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

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 increasing global population, urbanization, and industrialization have led to heightened wastewater generation, challenging sustainable water management. This surge is evident from the continuous rise in the world population from approximately 5.3 billion in 1992 to about 7.4 billion in 2016, with projections exceeding 8 billion by 2030 and 9 billion by 2050 (World Population Data Sheet, 2016; Li et al., 2011). With water consumption escalating due to rapid population growth, wastewater and sewage sludge production have also increased substantially. In response to diminishing freshwater resources, utilizing sewage water for crop production has gained traction as a potential solution to address water scarcity and improve agricultural sustainability. However, this approach poses concerns regarding its impact on soil physical and biological properties, necessitating a thorough exploration of the implications. Agriculture, being the largest user of water resources globally, draws approximately 92% of total water withdrawals in arid and semi-arid regions (FAO, 2013; Forouzani et al., 2013). Given the imperative to enhance water usage efficiency and explore alternative resources in such environments, the application of treated wastewater emerges as a viable strategy to alleviate water scarcity while preserving freshwater reserves (Garrone et al., 2018).

Treated sewage water, enriched with essential nutrients like nitrogen, phosphorus, and potassium, as well as organic matter, micronutrients, and beneficial microbial communities, offers a potential substitute for conventional irrigation water and chemical fertilizers. However, concerns arise regarding the introduction of contaminants such as heavy metals, pathogens, and organic pollutants, which could compromise soil fertility and ecosystem health over time. Furthermore, long-term irrigation with sewage water may alter soil physical properties, including structure, texture, and hydraulic conductivity, thereby affecting water infiltration, root growth, and overall crop productivity. Understanding the intricate interactions between sewage water application, soil properties, and crop responses is pivotal for devising effective management strategies that optimize agricultural productivity while safeguarding environmental and human health. Synthesizing existing literature on sewage water use in crop production, particularly its effects on soil physical and biological properties, is essential for informing policymakers, researchers, and agricultural practitioners about its sustainable utilization and implications across diverse agroecosystems. This approach not only reduces stress on freshwater resources, primarily utilized for human and industrial purposes but also addresses waste disposal concerns (Hajjami et al., 2012; Cheftez et al., 2006). Peri-urban farmers perceive wastewater as a valuable, cost-free water source rich in fertilizers (Tamrabet, 2011).

However, the utilization of treated wastewater may have varying effects, impacting crops (Yadav et al., 2002) and altering the physical and chemical properties of soils (Tarchouna et al., 2010; Mamedov et al., 2000). Changes in soil characteristics resulting from irrigation with treated wastewater may affect its hydrodynamic properties (Tarchitzky et al., 1999). Quality of irrigation water, as posited by Shainberg and Oster (1978), influences soil properties, crop yield, and water management in agricultural activities. Studies have shown improvements in the physiochemical characteristics of soil following sewage water irrigation (Antil, 2012). Domestic wastewater, containing essential plant nutrients such as nitrogen, phosphorus, potassium, and micronutrients, positively influences plant growth (Kiran et al., 2012; Agrawal et al., 2014). Evaluation of soil parameters post domestic wastewater discharge indicates an increase in soil pH, electrical conductivity, organic matter content, major elements (nitrogen, phosphorus, potassium, sodium, chloride, and magnesium), salts, and heavy metals such as manganese, zinc, and iron compared to well water irrigation (Bedbabis et al., 2015). Therefore, ongoing research discusses the components of sewage and industrial effluents in India and their potential impact on soil and plant health

