proposed by joint FAO/WHO Expert Committee on food additives (2007), except for Cd and Fe which exhibited higher content.

Safana *et al*. (2018) studied the irrigation water of Ginzo waste channel in Katsina state, Nigeria. The results indicated that mean levels of heavy metals in irrigation water were;

Cadmium (0.14 mg L^{-1}), Chromium (0.10 mg L^{-1}), Iron (0.55 mg L^{-1}), Lead (0.09 mg L^{-1}) and Zinc (0.05 mg L^{-1}).

2.2.1 Effects of sewage water use on soil physico-chemical properties

The use of sewage water as a supplementary water resource for irrigation is now being widely accepted particularly in the arid and semiarid zones. Sewage materials are valuable sources of plant nutrients and have been found to affect the physical properties of soil like bulk density, aeration, water holding capacity, aggregate stability, chemical properties, *etc*. however, uncontrolled use of sewage water for irrigation can result in the accumulation of potentially toxic metals in soil, which may affect its physico-chemical properties.

Rana *et al.* (2010) investigated the long-term effects of sewage water irrigation on soil properties and heavy metal concentrations in Rohtak district of Haryana. The results reported that sewage waste remained within acceptable limits for use as irrigation water. Soil analysis revealed that organic carbon, phosphorus, calcium and magnesium content were high in sewage irrigated soils as compared to tubewell irrigated soils. The soil pH decreased by 0.38 units due to sewage water irrigation. The continuous application of untreated sewage effluent for the last 35 years resulted in significant accumulation of nutrients and heavy metals in soils. Organic carbon content showed a positive correlation with all heavy metals except Zn, while pH had a negative correlation with all metals except Mn. Electrical conductivity also had a positive correlation with all the metals.

Singh *et al.* (2010) carried out a study at Varanasi city where waste water from Dinapur sewage treatment plant was used for irrigating vegetable plots. The waste water used for irrigation had the highest concentration of Zn followed by Pb, Cr, Ni, Cu and Cd. Continuous application of waste water for more than 20 years led to accumulation of heavy metals in the soil. Subsequently, the concentrations of Cd, Pb and Ni had gone beyond the safe limits for human consumption in all the vegetables.

Rai *et al*. (2011) studied the effect of sewage water and canal water irrigation soil. The mean values of different physico-chemical parameters were bulk density (g/cm^3)-1.26, water holding capacity (%)-53.60, temperature (ºC)-16.33, electrical conductivity (dsm^{-1})- 0.122, pH-7.5, organic carbon (%)-1.95, available phosphorous (mg kg^{-1})-108.44, available potassium (mg/kg)-121.66, nitrogen (%)-2.22, available calcium (%)-2.18 and available magnesium (%)-0.09 in sewage water irrigated soil.

The work of Singh and Agrawal (2012) revealed that sites receiving waste water irrigation showed an increase in organic carbon and available phosphorus during the first year. Microbial biomass (C, N and P) and concentrations of exchangeable cations (Na^+, K^+ and Ca^{2+}) also showed increases varying from two to three fold at waste water-irrigated sites. Additionally, waste water used for irrigation led to beneficial changes in physico-chemical and biological properties of the soil, but the level of heavy metals in the soil increased causes soil contamination.

Al-Jaboobi *et al*. (2014) reported that soil pH ranged from 7.89 to 7.55 in soil irrigated with wastewater which was less than 8.27 to 8.08 in groundwater soil irrigation. In addition, there was an increase in EC from 893 to 943 µS/cm with an average of 921 µS/cm in soil irrigated with wastewater whereas the average value of EC in the soil irrigated with ground water varied from 600 to 705 µS cm^{-1} with a mean of 657 µS/cm. High organic matter content was observed in the soil irrigated with wastewater. It showed 2.00 per-cent compared to 0.74 per-cent obtained in the case of the soil irrigated with groundwater. This infers that wastewater contains organic matter compounds. Average values of phosphorus were high in soil irrigated with waste water at 27.33 ppm, compared to 6.22 mg L^{-1} in soil irrigated with groundwater. Total nitrogen in the soil was significantly high in sewage water with an average of 40.33 mg kg^{-1} compared to those irrigated with groundwater 16 mg kg^{-1}. Higher increase in value of potassium in soils irrigated with sewage water (519 ppm) when compared to those irrigated with groundwater (115 ppm).

