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Assessment of Soil Quality of Rice Fields under Irrigation with Different Water Sources

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Abstract

Irrigation water quality is crucial in maintaining soil health and productivity, particularly in semi-arid regions where agriculture heavily relies on irrigation. This study aimed to assess the impact of different irrigation water sources (groundwater, canal water, and treated and disinfected sewage water) on soil quality in rice fields in Kurukshetra, Haryana, India. Water and soil samples were collected from rice fields irrigated with each water source and analyzed for various physicochemical parameters. The results revealed significant differences in irrigation water quality, with STP exhibiting higher salinity levels, as indicated by elevated electrical conductivity (EC), total dissolved solids (TDS), sodium, chloride, and sulphate concentrations. Soil quality parameters also varied significantly among rice fields irrigated with different water sources. Rice fields irrigated with STP had higher soil EC and higher concentration cations and anions along with organic carbon content potentially due to the contribution of organic load and nutrients from sewage treatment plants. It was inferred from the study that disinfected sewage effluent has the potential to be used in irrigation, provided that regular monitoring is done. The findings highlight the importance of considering irrigation water quality in agricultural practices and the need for appropriate water management strategies to maintain soil quality and ensure sustainable rice production in the region.

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irrigation;
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Introduction

Rice (*Oryza sativa*) is a staple food crop that feeds a significant portion of the world's population, particularly in Asia, where it accounts for more than 90% of global rice production.[1] In India, rice cultivation plays a crucial role in ensuring food security and supporting the livelihoods of millions of farmers.[2] Kurukshetra, a district in Haryana, is a prominent rice-growing region known for its fertile alluvial soil and extensive irrigation facilities. However, the quality of irrigation water can significantly impact soil properties and, consequently, crop productivity.[3]

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Irrigation water sources can vary in their chemical composition, with the potential presence of contaminants such as salts, heavy metals, and other pollutants.[4,5] These contaminants can accumulate in the soil over time, leading to soil degradation, nutrient imbalances, and reduced crop yields.[6,7] Additionally, the quality of irrigation water can influence soil properties like pH, electrical conductivity, and organic matter content, all of which are crucial for maintaining optimal soil health and productivity.[3] The pH of irrigation water can affect the solubility and availability of nutrients in the soil. Most crops grow well in a pH range of 6.0 to 8.3, so irrigation water with a pH within this range is desirable.[8] TDS is the total amount of dissolved minerals and salts in the water. High TDS levels can lead to soil salinity and can negatively affect plant growth. High values of Electrical conductivity may also lead to salinity problems. Alkalinity and bicarbonate content are also known to cause soil alkalinity and thereby affecting nutrient availability and plant growth. Chloride is an essential micronutrient for plant growth, but excessive chloride levels in irrigation water can lead to toxicity and reduced growth. Sulphate is a source of sulphur, an essential macronutrient for plant growth. However, high sulphate levels in irrigation water can lead to soil salinity and can negatively affect plant growth. Phosphate and nitrate are also accounted as essential and important macronutrients for the growth of plant, but their excessive amount in irrigation water can lead to pollution of water bodies and other environmental and health related problems. Hard water can also affect soil structure by contributing to soil compaction and reducing water infiltration. Irrigation water with high calcium and magnesium levels can be beneficial for plant growth, but excessive levels can lead to soil alkalinity In recent years, there has been growing concern about the sustainability of agricultural practices in Kurukshetra, particularly regarding the impact of different irrigation water sources on soil quality. Further, intensive irrigation requirements in agricultural fields are putting pressure on groundwater resources leading to water scarcity. To overcome water scarcity in agriculture, alternative water sources must be considered that can be put into use without harmful or deleterious effects on soil properties and/or crop health. Understanding the relationship between irrigation water sources and soil quality is essential for developing sustainable agricultural practices and ensuring long-term productivity in the region.

This study aims to assess the soil quality of rice fields in Kurukshetra, Haryana, India, under irrigation with different water sources (canal water, groundwater, and treated and disinfected sewage water). The specific objectives of this research include: (1) characterizing the chemical and physical properties of irrigation water sources used for rice cultivation, (2) evaluating the impact of these water sources on soil quality parameters.

The findings of this study will contribute to the development of sustainable irrigation practices and soil management strategies, ultimately supporting the long-term productivity and environmental sustainability of rice cultivation in Kurukshetra.

Materials and Methodology

The study was conducted in the Kurukshetra district of Haryana, India, a prominent rice-growing region that lies between latitude 29°52' to 30°12' and longitude 76°26' to 77°04' in the North-Eastern part of the State. The district has an average annual rainfall of around 700 mm and a semi-arid climate.[9] Rice cultivation in the region heavily relies on irrigation from various water sources, including groundwater and canal. Also, in some areas, the treated and disinfected sewage water is now used for irrigating the nearby agricultural fields. A stratified random sampling approach was employed to select rice fields for soil and water sampling. The stratification was based on the different water sources used for irrigation, such as groundwater (tube wells-TW), canal water (CN), and treated and disinfected sewage (STP) from a treatment plant. The disinfection was done through chlorination. Within each stratum, rice fields were randomly selected to ensure representative sampling.