Table -1: Toxic effects of Metals/Metalloids in different Plant systems

| Plant System | Metal/Metalloid | Toxic Effects |
|---|---|---|

| | | |
|---|---|---|
| Root System | Lead (Pb) | Inhibition of root elongation, reduced nutrient uptake |
| | Cadmium (Cd) | Reduced root growth, damage to root structure |
| | Arsenic (As) | Inhibition of root growth, oxidative stress |
| | Mercury (Hg) | Inhibition of root growth, disruption of nutrient uptake |
| Shoot System | Lead (Pb) | Reduced shoot biomass, chlorosis |
| | Cadmium (Cd) | Chlorosis, necrosis, reduced photosynthesis |
| | Arsenic (As) | Leaf wilting, chlorosis, reduced photosynthesis |
| | Mercury (Hg) | Stunted growth, chlorosis, reduced leaf area |
| Physiological System | Lead (Pb) | Disruption of photosynthesis, enzyme inhibition |
| | Cadmium (Cd) | Oxidative stress, disruption of water balance |
| | Arsenic (As) | Interference with mineral nutrient uptake, oxidative stress |
| | Mercury (Hg) | Disruption of water balance, inhibition of enzyme activity |

## 2. Review of Literature

The escalating industrialization and urbanization of societies have underscored the critical role of sewer systems as pivotal components for efficient wastewater disposal. Sewage water, laden with essential macro and micro-nutrients, holds promise for enhancing soil fertility. In agricultural practices, the quality of irrigation water significantly influences soil characteristics, which, in turn, impact crop yield. However, the presence of ubiquitous metals and metalloids in sewage water can exert both beneficial and detrimental effects on living organisms, particularly plants. While essential metals (such as iron, zinc, and copper) play pivotal roles in various physiological processes, excessive concentrations of non-essential metals and metalloids can lead to toxicity, impairing plant growth and development. Understanding the toxic effects of these elements on different plant systems—root structures, aerial shoots, and overall plant physiology—is paramount for mitigating environmental contamination and ensuring food safety. This comprehensive review aims to elucidate the diverse mechanisms by which metals and metalloids elicit toxicity in plants across various physiological systems, including roots, shoots, and overall plant physiology (Table 1). Raw sewage water is purportedly rich in organic matter and essential nutrients. Urban wastewater primarily consists of approximately

99% water, with moderately low concentrations of suspended and dissolved organic and inorganic solids. However, in cases where industrial waste is discharged into sewer systems, city sewage water may contain elevated levels of toxic metals. The composition of sewage can vary temporally (hourly, daily, seasonally) based on the intensity and nature of local activities, as well as the methods of collection and treatment procedures in place.

### 2.1 Chemical composition of sewage water

Studies by Maheshwari et al. (2008) revealed the presence of Cd, Cr, Pb, and Ni in industrial waste, sludge, and sewage samples from Karnal, Panipat, and Sonepat. Soluble heavy metal concentrations 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). Total heavy metal concentrations varied for 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). Similarly, Dash et al. (2009) characterized 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 NH4-N, NO3-N, PO4, 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. However, 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. Yadav et al. (2013) assessed the levels of different heavy metals (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 as follows: Fe: 0.249 - 0.257, Zn: 0.049 - 0.056, Cd: 0.028 - 0.036, Cu: 0.015 - 0.019 . These levels were generally lower than the recommended maximum tolerable levels proposed by the joint FAO/WHO Expert Committee on food additives (2007), except for Cd and Fe, which exhibited higher content.

**Table 2: Tolerance limits of heavy metals in plants and its physiological impacts**

| **Heavy Metal** | **Tolerance Limit (mg/kg)** | **Plant Impact** |
|---|---|---|

| | | |
|---|---|---|
| **Cadmium (Cd)** | 1.5 - 3 | Inhibits photosynthesis and water absorption |
| **Chromium (Cr)** | 5 - 10 | Affects root growth and enzyme activity |
| **Copper (Cu)** | 20 - 30 | Essential in small amounts, toxic in excess |
| **Nickel (Ni)** | 15 - 20 | Affects seed germination and leaf growth |
| **Lead (Pb)** | 5 - 10 | Causes oxidative stress and damages cell membranes |
| **Zinc (Zn)** | 50 - 100 | Essential for plant growth, toxic at high concentrations |
| **Mercury (Hg)** | 0.1 - 0.5 | Impairs root and shoot growth |

