DOI: https://doi.org/10.70749/ijbr.v2i02.393

INDUS JOURNAL OF BIOSCIENCES RESEARCH
https://induspublisher.com/IJBR
ISSN: 2960-2793/ 2960-2807

Evaluating the Impact of Wastewater Irrigation on Soil Health and Maize Productivity

Aniqa Mubeen[1], Waseem Ur Rehman[2], Abdul Momin[3], Maryam Hayat[4], Ghazanfar Ullah[5], Adila Iram[1], Rafia Naheed[3], Ayesha Irum[6] and Sami Ullah[7]

[1]Agronomic Research Institute, Ayub Agricultutre Research Institute, Faisalabad, Punjab, Pakistan.
[2]Agriculture Extension Education and Communication, University of Agriculture, Peshawar, KP, Pakistan.
[3]Department of Botany, Kohat University of Science & Technology, Kohat, KP, Pakistan.
[4]Arid Zone Research Institute, Bahawalpur, Punjab, Pakistan.
[5]Department of Agronomy, Gomal University, Dera Ismail Khan, KP, Pakistan.
[6]Agricultural Biotechnology Research Institute, AARI, Faisalabad, Punjab, Pakistan.
[7]Institute of Plant Nutrition and Soil Science, University of Kiel, Germany/Pakistan Agricultural Research Council, Arid Zone Research Centre, Dera Ismail Khan, KP, Pakistan/On Farm Water Management, Agriculture, Punjab, Pakistan.

ARTICLE INFO

Keywords

Wastewater Irrigation, Soil Health, Maize Productivity, Heavy Metals, Sustainable Agriculture.

Corresponding Author: Aniqa Mubeen, Agronomic Research Institute, Ayub Agricultutre Research Institute, Faisalabad, Punjab, Pakistan.
Email: aniqamubeen04@gmail.com

Declaration

Author's Contributions: All authors contributed to the study and approved the final manuscript.
Conflict of Interest: The authors declare no conflict of interest.
Funding: No funding received.

Article History

Received: 10-10-2024
Revised: 29-11-2024
Accepted: 07-12-2024

ABSTRACT

The increasing scarcity of freshwater resources necessitates the exploration of alternative water sources for agricultural irrigation. This study evaluates the impact of different water sources canal water, tubewell water, sewerage water, and industrial wastewater on soil health and maize productivity. Conducted over two growing seasons, the experiment was laid out in a randomized complete block design with four replications at research area of Ayub Agriculturte Research Institute, Faisalabad. Key soil physical properties, including bulk density, porosity, and infiltration rate, were assessed pre- and post-irrigation. Concurrently, maize growth parameters such as germination rate, plant height, biomass, and grain yield were meticulously recorded. The results indicated that soil irrigated with sewerage and industrial wastewater exhibited significant increases in bulk density and reductions in porosity and infiltration rates compared to canal and tubewell water. Despite these alterations in soil physical properties, maize irrigated with sewerage water showed a comparable growth pattern to that irrigated with canal and tubewell water, with no significant differences in germination rate or plant height. However, grain yield and biomass were significantly higher in plots irrigated with canal water, followed closely by tubewell water, sewerage water, and lastly, industrial wastewater. Industrial wastewater irrigation notably decreased soil health and maize productivity due to the presence of heavy metals and other pollutants. In contrast, sewerage water, while still inferior to canal and tubewell water, provided a viable alternative, maintaining acceptable soil health and maize yield levels. This study underscores the potential of using treated wastewater for irrigation in regions facing water scarcity, highlighting the need for stringent quality monitoring and treatment protocols to mitigate adverse effects on soil health and crop productivity.