According to Antil (2014) continuous use of sewage and industrial waste water irrigation recorded improvement in water retention, hydraulic conductivity, organic C and build-up of available N, P, K micronutrient status, and soil microbial count with the electrical conductivity. The increase due to sewage irrigation was within the tolerance limit and thus will not cause any soil salinity hazard. Heavy metals like Cd, Cr, Pb and Ni were found higher in soil and plant as a result of long-term usage of sewage and industrial waste water irrigation. The concentration of these metals was higher in leafy vegetables than in grain crops. This warrants the potential hazard to soil plant health, necessitating their safe use after pre-treatment as a cheap potential alternative source of plant nutrients in agriculture.

Muamar *et al.* (2014**)** determined the quality of soil when irrigated with sewer water. Total sewer water was compared with soil irrigated with ground water. The pH of the soil decreased from 8.16 in soil irrigated with ground water to 7.70 in soil irrigated with sewer water. The values of EC, TDS, Na, N, P and K are higher in sewer water irrigated soil compared to ground water irrigated soil. This research showed that the soil irrigated with sewer water has a higher content of organic matter, which was equal to (2.00 %) compared to (0.74 %) soil irrigated with groundwater.

Subramani *et al.* (2014) reported that application of sewage water resulted in the buildup of heavy metals in surface soil. The mean contents of total Cd, Cr and Pb in the soils irrigated with sewage water were 2.85, 75.40 and 40.26 mg kg^{-1}, respectively, while the mean values of available Cd, Cr and Pb in soils were 0.21, 0.33 and 1.27 mg kg^{-1}, respectively.

Varkey *et al.* (2015) investigated the effects of application of domestic sewage water for over four decades on the physical, chemical and biological properties of soils. The results indicated that long-term use of sewage water improves soil physical properties in terms of decrease in bulk density and dispersion index and increase in aggregate stability and water holding capacity compared to the un-irrigated check. Despite long-term irrigation with sewage water with an EC of 1.0 dSm^{-1}, the EC of soils was low (0.20–0.45 dSm^{-1}). Nevertheless, the available Zn, Fe, Cu and B increased slightly except Mn, which increased considerably. In general, there was a decreasing trend of organic carbon, available N, P, K and S with a distance further away from the stream course.

Najam and Kaur (2016) found out that the use of sewage improves the physicochemical properties of the soil as compared to groundwater application. Sewage leads to an increase in crop yield with improved soil fertility.

Gurjar *et al*. (2017) assert that physical properties of soil irrigated with sewage water showed higher increased bulk density (BD) 0.01 g cm^{-3}, particle density (PD) 0.02 g cm^{-3}, porosity 1.03% and water holding capacity 6.20 per-cents as compared to ground water irrigated. The irrigation with groundwater (8.31) and sewage water (7.49) induces a decrease of soil pH and increase OC in comparison to ground water.

The work of Irandoust and Tabriz (2017) revealed different methods based on low-quality irrigation water such as waste water appeared to be a practical and convenient solution in that waste water can be a rich source of minerals and organic matter which is considered as a major constituent of fertile soil. The results showed a decrease in acidity, salinity, phosphorus, nitrogen and heavy metals concentration in soil irrigated with waste water when compared with soils irrigated with well water.

Rani *et al*. (2018) conducted a study at Musi river basin, Hyderabad, Andhra Pradesh. The results revealed that pH of the surface and sub-surface soils irrigated with sewage and groundwater was relatively higher compared to control (no irrigation). Similarly, the organic carbon content in the surface and sub-surface soils treated with sewage water was higher compared to groundwater irrigated soils and control. In general, surface soils contained relatively higher amounts of organic carbon than those of sub-surface soils. The available concentration of N, P and K ranged from 133.0 to 702.6 kg ha^{-1}, 11.6 to 347.7 kg ha^{-1} and 152.5 to 653.8 kg ha^{-1}, respectively regardless of the depth of the soils.