**Table 3: Average concentration of heavy metals and their potential effect on human system**.

| **Heavy Metal** | **Average Concentration** | **Potential Effects** |
|---|---|---|
| **Cadmium (Cd)** | 1-10 mg/kg | Kidney damage, skeletal damage |
| **Chromium (Cr)** | 10-50 mg/kg | Skin irritation, lung cancer |
| **Copper (Cu)** | 100-500 mg/kg | Liver damage, gastrointestinal distress |
| **Nickel (Ni)** | 10-100 mg/kg | Allergic reactions, lung and nasal cancer |
| **Lead (Pb)** | 10-100 mg/kg | Neurological disorders, developmental delays |
| **Zinc (Zn)** | 300-1000 mg/kg | Nausea, immune system dysfunction |
| **Mercury (Hg)** | 0.1-1 mg/kg | Neurological |

|  |  |  |
|---|---|---|
|  |  | damage, cognitive impairments |

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

The utilization of sewage water as a supplementary water resource for irrigation is increasingly accepted, particularly in arid and semiarid zones. Sewage materials serve as valuable sources of plant nutrients and have been found to influence soil physical properties, including bulk density, aeration, water holding capacity, aggregate stability, and chemical composition. However, uncontrolled sewage water use for irrigation can lead to the accumulation of potentially toxic metals in soil, which may significantly affect its physico-chemical properties. Rana et al. (2010) conducted a long-term investigation on the effects of sewage water irrigation on soil properties and heavy metal concentrations in Rohtak district, Haryana. Their results indicated that sewage waste remained within acceptable limits for use as irrigation water. Soil analysis revealed elevated organic carbon, phosphorus, calcium, and magnesium content in sewage-irrigated soils compared to tubewell-irrigated soils. The soil pH decreased by 0.38 units due to sewage water irrigation. Over 35 years of continuous untreated sewage effluent application resulted in significant nutrient and heavy metal accumulation in soils. Organic carbon content positively correlated with all heavy metals except Zn, while pH negatively correlated with all metals except Mn. Electrical conductivity also positively correlated with all the metals.

Singh et al. (2010) conducted a study in Varanasi city, where wastewater from the Dinapur sewage treatment plant was used for irrigating vegetable plots. The wastewater used for irrigation had the highest concentration of Zn, followed by Pb, Cr, Ni, Cu, and Cd. Continuous wastewater application for over 20 years led to heavy metal accumulation in the soil. Consequently, the concentrations of Cd, Pb, and Ni exceeded safe limits for human consumption in all the vegetables. Rai et al. (2011) investigated the effect of sewage water and canal water irrigation on soil properties. The mean values of different physico-chemical parameters were as follows: bulk density (g/cm³) - 1.26, water holding capacity (%) - 53.60, temperature (ºC) - 16.33, electrical conductivity (dS/m) - 0.122, pH - 7.5, organic carbon (%) - 1.95, available phosphorus (mg/kg) - 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. Singh and Agrawal (2012) investigated the effects of wastewater irrigation on soil properties and heavy metal concentrations. Their findings revealed several important points. First, sites receiving wastewater 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 Ca2+) also increased significantly at wastewater-irrigated sites. Additionally, wastewater used for irrigation led to beneficial changes in physico-chemical and biological properties of the soil. However, the level of heavy metals in the soil increased, causing soil contamination. The use of sewage water as a supplementary resource for irrigation is increasingly accepted, especially in arid and semiarid regions. Sewage materials provide valuable plant nutrients and influence soil physical properties. However, uncontrolled sewage water use can lead to toxic metal accumulation in soil, affecting its physico-chemical properties. Long-term sewage water irrigation in Rohtak district, Haryana, resulted in elevated organic carbon, phosphorus, calcium, and magnesium content.