INTRODUCTION

As global populations grow and climate change intensifies, freshwater resources are increasingly under pressure, particularly in arid and semi-arid regions where water scarcity is already severe. Agriculture, the world's largest consumer of freshwater, uses about 70% of available water, intensifying competition with other sectors, including municipal and industrial demands [1]. This competition is expected to worsen as global demand for food production rises to meet the needs of an expanding population. Consequently, alternative water sources, particularly wastewater, have garnered attention as potential solutions to support agriculture in water-scarce regions. Wastewater, derived from municipal, industrial, and agricultural sources, is increasingly used for irrigation, especially in developing countries where access to treated water may be limited [2].

The use of wastewater for irrigation offers a unique set of advantages and challenges. On the one hand, wastewater contains essential nutrients such as nitrogen, phosphorus, and potassium, which can reduce the need for synthetic fertilizers and help support soil fertility over time [3]. This nutrient-rich quality has led to a rise in wastewater reuse in agriculture, which can lower production costs for farmers and help recycle nutrients within agricultural systems. Studies have shown that properly treated wastewater can contribute positively to soil organic matter, which is essential for improving soil structure, water retention, and microbial activity [4].

However, wastewater can also carry various contaminants, including heavy metals, pathogens, and organic pollutants. If not adequately treated, these contaminants can pose significant risks to soil health and crop productivity [5]. Heavy metals, in particular, can accumulate in soils over time, leading to potential toxicity for plants and, subsequently, for human and animal consumers. Contaminants such as lead, cadmium, and arsenic have been linked to inhibited plant growth, reduced crop yield, and compromised food safety [6]. Therefore, understanding the impacts of wastewater irrigation on soil health is crucial for developing safe and sustainable practices for its use in agriculture.

Soil health is fundamental to agricultural productivity, as it influences a range of ecosystem services, including nutrient cycling, water infiltration, and disease suppression [7]. Key physical properties of soil, such as bulk density, porosity, and infiltration rate, are critical indicators of soil structure and function. Bulk density, which measures soil compaction, can affect root penetration and water movement, while porosity determines soil's capacity to hold water and air. Infiltration rate, the rate at which water enters the soil, is essential for efficient water use and to prevent surface runoff and erosion [8]. When using wastewater for irrigation, assessing these properties pre- and post-irrigation is necessary to identify potential impacts on soil structure and overall health.

Maize (*Zea mays* L.) serves as an ideal crop for evaluating the effects of wastewater irrigation due to its high water and nutrient requirements. As one of the world's most widely cultivated crops, maize is integral to food security in many regions, particularly in sub-Saharan Africa, Asia, and Latin America. Additionally, maize's sensitivity to soil health and water quality makes it a valuable indicator crop for testing the suitability of wastewater as an irrigation source [9]. Maize growth and productivity are influenced by various factors, including soil fertility, water availability, and environmental conditions. By observing growth parameters such as germination rate, plant height, biomass accumulation, and grain yield, researchers can assess the efficacy and safety of wastewater irrigation practices on this staple crop [10].

Given these considerations, this study aims to evaluate the viability of wastewater as an irrigation source for maize under field conditions.

MATERIALS AND METHODS

Experimental Design and Location

The experiment was conducted during spring maize growing season at Ayub agriculrure Research Institute, Faisalabad. The study area experiences a semi-arid climate with average temperatures ranging from 25 to 49°C during whole growing season. The soil type at the experimental site was identified as sandy clay loam, with an initial pH of 8.1, EC of 2.48 dSm^{-1} and organic matter content of 0.57%.

A randomized complete block design (RCBD) was employed with four treatments and four replications to minimize experimental error. The treatments included four irrigation sources:

1. **Canal Water** (CW)
2. **Tubewell Water** (TW)
3. **Sewerage Water** (SW)
4. **Industrial Wastewater** (IW)

Each treatment plot measured 10x10 m^2, and plots were separated by 1 m buffer zones to prevent cross-contamination.

Soil and Water Analysis

Prior to the experiment, samples of each water source were collected and analyzed for pH, electrical conductivity (EC), and concentrations of key nutrients nitrogen, phosphorus, potassium and contaminants i.e., heavy metals like lead, cadmium using atomic absorption spectrophotometer (AAS) (Table 1).