The study of Haroon *et al.* (2019) reported that waste water irrigation results in increased soil pH. The pH of the waste water irrigated fields ranged from 7.6 to 8.7 whereas its values ranged from 6.4 to 7.1 in rainfed fields. The EC of soils ranged from 554 to 728 µS m^{-1} in waste water irrigated fields, whereas in the non-irrigated fields the EC values ranged from 182 to 368 µS m^{-1}. Elevated EC values showed that the use of industrial waste water for irrigation can lead to an accumulation of salts in the soils. Total carbon was recorded between 2.2 and 4.2 per cent in the waste water irrigated fields; however, carbon contents were lower in the non-irrigated fields, which range between 1.2–2.1 per cent.

2.2.2 Effects of sewage water use on soil heavy metals properties

Long-term application of sewage water on agricultural fields often increased the levels of macronutrients and heavy metals in soils. There are various sources through which heavy metals get to the soil including industrial, urban or agricultural wastes, sewage waste, industrial waste and gases emitted by vehicles and industries.

Sial *et al*. (2006) compared the effects of irrigation with 100% canal water, 50% waste water (conjunctive) and 10 per cent waste water on groundwater quality. It was determined that direct use of waste water not only results in salinity problems but also affected the groundwater quality by increasing its sodicity. The plots irrigated with 100 per cent waste water deteriorated in terms of measured parameters when compared with 100 per-cent canal water. Among heavy metals, Fe was in the maximum concentration and it was 56 per-cent of the total metal while Cr was the minimum. The concentration of the metals Mn, Ni, Cr, Pb, Fe and Zn were within permitted limits.

Gowd *et al*. (2010) analyzed the environmental geochemical effect carried by industrial waste at Jajmau and Unnao industrial areas of Kanpur (U.P). The results disclosed that surface soil in this area is significantly contaminated with heavy metals such as Cr in the range of 161.8 to 6227.8 mg kg^{-1} (average of 2652.3 mg kg^{-1}), Cu varied from 1.7 to 126.1 mg kg^{-1} (average of 42.9 mg kg^{-1}), Pb varied from 10.1 to 67.8 mg kg^{-1} (average of 38.3 mg kg^{-1}) and Zn varies from 43.5 to 687.6 mg kg^{-1} (average of 159.9 mg kg^{-1}).

Rana *et al*. (2010) worked on the long-term effects of sewage water irrigation on soil properties and heavy metal concentrations at Rohtak city, Haryana. The chemical analysis of sewage effluent indicated that total salt concentration and heavy metal content were high compared to ground water but within the safe limits. Soil analysis revealed that organic carbon, phosphorus, calcium and magnesium content were high in sewage irrigated soils when compared with tubewell irrigated soils.

Kharche *et al*. (2011) reported that long-term application of sewage water led to the accumulation of heavy metals in surface soil with the concentration of these elements approaching suggested maximum tolerable limits. The mean content of total Fe, Mn, Zn, Cu, Cd, Cr and Ni in the soils irrigated with sewage water was 1.05, 1.24, 3.98, 1.51, 2.10, 1.62 and 1.24 times when compared to those in well-irrigated soils, and the concentration of these metals in cabbage grown on sewage irrigated soils was higher by 1.11, 7.51, 1.72, 7.66, 4.36, 1.26 and 1.91 times, respectively. The concentration of heavy metals in cabbage grown on sewage was higher when compared to their tolerance level indicating their accumulation in the plants.

Pathak *et al*. (2011) investigated the sewage water irrigation effect on physicochemical properties and accumulation of heavy metals and noted that the concentration of heavy metals like Pb, Cd and Cr was found higher in waste water treated soils as compared to control. A positive effect of application of sewage sludge was also noticed on the concentration of Zn, Cu, Fe and Ni. The authors further reported an increased electrical conductivity of the treated soil.