Al-Jaboobi et al. (2014) reported that soil pH ranged from 7.89 to 7.55 in soil irrigated with wastewater, which was lower than the pH range of 8.27 to 8.08 in groundwater-irrigated soil. Furthermore, there was an increase in electrical conductivity (EC) from 893 to 943 µS/cm in soil irrigated with wastewater, whereas the average EC value in soil irrigated with groundwater varied from 600 to 705 µS/cm, with a mean of 657 µS/cm. The higher organic matter content observed in wastewater-irrigated soil (2.00%) compared to groundwater-irrigated soil (0.74%) indicated the presence of organic matter compounds in wastewater. Additionally, phosphorus levels were significantly higher in soil irrigated with wastewater (27.33 ppm) compared to groundwater-irrigated soil (6.22 mg L-1). Total nitrogen content in sewage-irrigated soil was significantly higher (40.33 mg kg-1) than in groundwater-irrigated soil (16 mg kg-1). Potassium levels were also elevated in soils irrigated with sewage water (519 ppm) compared to groundwater-irrigated soils (115 ppm). According to Antil (2014), continuous use of sewage and industrial wastewater irrigation resulted in improved water retention, hydraulic conductivity, organic carbon content, and the build-up of available nutrients (N, P, K) and soil microbial count. The increase due to sewage irrigation remained within tolerance limits, thus avoiding soil salinity hazards. However, heavy metals such as Cd, Cr, Pb, and Ni were found to be higher in both soil and plants due to long-term sewage and industrial wastewater usage. Leafy vegetables exhibited higher metal concentrations than grain crops, highlighting potential hazards to soil-plant health. Pre-treatment is necessary to safely utilize sewage water as a cost-effective alternative source of plant nutrients in agriculture. Muamar et al. (2014) assessed soil quality when irrigated with sewer water. The pH of soil irrigated with groundwater decreased from 8.16 to 7.70 when irrigated with sewer water. Sewer water-irrigated soil had higher organic matter content (2.00%) compared to groundwater-irrigated soil (0.74%). Subramani et al. (2014) reported that the application of sewage water resulted in the buildup of heavy metals in surface soil. The mean contents of total Cd, Cr, and Pb in 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 long-term application of domestic sewage water on soil physical, chemical, and biological properties. They found that sewage water improved soil physical properties, including decreased bulk density and dispersion index, and increased aggregate stability and water holding capacity compared to un-irrigated soil. Despite an electrical conductivity (EC) of 1.0 dS/m due to sewage water irrigation, the EC of soils remained low (0.20–0.45 dS/m). Available Zn, Fe, Cu, and B increased slightly, except for Mn, which showed considerable increase. Organic carbon, available N, P, K, and S exhibited a decreasing trend with increasing distance from the stream course. Najam and Kaur (2016) observed that sewage water improved the physicochemical properties of soil compared to groundwater application, leading to increased crop yield and improved soil fertility. Gurjar et al. (2017) asserted that soil irrigated with sewage water exhibited higher bulk density (BD), particle density (PD), porosity, and water holding capacity compared to groundwater-irrigated soil. The pH of sewage-irrigated soil (7.49) was lower than groundwater-irrigated soil (8.31), and organic carbon content increased. Irandoust and Tabriz (2017) explored low-quality irrigation methods, including wastewater, as practical solutions. Wastewater served as a rich source of minerals and organic matter, contributing to fertile soil. Their results indicated decreased acidity, salinity, phosphorus, nitrogen, and heavy metal concentrations in soil irrigated with wastewater compared to well water-irrigated soil.