Table 1

Characteristics of irrigation waters used for treatment

Water	pH	EC	N	P	K	Pb	Cd
		dSm^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
CW	7.02	0.74	2.05	2.13	13.42	ND	ND
TW	7.10	1.13	0.13	0.17	1.07	ND	ND
SW	6.89	1.79	4.02	3.41	2.73	0.07	0.02
IW	7.32	2.34	0.68	0.74	1.46	3.18	0.41

Soil samples were also collected before (Table 2) and after the growing seasons to measure changes in physical properties, including:

- **Bulk Density**: Determined using the core method [11].
- **Porosity**: Calculated based on bulk density and particle density.
- **Infiltration Rate**: Measured using a double-ring infiltrometer [12].

Table 2

Characteristics of soils before cultivation

Parameter	Unit	Quantity
pH		8.1
Organic Matter	%	0.57
EC	dSm^{-1}	2.48
Texture	Sandy Clay Loam	
N	%	0.15
P	mg kg^{-1}	7.43
K	mg kg^{-1}	112.6
Bulk Density	g cm^{-3}	1.31
Porosity	%	50.6
Infiltration Rate	mm ha^{-1}	3.42

Maize Growth Measurements

Maize seeds were sown at a recommended density with a standard fertilization regimen. Key growth parameters were recorded at regular intervals throughout the growing season:

- **Germination Rate**: Percentage of seeds that germinated within two weeks.
- **Plant Height**: Measured at 4, 8, and 12 weeks post-germination.
- **Biomass**: Fresh and dry weight of above-ground plant parts at harvest.
- **Grain Yield**: Total grain weight per plot, adjusted to per hectare basis.

Statistical Analysis

Data were analyzed using Analysis of Variance (ANOVA) to determine the statistical significance of differences among treatments. The Least Significant Difference (LSD) test was used for post-hoc comparisons at a 5% significance level. Statistical analysis was performed using Statistix 8.1® software.

RESULTS AND DISCUSSION

Soil Physical Properties

The results in table 3 revealed that the use of sewerage water (SW) and industrial wastewater (IW) for irrigation significantly altered soil physical properties, impacting bulk density, porosity, and infiltration rate. Bulk density notably increased in SW and IW-irrigated plots, with soils exhibiting values up to 15% higher than those irrigated with canal water (CW). Specifically, IW-treated soils showed substantial compaction, with bulk density increasing from 1.29 g/cm³ to 1.48 g/cm³, while SW resulted in a moderate increase. The elevated bulk density in IW-irrigated soils suggests soil structure degradation due to high levels of dissolved and suspended solids, a phenomenon commonly observed in wastewater-irrigated soils [13,14]. This compaction effect likely results from the accumulation of heavy metals and particulates, which clog soil pores, impeding root penetration and water movement.

Conversely, porosity and infiltration rate decreased in SW- and IW-treated soils. Porosity was reduced by 16% in IW plots, indicating a loss of soil aeration capacity, which is essential for root respiration and microbial activity. This reduction aligns with findings by Rattan et al. [15], who noted that repeated application of industrial wastewater leads to the deposition of fine particulates and metal complexes within soil aggregates, reducing air space. Lower infiltration rates were also observed, with IW plots experiencing a 20%

reduction compared to CW-treated soils. This diminished infiltration capacity suggests limited water movement into the soil profile, potentially causing surface runoff and erosion during heavy rainfall events [16]. Reduced infiltration can severely affect water availability to plants, especially in arid regions where rainfall is scarce and irrigation is the primary water source.

The data indicate that IW irrigation promotes soil compaction, which could have long-term implications for soil structure, plant growth, and overall soil health. Though SW-treated soils exhibited some structural degradation, they maintained relatively better porosity and infiltration rates compared to IW, suggesting that treated sewerage water could be a viable alternative for irrigation with moderate soil health impacts. However, these results emphasize the importance of regular soil monitoring and treatment adjustments to mitigate the risk of compaction in wastewater-irrigated fields [4].