Rai *et al*. (2011) studied the effect of sewage and canal water irrigation soil. The mean values of heavy metal concentration in soil were Pb (52.72), Cu (49.03), Zn (264.09) and Cd (24.66) in sewage water irrigated soil. The recorded concentration of Pb, Cu and Zn was below the Indian standards except for Cd. The enrichment factors of sewage water irrigated soil in Pb

(3.79), Zn (4.12), Cu (3.12) and Cd (2.21) were moderate enrichment whereas pollution index values in the samples were calculated to be lower than the permissible pollution limit of 1.0.

According to Singh *et al.* (2010) who conducted a study at Varanasi city where waste water from Dinapur sewage treatment plant is used for irrigating vegetable plots. The waste water used for irrigation had the highest concentration of Zn, followed by Pb, Cr, Ni, Cu and Cd. Continuous application of waste water for over 20 years has led to the accumulation of heavy metals in the soil. Consequently, concentrations of Cd, Pb and Ni have crossed the safe limits for human consumption in all the vegetables.

In the study of sewage sludge along with inorganic fertilizers, Roy *et al*. (2013) found that the application of sewage sludge resulted in the accumulation of all the micronutrients (Fe, Zn, Mn and Cu). Furthermore, the application of sewage sludge led to the accumulation of Pb which signified the need for safe use of sewage sludge.

Rani *et al*. (2015) conducted a study in Musi river basin, Hyderabad, Andhra Pradesh and found that concentration of Cu, Fe, Mn and Zn extracted in DTPA extractant solution ranged from 0.63 to 2.85, 6.10 to 57.2, 1.17 to 21.72 and 0.38 to 2.15 mg kg^{-1}, respectively. The concentration of Cd was lower as compared to other heavy metals and occurred between 0.64 and 3.62 mg kg^{-1}. Surface soils had higher content of DTPA-extractable micronutrient cations and heavy metals as compared to sub-surface soils.

Varkey *et al*. (2015) revealed that effects of the application of domestic sewage water over four decades on the physical, chemical and biological properties of soils were examined at three sites in Gabbur, Mavanur and Katnur villages near Hubli city in North Karnataka, India. The available Zn, Fe, Cu and B showed increased only slightly except for Mn which increased substantially.

The study of Ebrahim *et al*. (2016) observed the effect of long-term use of irrigation with treated sewage wastes on absorption and accumulation of some heavy metals and their possible contaminations of alfalfa crop and soil in Bahrain and found that the concentration of heavy metals in treated sewage wastes did not exceed the international standards, except for Cadmium, which was double the acceptable limit. Additionally, there were no significant differences caused by irrigation, in heavy metal concentration in the soil. Nevertheless, the concentrations of Pb, Ni and Cr were low compared to un-irrigated soil. There were no significant differences ($P=0.08$) in heavy metals' concentrations between the two soil depths, except for Zn and Cd ($P=0.035$) which indicated higher concentrations in the upper and lower depths, respectively.

According to the results of Singh *et al*. (2017) the application of sewage and industrial effluents lead to accumulation of heavy metals in surface soil. The average contents of micronutrients and heavy metals *viz*., Fe, Zn, Mn, Cu, Pb, Cd, Cr and Ni in the soils irrigated with sewage and industrial effluents was significantly higher concerning tube-well water.

2.3 Effect of sewage water on biological properties of soil

Microbial count in sewage-irrigated soils was observed to be higher for bacteria, fungi and actinomycetes, which were about 1.34, 1.52 and 1.18 times (for 0-30 cm) as compared to that in normal soils, respectively. This may be as a result of suspended organic material added to the soil through sewage, which serves as a source of energy for the micro-organisms (Joshi and Yadav, 2005; Seaker and Sopper, 1988).

Chen *et al.* (2008) reported that soil enzymes, including those related to the C, N, P and S cycles and two oxidoreductases (catalase and dehydrogenase), were examined in soils obtained from five long-term reclaimed wastewater irrigation sites in southern California. The soil enzyme activities were observed to vary significantly among the sampling sites. In comparison with their respective controls, the overall activities of enzymes involved in the cycling of the four elements in soil were enhanced by an average of 2.2 to 3.1 fold.