Rani et al. (2018) conducted a study in the Musi river basin, Hyderabad, Andhra Pradesh. Their results indicated that the pH of surface and sub-surface soils irrigated with sewage and groundwater was relatively higher compared to the control (no irrigation). Additionally, organic carbon content in surface and sub-surface soils treated with sewage water was higher compared to groundwater-irrigated soils and the control. Surface soils generally contained relatively higher amounts of organic carbon than sub-surface soils. The available concentrations of nitrogen (N), phosphorus (P), and potassium (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 soil depth. Haroon et al. (2019) reported that wastewater irrigation led to increased soil pH. The pH of wastewater-irrigated fields ranged from 7.6 to 8.7, while rainfed fields had pH values ranging from 6.4 to 7.1. Soil electrical conductivity (EC) ranged from 554 to 728 μS m–1 in wastewater-irrigated fields, whereas non-irrigated fields had EC values ranging from 182 to 368 μS m–1. Elevated EC values indicated that industrial wastewater irrigation could lead to salt accumulation in soils. Total carbon content ranged between 2.2% and 4.2% in wastewater-irrigated fields, while non-irrigated fields had lower carbon contents (1.2–2.1%)

### 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.

Wastewater irrigation is increasingly accepted, especially in arid regions, as it provides valuable plant nutrients. However, uncontrolled use can lead to toxic metal accumulation in soil, affecting its physico-chemical properties. Long-term sewage water irrigation in Rohtak district, Haryana, resulted in elevated organic carbon, phosphorus, calcium, and magnesium content. Similarly, Kharche et al. (2011) found heavy metal accumulation in surface soil due to long-term sewage water application. The concentration of heavy metals in cabbage grown on sewage-irrigated soil exceeded tolerance levels. Pathak et al. (2011) observed higher heavy metal concentrations in wastewater-treated soils compared to control. Rai et al. (2011) studied sewage and canal water irrigation effects on soil, with moderate enrichment in Pb, Zn, Cu, and Cd. Singh et al. (2010) reported heavy metal accumulation in soil due to continuous wastewater application, exceeding safe limits for human consumption in vegetables. Roy et al. (2013) investigated sewage sludge application along with inorganic fertilizers. They found that sewage sludge led to the accumulation of micronutrients (Fe, Zn, Mn, Cu) and also increased Pb levels, emphasizing the need for safe sewage sludge utilization. Rani et al. (2015) studied the Musi river basin in Hyderabad, Andhra Pradesh. Concentrations of Cu, Fe, Mn, and Zn extracted using DTPA extractant 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. Surface soils had higher DTPA-extractable micronutrient cations and heavy metals compared to sub-surface soils.

Ebrahim et al. (2016) examined long-term sewage irrigation effects on heavy metal absorption and accumulation in alfalfa crop and soil in Bahrain. Heavy metal concentrations in treated sewage wastes did not exceed international standards, except for Cd. No significant differences were observed between soil depths, except for Zn and Cd. Singh et al. (2017) reported heavy metal accumulation in surface soil due to sewage and industrial effluent application. Micronutrients and heavy metals (Fe, Zn, Mn, Cu, Pb, Cd, Cr, Ni) were significantly higher in soils irrigated with sewage and industrial effluents compared to tube-w well water.

**Table 4. Effect of heavy metals on Physico-chemical and biological properties of soil.**

| Heavy Metal | Physico-Chemical Effect | Biological Effect |
|---|---|---|
| **Lead (Pb)** | Decreased soil porosity and increased compaction | Reduced microbial activity and plant growth |
| **Cadmium (Cd)** | Lowered soil pH and increased acidity | Inhibition of enzyme activities in plants |
| **Chromium (Cr)** | Altered soil structure and reduced cation exchange capacity | Negative impact on soil microorganisms |
| **Copper (Cu)** | Affected organic matter decomposition rates | Toxicity to earthworms and other soil fauna |
| **Zinc (Zn)** | Increased soil salinity and electrical conductivity | Disruption of nitrogen fixation by bacteria |
| **Mercury (Hg)** | Diminished water holding capacity | Impairment of root development and microbial diversity |
| **Nickel (Ni)** | Interference with nutrient uptake | Adverse effects on soil enzyme activities |

### 2.3 Effect of sewage water on biological properties of soil

In sewage-irrigated soils, microbial counts for bacteria, fungi, and actinomycetes were significantly higher (approximately 1.34, 1.52, and 1.18 times, respectively, for the 0-30 cm depth) compared to normal soils. This increase may be attributed to the suspended organic material introduced through sewage, serving as an energy source for microorganisms (Joshi and Yadav, 2005; Seaker and Sopper, 1988). Chen et al. (2008) investigated soil enzymes related to carbon ©, nitrogen (N), phosphorus (P), sulfur (S) cycles, and oxidoreductases (catalase and dehydrogenase) in soils from long-term reclaimed wastewater irrigation sites in southern California.