Table 3

Effect of different types of water applications on soil physical health parameters

Treatment Water	Bulk Density	Total Porosity	Infiltration Rate
	$g\ cm^{-3}$	%	$mm\ hr^{-1}$
Canal Water (CW)	1.29 c	51.3 a	4.17 a
Tubewell Water (TW)	1.32 bc	50.2 b	3.62 b
Sewerage Water (SW)	1.37 b	49.3 c	3.41 b
Industrial Water (IW)	1.48 a	44.16 d	2.99 c
LSD	0.07	0.43	0.23

Maize Growth Parameters

Maize growth parameters, including germination rate, plant height, and biomass, responded variably to the different irrigation sources as evident from table 4. Germination rates remained unaffected across treatments, suggesting that initial soil moisture and nutrient levels were sufficient to support uniform seed germination. However, differences in plant height and biomass accumulation emerged as plants advanced in their growth stages. At 4 and 8 weeks, plant height in SW and CW-irrigated plots was comparable, indicating that both water sources provided adequate nutrients and hydration during early vegetative growth. By 12 weeks, however, plants irrigated with CW were significantly taller, reaching an average of 164.3 cm, compared to 142.1 cm in IW-treated plots, where heavy metal toxicity may have impeded growth [17].

The trend in biomass accumulation mirrored that of plant height, with CW-irrigated plants yielding the highest biomass, followed by TW, SW, and IW treatments. CW and TW irrigation, which are free from heavy metal contaminants, provided optimal conditions for nutrient uptake, supporting robust growth and biomass production. In SW-irrigated plots, moderate biomass was observed, suggesting that sewerage water, though less ideal than CW, still offered nutritional benefits without severely limiting growth. On the other hand, IW-treated plants displayed reduced biomass accumulation, which can be attributed to the high heavy metal content in industrial wastewater [18]. Toxic metals such as cadmium and lead have been shown to interfere with physiological processes in plants, including photosynthesis and enzyme activity, ultimately reducing growth and biomass [19].

These findings underscore the differential impact of irrigation water sources on maize growth, highlighting that while SW provides a tolerable alternative, IW's heavy metal load can hinder growth. Further research on specific contaminants in IW could offer insight into their individual effects on plant metabolism and the threshold levels beyond which growth suppression occurs [20].

Table 4

Effect of different types of water applications on maize growth parameters

Treatment Water	Germination	Plant Height (cm)			Biomass	Grain Yield
	%	4 WAS	8 WAS	12 WAs	$t\ ha^{-1}$	$t\ ha^{-1}$
CW	95.78	52.7	113.4	164.3 a	18.17 a	7.0 a
TW	95.91	51.9	112.4	157.8 a	17.08 b	6.93 a
SW	95.81	50.4	109.9	145.6 b	13.42 c	5.01 b
IW	95.77	50.3	109.3	142.1 b	12.80 c	4.42 c
LSD	0.17	1.43	4.57	6.78	0.81	0.23

Maize Yield

The yield analysis revealed that maize grain yield was highest in CW-irrigated plots at 7.0 t/ha, closely followed by TW-irrigated plots (Table 4). SW-irrigated plots produced a moderate yield, suggesting that treated sewerage water can maintain reasonable productivity levels, although not equivalent to freshwater sources. However, IW-irrigated plots recorded the lowest yields, significantly lower than CW and TW treatments, due to the adverse impact of heavy metals and potential toxic elements present in industrial wastewater [21]. The low yield in IW plots highlights the inhibitory effect of heavy metals on nutrient uptake and plant metabolism, aligning with findings from previous studies [6,15].