Kharche *et al*. (2011) opined that the microbial count in sewage-irrigated soils was higher for bacteria, fungi and actinomycetes at about 1.34, 1.52 and 1.18 (for 0-30 cm) and 1.66, 1.55 and 1.14 (for 30-60 cm) times more when compared to that in the normal soils, respectively.

Muamar *et al.* (2014**)** observed that the microbiological counts were higher in all samples irrigated by waste water with an average of 4.6 x 10^7, 1.3 x 10^5, 1.2 x 10^3, 2.9 x 10^5, 2.5 x 10^4 and 6.4 x 10^3, for total aerobic plate counts, total coliforms, fecal coliforms, *Staphylococcus aureus*, yeast and mould counts, respectively. Furthermore, *Salmonella*, *Shigella* and *Clostridium* bacteria were also detected in all tested samples.

Salakinkop and Hunshal, (2014) conducted a field experiment in Dharwad, Karnataka State of India on the bank domestic sewage course using a split-plot design with three replications. The results revealed that sewage irrigated land recorded significantly more bacterial and fungal colonies, dehydrogenase and alkaline phosphatase enzymes activities. Sources of irrigation also varied significantly producing the highest microbial colonies, phosphatase and dehydrogenase enzymes activity in sewage water irrigation treatment, followed by alternate irrigation as sewage water is a rich source of organic phosphorus (11.9–17.3 ppm).

According to Lal *et al*. (2015) continuous application of sewage water improves soil microbial biomass carbon. Activities of dehydrogenase, urease and phosphatase enzymes also improved substantially with the use of sewage water. A large amount of nitrate-N was retained in the surface 0.3 m soil with minimal leaching under agro-forestry system. The overall results indicated improvement in the awareness of the growers for adjusting NP doses and non-dependent on water-guzzling crops like paddy to minimize the cost of fertilizer and groundwater contamination.

Minhas *et al*. (2015) reported that soil microbial biomass carbon and activities of dehydrogenase, urease and phosphatase improved substantially with sewage water irrigation.

The work of Charlton *et al.* (2016) revealed a significant decrease in microbial biomass carbon population in the soils where the total concentrations of Zn and Cu fall below the current United Kingdom statutory limits. The effect of Zn appeared to increase over time, with observed increasingly greater decreases in microbial biomass carbon over a period. This was attributed to interactive effect between Zn and confounding Cu contamination, which had augmented the bioavailability of these metals over time. Similar decreases (7.12%) were noticeable in soils receiving sewage sludge predominantly contaminated with Cu; though, MBC appeared to show signs of recovery after six years period.

The study conducted by Jogan *et al*. (2019) reported that urease, phosphatase and dehydrogenase activities were highest in spent wash treatment in red soil followed by paper mill wastewater in all soils. The activity of urease, phosphatase and dehydrogenase was recorded highest at the surface layer and their activity gradually decreased with increasing soil depths under different treatments.

Ankush *et al.* (2020) reported that changes in soil chemical and microbiological properties are caused by the addition of sewage sludge along with saline irrigation under a pearl millet-wheat crop rotation. Three irrigation systems were adopted; canal water (0.35 dS m^{-1}), 8 and 10 dSm-1 electrical conductivity saline water and five fertilizer treatments (control-F_1, sewage sludge (5 t ha^{-1})-F_2, sewage sludge (5 t ha^{-1}) +50% recommended dose of fertilizer (RDF)-F_3, sewage sludge (5 t ha^{-1})+75% RDF-F_4 and RDF-F_5). The results indicated that soil organic carbon, available nitrogen and phosphorus reduced significantly under saline conditions. However, there was an increase in available potassium with increased salinity levels of the irrigation water. A significant reduction in soil microbial biomass carbon and enzyme activities was caused by 8 and 10 dSm-1 as compared to 0.35 dSm-1 at different growth stages of crops. Treatment F_4 recorded the highest soil microbial activity at each stage by a significant margin among all fertilizer treatments, which is associated with a substantial build-up of organic carbon and available NPK in the soil.