Enzyme activities varied significantly among sampling sites, with an overall enhancement (average of 2.2 to 3.1 fold) compared to respective controls. Kharche et al. (2011) also observed increased microbial counts (bacteria, fungi, and actinomycetes) in sewage-irrigated soils, particularly at depths of 0-30 cm and 30-60 cm. Muamar et al. (2014) found higher microbiological counts in waste water-irrigated samples, including total aerobic plate counts, total coliforms, fecal coliforms, Staphylococcus aureus, yeast, and mold counts. Additionally, Salmonella, Shigella, and Clostridium bacteria were detected in all tested samples. Salakinkop and Hunshal (2014) conducted a field experiment in Dharwad, Karnataka, India, using sewage-irrigated land. Bacterial and fungal colonies, as well as dehydrogenase and alkaline phosphatase enzyme activities, were significantly higher in sewage water-irrigated plots. Lal et al. (2015) found that continuous sewage water application improved soil microbial biomass carbon and enzyme activities (dehydrogenase, urease, and phosphatase). Nitrate-N retention was observed in the surface soil under agro-forestry systems. Minhas et al. (2015) also reported positive effects of sewage water irrigation on soil microbial biomass carbon. Charlton et al. (2016) observed decreased microbial biomass carbon in soils with low Zn and Cu concentrations, attributed to their interactive effects over time. Jogan et al. (2019) found highest urease, phosphatase, and dehydrogenase activities in spent wash-treated red soil. Ankush et al. (2020) studied the impact of sewage sludge addition under saline irrigation. Soil organic carbon, available nitrogen, and phosphorus decreased under saline conditions, while available potassium increased. Soil microbial biomass carbon and enzyme activities were significantly reduced at higher salinity levels, but treatment F4 showed the highest microbial activity due to organic carbon and NPK buildup.

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

Aljaloud (2010) highlights that treated wastewater used for irrigation provides essential nutrients (nitrogen, phosphorus, potassium, and micro-nutrients) to plants. It significantly reduces fertilization costs (45% for wheat, 94% for alfalfa) while increasing yields (11% for wheat, 23% for alfalfa). Heavy metal concentrations (Copper, Lead, Cobalt) in plant tissue remain below hazardous levels compared to established standards. However, Nauman and Khalid (2010) caution against using wastewater samples from Rawalpindi for irrigation due to potential toxic metal accumulation in soils. Singh et al. (2010) report heavy metal accumulation in soil after continuous wastewater application, exceeding safe limits for human consumption in vegetables. Begum et al. (2011) studied industrial wastewater effects on Boro rice, with uncontaminated field + fresh water showing the best yield and nutrient uptake

Kharche et al. (2011) reported that cabbage grown on sewage-irrigated soils exhibited significantly higher mean concentrations of Fe, Mn, Zn, Cu, Cd, Cr, and Ni compared to well-irrigated soils. These elevated levels in soil were reflected in plant parts, with the extent of accumulation varying based on the element type and plant part. To mitigate risks, it is advisable to remove undesirable elements or reduce their concentration before using sewage water for irrigation. Akbari et al. (2012) found that Talebabad’s sewage increased heavy metal accumulation in beans, especially in roots, compared to other sewage sources. Although bean pods and seeds had lower heavy metal quantities than roots and leaves, careful monitoring is essential. Hassan et al. (2013) observed a decreasing trend in metal concentrations (Zn > Fe > Mn > Cu > Pb > Cd > Ni > Cr) in wheat grains irrigated with municipal wastewater, but some metals exceeded recommended dietary limits. Khan et al. (2014) investigated sewage water contamination in soil near District Sargodha, Pakistan, revealing varying metal concentrations. Lady Finger (*Abelmoschus esculentus*) grown in these soils also exhibited elevated heavy metal levels. Rani et al. (2018) assessed Cd content in various plant samples under sewage-irrigated conditions, while groundwater irrigation resulted in significantly lower Cd levels. Salakinkop and Hunshal (2014) found that crop growth was significantly higher in sewage-irrigated soil, with wheat grain yield, gluten, and protein content superior. However, heavy metal accumulation was higher in roots and stems than in grains. Additionally, in Dharwad, Karnataka State, India, Salakinkop and Hunshal (2014) conducted a field experiment and found that sewage-irrigated land exhibited better soil physical qualities, particularly bulk density and moisture retention ability, compared to bore well-irrigated land. These soil parameters contribute to sustainable agriculture practices