Despite a moderate yield, SW-treated plots demonstrated sufficient productivity to be considered a potential irrigation option in water-scarce regions. The comparable grain yields in CW and SW plots suggest that treated sewerage water may contain beneficial nutrients like nitrogen and phosphorus, which support grain filling and increase yield [4]. However, to maximize the safety and effectiveness of SW as an irrigation source, ongoing monitoring of nutrient and contaminant levels is essential to ensure that adverse effects on soil and crop productivity are minimized [3].

Soil Health Implications

The implications for soil health are crucial when considering the use of wastewater for irrigation. The study highlights that untreated or inadequately treated wastewater, especially industrial wastewater, leads to the accumulation of heavy metals in soils, posing risks for long-term soil health and productivity. Contaminants such as lead and cadmium commonly found in industrial effluents, can bind to soil particles, reducing microbial activity, nutrient cycling, and root growth over time [13,16]. Such accumulation not only degrades soil structure but also risks contaminating crops and, by extension, the food chain, making it imperative that water quality be carefully monitored.

Table 4

Effect of different types of water applications and soil health implications

Treatment Water	Cadmium (Cd) mg kg^{-1}	Lead (Pb) mg kg^{-1}
Canal Water (CW)	ND	ND
Tubewell Water (TW)	ND	ND
Sewerage Water (SW)	0.14	0.97
Industrial Water (IW)	1.48	8.42

SW also poses some risks, particularly with regard to soil compaction, the study suggests that treated sewerage water could offer a viable alternative to freshwater sources if properly managed. SW irrigation, by supplying organic and inorganic nutrients, has the potential to improve soil fertility while maintaining maize productivity. Nonetheless, regular soil testing, treatment adjustments, and contaminant monitoring are recommended to ensure that prolonged SW use does not compromise soil health [14].

These findings highlight the importance of developing treatment protocols and quality assessment standards for wastewater used in agriculture. By removing heavy metals and reducing the organic pollutant load, treated wastewater could serve as a sustainable alternative in regions facing water scarcity, aligning with the goals of integrated water resource management and sustainable agriculture [3,4].

Conclusion

This study demonstrates that wastewater irrigation affects both soil health and maize productivity. Canal water and tubewell water remain the most beneficial sources for irrigation, supporting optimal soil structure and crop yield. However, treated sewerage water emerged as a viable alternative, sustaining acceptable maize productivity without significant degradation to soil health. Industrial wastewater, on the other hand, adversely impacted soil properties and reduced crop yield, underscoring the need for effective treatment protocols to mitigate the risks associated with heavy metal accumulation. In regions facing freshwater shortages, treated wastewater, particularly sewerage water, holds potential for sustainable irrigation if carefully monitored and managed. Future research should focus on developing treatment methods to improve wastewater quality and investigating the long-term effects of wastewater irrigation on soil and crop health.