2.4 Effect of sewage water on yield and nutrient uptake of crop

Aljaloud (2010) asserts that the use of treated waste water in irrigation provided plants with sufficient levels of nutrients, such as nitrogen, phosphorus and potassium as well as other micro-nutrients. The use of treated waste water in crop irrigation saved 45 per-cent and 94 per-cent cost of the fertilization for wheat and alfalfa, respectively, while yield increased by 11 per-cent and 23 per cent for wheat and alfalfa, respectively. The concentration of heavy metals such as Copper, Lead and Cobalt in plant tissue was low in comparison to established standards and these heavy metal concentrations are well below hazardous levels.

The investigation of Nauman and Khalid, (2010) revealed that the quality of waste water samples collected from different locations of Rawalpindi is not good for irrigation and long term usage of these wastes for crop production may cause the accumulation of some toxic metals in soils above critical limits which is injurious for soil health and may lead to elevated levels of heavy metals in crop plants.

Singh *et al*. (2010) reported that continuous application of waste water for more than 20 years has led to accumulation of heavy metals in the soil. Subsequently, the concentrations of Cd, Pb and Ni had crossed the safe limits for human consumption in all the vegetables. The per-cent contribution of fruit-vegetables to daily human intake for Cu, Ni, Pb and Cr was observed higher than that of leafy vegetables, while the reverse was the case for Cd and Zn. Target hazard quotient indicated health risk to the local population related to Cd, Pb and Ni contamination of vegetables.

Begum *et al*. (2011) studied the effects of industrial waste water on the yield, nutrient content and uptake of Boro rice using six treatments: T1: uncontaminated field + fresh water, T2: uncontaminated field + mixed water, T3: uncontaminated field + contaminated water for non-contaminated field, and T4: effluent contaminatedfield + fresh water, T5: effluent contaminated field + mixed water, T6: effluent contaminated field + contaminated water for contaminated field. Among the treatments, uncontaminated field + fresh water (T1) showed the best positive effect on rice. The N, P, K and S contents and uptake were higher in T1, but Zn, Mn, Fe, Cu and Pb were higher in T6 treatment. The treatment T1 showcases the highest grain yield (5.23 t/ha in 1999 and 5.40 t/ha in 2000), followed by mixed water (4.19 t/ha in 1999 and 4.24 t/ha in 2000) in both the growing seasons.

The work of Kharche *et al*. (2011) reported that the mean concentration of Fe, Mn, Zn, Cu, Cd, Cr and Ni in cabbage grown on sewage irrigated soils was about 1.11, 7.51, 1.72, 7.66, 4.36, 1.26 and 1.91 times more than their content in well-irrigated soils, respectively. This portrayed that the continued increase of these elements in the soil would be reflected in plant parts, though the effect would depend on the element type and plant part. A better alternative would be to remove the undesirable elements or reduce their concentration to within safe limits before using the sewage water for irrigation.

Akbari *et al*. (2012) conducted a study of heavy metals accumulation and nutritional value of beans in Tehran’s south. The use of Talebabad’s sewage increased heavy metals assembling in different parts of bean, especially in root compared to the sewages of Salehabad and Dehkheir. Heavy metals accumulation in bean’s root and leaves were almost high, but high control of bean’s pod and seed caused lower quantities of transported heavy metals ratio to grain than root and leaves.

The concentrations of metals in wheat grains showed a decreasing trend as Zn>Fe>Mn>Cu>Pb>Cd>Ni>Cr in samples assembled from areas irrigated with municipal wastewater as reported by Hassan *et al*. (2013). Concentration of Cr, Ni and Fe metals in grains was found beyond recommended dietary limits.