**Table 5: Yield impact of sewage water on different crops**

| Crop | Yield Impact | Nutrient Uptake |
|---|---|---|
| **Pearl Millet-Wheat System** | Yield reduction under saline conditions | Heavy metals accumulation affects nutrient content |
| **Winter Wheat** | Increased yield with optimal nitrogen application | Improved nitrogen use efficiency and water use efficiency |
| **Forage Crops** | Increased yield with treated wastewater irrigation | Higher nutrient content, especially nitrogen |
| **Rice** | Growth and yield enhancement with wastewater irrigation | Enrichment and bioaccumulation of nutrients and metals |

## Conclusion

The utilization of sewage water in agriculture offers a dual-edged sword of potential benefits and significant risks. On one hand, sewage water serves as a rich source of essential nutrients like nitrogen, phosphorus, and potassium, which can enhance soil fertility and potentially lead to increased crop yields. This is supported by recent studies such as the one by Bertanza et al. (2024), which emphasize the importance of developing protocols for the characterization of sewage sludge to determine its suitability for agricultural use. On the other hand, the long-term application of sewage water raises concerns about the accumulation of hazardous heavy metals in the soil, which can be taken up by crops and enter the food chain, posing serious health risks[23]. This necessitates the implementation of stringent monitoring and management practices to ensure consumer safety, particularly for crops like leafy vegetables that are prone to higher heavy metal uptake. To mitigate these risks, a proactive approach involving pretreatment measures and continuous quality assessment protocols is essential. This will help in promoting the sustainable use of sewage water resources while minimizing potential hazards. Moreover, technological advancements in sewage treatment and risk assessment are paving the way for safer and more efficient use of this resource. In conclusion, the strategic use of sewage water in agriculture requires a holistic, multidisciplinary strategy that encompasses scientific research, policy development, and active stakeholder participation. Such an approach is crucial for navigating the complexities of sewage water use while safeguarding environmental integrity and public health. It is imperative to stay abreast of the latest research findings on sustainable wastewater application, the associated risks, and the technological innovations that support safe irrigation practices.

**Table 6: Table depicting hyperaccumulators of different elements**

| Plant Family | Element | Hyperaccumulator Example | Notes |
|---|---|---|---|
| Brassicaceae (Cruciferous) | Sulfur | Arabidopsis halleri | This plant is known for accumulating heavy metals and sulfur, which is used in phytoremediation1. |
| Solanaceae (Tuber crops) | Potassium | Solanum tuberosum (Potato) | Potatoes require high levels of potassium, especially during the tuber bulking phase23. |
| Fabaceae | Nickel | Alyssum bertolonii | This plant can accumulate high levels of nickel, which can be useful for phytomining1. |
| Caryophyllaceae | Cadmium | Thlaspi caerulescens | Also known as alpine penny-cress, it is a well-known cadmium and zinc hyperaccumulator1. |
| Asteraceae | Selenium | Stanleya pinnata | Known as the prince’s plume, it can |

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|---|---|---|---|
|  |  |  | hyperaccumulate selenium1. |

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