REFERENCES

1. FAO. (2017). *Water for Sustainable Food and Agriculture: A Report Produced for the G20 Presidency of Germany*. Food and Agriculture Organization of the United Nations; 2017.
2. Corcoran, E. (2010). *Sick water?: the central role of wastewater management in sustainable development: a rapid response assessment*. UNEP/Earthprint.
3. Toze, S. (2006). Reuse of effluent water—benefits and risks. *Agricultural Water Management*, *80*(1-3), 147-159. https://doi.org/10.1016/j.agwat.2005.07.010
4. Pedrero, F., Kalavrouziotis, I., Alarcón, J. J., Koukoulakis, P., & Asano, T. (2010). Use of treated municipal wastewater in irrigated agriculture—Review of some practices in Spain and Greece. *Agricultural Water Management*, *97*(9), 1233-1241. https://doi.org/10.1016/j.agwat.2010.03.003
5. Qadir, M., Wichelns, D., Raschid-Sally, L., McCornick, P., Drechsel, P., Bahri, A., & Minhas, P. (2010). The challenges of wastewater irrigation in developing countries. *Agricultural Water Management*, *97*(4), 561-568. https://doi.org/10.1016/j.agwat.2008.11.004
6. Singh, A., Agrawal, M., & Marshall, F. M.(2012). Effects of wastewater irrigation on soil properties and heavy metal uptake by vegetable crops grown along the Yamuna River in Delhi, India. *Environ Monit Assess, 184*(3), 6153-6162.
7. Doran, J. W., & Zeiss, M. R. (2000). Soil health and sustainability: Managing the biotic component of soil quality. *Applied Soil Ecology*, *15*(1), 3-11. https://doi.org/10.1016/s0929-1393(00)00067-6
8. Brady, N., C. & Weil, R. R. (2016). *The Nature and Properties of Soils*. 15th ed. Upper Saddle River, NJ: Prentice Hall.
9. CIMMYT. (2014). (International Maize and Wheat Improvement Center). *Maize – Global Alliance for Improving Food Security and the Livelihoods of the Resource-poor in the Developing World.* CIMMYT.
10. Rao DLN, Giller KE, Yadav AK. Nutrient use efficiency in cereals and impact on greenhouse gases. *Indian J Fert.* 2016;12(5):94-105.
11. Blake, G. R., & Hartge, K. H. (2018). Bulk density. *SSSA Book Series*, 363-375. https://doi.org/10.2136/sssabookser5.1.2ed.c13
12. Bouwer, H. (2018). Intake rate: Cylinder Infiltrometer. *SSSA Book Series*, 825-844. https://doi.org/10.2136/sssabookser5.1.2ed.c32
13. Chaudhry, T. M., Hayes, W. J., Khan, A. G., & Khoo, C. S.(2000). Phytoremediation—focusing on accumulator plants that remediate metal-contaminated soils. *Aust J Ecotoxicol*, *6*(1), 37-51. https://www.sid.ir/paper/552111/en
14. Castro, E., Mañas, M. P., & Heras, J. D. (2011). Effects of wastewater irrigation on soil properties and turfgrass growth. *Water Science and Technology*, *63*(8), 1678-1688. https://doi.org/10.2166/wst.2011.335
15. Rattan, R., Datta, S., Chhonkar, P., Suribabu, K., & Singh, A. (2005). Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. *Agriculture, Ecosystems & Environment*, *109*(3-4), 310-322. https://doi.org/10.1016/j.agee.2005.02.025
16. Qadir, M., Boers, T., Schubert, S., Ghafoor, A., & Murtaza, G. (2003). Agricultural water management in water-starved countries: Challenges and opportunities. *Agricultural Water Management*, *62*(3), 165-185. https://doi.org/10.1016/s0378-3774(03)00146-x
17. Ghosh, M., Singh, S., P., & Shukla, A. K.(2012). Metal toxicity in plants: response mechanisms and remediation strategies. *Plant Soil, 12*(4), 415-432.
18. Khan, A., Kuek, C., Chaudhry, T., Khoo, C., & Hayes, W. (2000). Role of plants, mycorrhizae and phytochelators in

heavy metal contaminated land remediation. *Chemosphere*, *41*(1-2), 197-207. https://doi.org/10.1016/s0045-6535(99)00412-9

19. Alkorta, I., Hernández-Allica, J., Becerril, J., Amezaga, I., Albizu, I., & Garbisu, C. (2004). Recent findings on the Phytoremediation of soils contaminated with environmentally toxic heavy metals and metalloids such as zinc, cadmium, lead, and arsenic. *Reviews in Environmental Science and Bio/Technology*, *3*(1), 71-90. https://doi.org/10.1023/b:resb.0000040059.70899.3d

20. McBride, M. B. (1995). Toxic metal accumulation from agricultural use of sludge: Are USEPA regulations protective? *Journal of Environmental Quality*, *24*(1), 5-18. https://doi.org/10.2134/jeq1995.00472425002400010

21. Alloway, B. J. (1995). The origins of heavy metals in soils. *Heavy Metals in Soils*, 38-57. https://doi.org/10.1007/978-94-011-1344-1_3