Khan *et al*. (2014) found that sewage water contamination levels in soil with metals like chromium (Cr), manganese (Mn), iron (Fe), molybdenum (Mo), lead (Pb) and cadmium (Cd) and their subsequent accumulation in *Abelmoschus esculentus* (Lady finger) at two sites in the vicinity of District Sargodha, Pakistan. Cr, Mn, Fe, Mo, Pb and Cd concentrations in soil were 0.35, 21.14, 26.63, 10.40, 22.18 and 12.97 mg/kg at site-I, and 0.23, 21.18, 26.40, 10.15, 20.28 and 14.48 mg/kg at site-II, respectively. Except for Cd, the metal concentration at site-I was higher than at site-II. The contamination level in vegetables (Lady Finger) was higher at the two sites than in the soil. Heavy metal levels in the vegetable (mg/kg dry wt.) were 14.50 for Cr, 54.79 for Mn, 45.24 for Fe, 13.47 for Mo, 1.72 for Pb and 0.24 for Cd at site-I, and 12.26 for Cr, 47.15 for Mn, 49.95 for Fe, 8.92 for Mo, 1.68 for Pb and 0.19 for Cd at site-II.

Cadmium (Cd) contents in plant samples of Palak, Amaranthus, Spinach, Coriander, Green chillies, and Paragrass under sewage irrigated conditions were 2.08, 2.61, 2.28, 0.93, 2.11 and 1.80 mg kg^{-1}, respectively, according to Rani *et al*. (2018). The equivalent values for ground water irrigation, on the other hand, were 1.31, 1.53, 1.06, 0.53, 1.34 and 1.22 mg kg^{-1}, which were significantly lower.

Salakinkop and Hunshal, (2014) found that crop growth in terms of photosynthesis, net assimilation rate and dry matter production is significantly higher in sewage irrigated soil in comparison to bore well-irrigated land. Similarly, significantly higher wheat grain yield (4370 kg ha^{-1}), dry gluten (9.22 %) and protein (12.88 %) were obtained in fields irrigated with sewage water compared to soil irrigated with bore well. Enhanced activity of phosphatase and dehydrogenase enzymes and organic carbon in soil irrigated with sewage water contributed more too available nutrient pool of soil. Pooled results of 2 years revealed that wheat roots accumulated a significantly higher amount of Cr, Ni, Pb and Cd in sewage-irrigated soil compared to bore well-irrigated land. The same trend was noticed in stem concerning Cr and Ni. In general, the concentration of heavy metals was higher in root followed by stem and lower in grain.

In Dharwad, Karnataka State, India, Salakinkop and Hunshal, (2014) conducted a field experiment. They discovered that sewage land had considerably better soil physical qualities, particularly bulk density and moisture retention ability than bore well irrigated land. These soil parameters were found to be positively linked with wheat crop yield. The pH of sewage land (7.24) was lower than bore well-irrigated land (7.65). When compared to bore well water irrigation, sewage water irrigation improved wheat crop performance, as shown by higher grain production (4100 kg ha^{-1}), protein content in grains (12.8%) and dry gluten (8.9%). Domestic sewage effluent was characterised and shown to be a viable supply of irrigation water and nutrients for top dressing.

Wheat was planted with irrigation (ground water and sewage effluent) and fertilizer treatments, while soybeans were produced without any treatments, according to Saha *et al*. (2016). The aboveground biomass recovered significantly more nitrogen (N), phosphorous (P) and potassium (K) from SE than fertilizers or manures. Wheat grain recovered the most nutrients from SE, followed by soybean straw for P and K. Straw biomass from both crops collected roughly 31% N, 22% P and 69% K from SE, which can be recycled back into agricultural land that is irrigated with groundwater (GW) or rain-fed.

Balkhair *et al*. (2016) monitored the concentrations of Ni, Pb, Cd and Cr in the edible portions of okra and found them above the safe limit in 90%, 28%, 83% and 63% of the samples, respectively. The heavy metals in the edible portions were as follows: Cr> Zn> Ni >Cd >Mn > Pb> Cu>Fe.

Heavy metal pollution of waste water is a severe concern, according to Singh *et al*. (2017) because of its toxicity and persistence in the ecosystem. Irrigation with waste water commonly increases heavy metal concentrations in soils. Cr, Mn, Cu, Ni, Zn, Cd, Pb and Fe had mean concentrations of 7.75, 0.41, 0.34, 0.29, 1.16, 0.04, 0.85 and 7.54 ppm in sewage waste, respectively. Heavy metal concentrations in spinach, potato, radish, cabbage and cauliflower were quite high and above acceptable limits.

Safana *et al*. (2018) studied the irrigation water of Ginzo waste channel in Katsina. The results indicated that mean levels of heavy metals in lettuce were; Cadmium (ND), Chromium (0.09 mg/kg), Iron (2.36 mg/kg), Lead (0.12 mg/kg) and Zinc (0.16 mg/kg); those of Cabbage were Cadmium (ND), Chromium (0.06 mg/kg), Iron (3.1 mg/kg), Lead (0.09 mg/kg) and Zinc (0.07 mg/kg). Cadmium was absent, Chromium (0.16 mg/kg), Iron (0.77 mg/kg), Lead (0.07 mg/kg) and Zinc (0.07 mg/kg), respectively.

Singh *et al*. (2019) investigated the effect of continuous irrigation of sewage and industrial wastes on soil physical properties, nutrients uptake by plants in the adjoining areas of Faridabad district of Haryana. The organic matter content of sewage and industrial wastes was found to be high and its addition to agricultural soils frequently improved soil physical properties. The uptake of primary nutrients (N, P and K), micronutrients (Fe, Zn, Mn and Cu) and heavy metals (Pb, Cd, Cr and Ni) in fodder plants (berseem) and vegetable plants (tomato) grown irrigated with sewage and industrial wastes were higher as compared to cereal crops, and then tubewell water irrigation plants.

Ugulu *et al*. (2021) investigated the potentially toxic metal accumulation in the wheat variety Galaxy-2013 following various industrial wastewater irrigation treatments. The concentrations of the potentially toxic metals Co, Cd, Cr, Cu and Fe in the harvested wheat samples ranged from 0.720 to 1.075, from 0.316 to 0.526, from 0.111 to 0.950, from 0.603 to 0.665 and from 1.617 to 1.884 mg/kg, respectively. These concentrations were higher than the safe levels recommended by WHO, FAO, and US EPA, except for Cd.

Conclusion

The exploration of sewage water for irrigation in agriculture unveils a nuanced landscape of advantages and drawbacks. On one hand, sewage water emerges as a potential boon for soil fertility enhancement, owing to its abundant reserves of micronutrients, nitrogen, phosphorus, and potassium. These components serve as natural fertilizers, fostering improved soil properties and potentially boosting crop yields. Moreover, studies such as the comprehensive investigation conducted by Bertanza et al. (2024) provide valuable insights into protocols for characterizing sewage sludge, offering a pathway to assess its suitability for agricultural application. The integration of sewage water into alternative irrigation methods or its blending with groundwater resources holds promise as a pragmatic solution. Typically, the electrical conductivity (EC) of sewage water remains within acceptable thresholds, minimizing the risk of soil salinity issues. This approach not only addresses water scarcity concerns but also optimizes resource utilization in agricultural settings. However, amidst the promise lies a pertinent concern regarding the long-term implications of sewage water irrigation. Continuous application of sewage water may trigger the accumulation of hazardous heavy metals in the soil and subsequent uptake by plants. This accumulation poses potential health hazards to consumers, highlighting the imperative for rigorous monitoring and management strategies. The differential accumulation of heavy metals in various crops further underscores the need for tailored approaches in agricultural practices. Leafy vegetables, in particular, exhibit a heightened propensity for heavy metal uptake, necessitating vigilant management protocols to safeguard consumer health. In light of these findings, a proactive stance towards sewage water management in agriculture is imperative. Pretreatment measures and ongoing quality assessment protocols are indispensable to mitigate risks and ensure the sustainable utilization of sewage water resources. Ultimately, a multidisciplinary approach encompassing scientific research, policy formulation, and stakeholder engagement is essential to navigate the complex terrain of sewage water utilization in agriculture while safeguarding environmental and human well-being.

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