Water Sample Collection and Analysis: A total of 18 water samples (6 from each source) from the identified irrigation sources (TW, CN, STP) were collected during the rice-growing season. Standard methods outlined by the American Public Health Association[10] were followed for water sample collection and preservation. Water quality parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), major cations (calcium, magnesium, sodium, and potassium), major anions (chloride, sulfate, phosphate, nitrate, and bicarbonate), and alkalinity were analyzed using standard analytical techniques.[10,11]

Table 1: Correlation matrix for different physio-chemical properties of water samples

		pH	EC	TDS	Chloride	Hardness	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Bicarbonate	Sulphate	Phopsphate	Nitrate
pH	Pearson Correlation	1	-0.982	-0.978	-0.993	-0.987	-0.475	-0.291	-0.350	-0.617	-0.961	-0.961	-0.986	-0.946	0.200
	Sig. (2-tailed)		0.123	0.134	0.075	0.102	0.685	0.812	0.772	0.577	0.179	0.179	0.106	0.210	0.872
EC	Pearson Correlation	-0.982	1	1.000*	.997*	0.938	0.634	0.468	0.523	0.756	0.996	0.996	1.000*	0.991	-0.384
	Sig. (2-tailed)	0.123		0.012	0.048	0.225	0.563	0.690	0.650	0.454	0.056	0.056	0.017	0.087	0.749
TDS	Pearson Correlation	-0.978	1.000*	1	0.996	0.932	0.649	0.485	0.539	0.768	.998*	.998*	.999*	0.993	-0.401
	Sig. (2-tailed)	0.134	0.012		0.060	0.237	0.551	0.678	0.638	0.442	0.044	0.044	0.029	0.075	0.737
Chloride	Pearson Correlation	-0.993	.997*	0.996	1	0.962	0.575	0.401	0.457	0.705	0.987	0.987	.999*	0.978	-0.314
	Sig. (2-tailed)	0.075	0.048	0.060		0.177	0.610	0.737	0.698	0.502	0.104	0.104	0.031	0.135	0.797
Hardness	Pearson Correlation	-0.987	0.938	0.932	0.962	1	0.328	0.134	0.196	0.483	0.904	0.904	0.947	0.883	-0.041
	Sig. (2-tailed)	0.102	0.225	0.237	0.177		0.787	0.914	0.874	0.679	0.281	0.281	0.208	0.312	0.974
Calcium	Pearson Correlation	-0.475	0.634	0.649	0.575	0.328	1	0.980	0.991	0.986	0.700	0.700	0.614	0.734	-0.957
	Sig. (2-tailed)	0.685	0.563	0.551	0.610	0.787		0.127	0.087	0.108	0.506	0.506	0.579	0.476	0.187
Magnesium	Pearson Correlation	-0.291	0.468	0.485	0.401	0.134	0.980	1	.998*	0.932	0.545	0.545	0.445	0.584	-0.996
	Sig. (2-tailed)	0.812	0.690	0.678	0.737	0.914	0.127		0.040	0.235	0.633	0.633	0.706	0.603	0.060
Sodium	Pearson Correlation	-0.350	0.523	0.539	0.457	0.196	0.991	.998*	1	0.953	0.596	0.596	0.500	0.634	-0.988
	Sig. (2-tailed)	0.772	0.650	0.638	0.698	0.874	0.087	0.040		0.196	0.593	0.593	0.667	0.563	0.099
Potassium	Pearson Correlation	-0.617	0.756	0.768	0.705	0.483	0.986	0.932	0.953	1	0.811	0.811	0.738	0.838	-0.895
	Sig. (2-tailed)	0.577	0.454	0.442	0.502	0.679	0.108	0.235	0.196		0.398	0.398	0.471	0.367	0.295
Alkalinity	Pearson Correlation	-0.961	0.996	.998*	0.987	0.904	0.700	0.545	0.596	0.811	1	1.000**	0.993	.999*	-0.464
	Sig. (2-tailed)	0.179	0.056	0.044	0.104	0.281	0.506	0.633	0.593	0.398		0.000	0.073	0.031	0.693
Bicarbonate	Pearson Correlation	-0.961	0.996	.998*	0.987	0.904	0.700	0.545	0.596	0.811	1.000**	1	0.993	.999*	-0.464
	Sig. (2-tailed)	0.179	0.056	0.044	0.104	0.281	0.506	0.633	0.593	0.398	0.000		0.073	0.031	0.693
Suphate	Pearson Correlation	-0.986	1.000*	.999*	.999*	0.947	0.614	0.445	0.500	0.738	0.993	0.993	1	0.987	-0.359
	Sig. (2-tailed)	0.106	0.017	0.029	0.031	0.208	0.579	0.706	0.667	0.471	0.073	0.073		0.104	0.766
Phopsphate	Pearson Correlation	-0.946	0.991	0.993	0.978	0.883	0.734	0.584	0.634	0.838	.999*	.999*	0.987	1	-0.506
	Sig. (2-tailed)	0.210	0.087	0.075	0.135	0.312	0.476	0.603	0.563	0.367	0.031	0.031	0.104		0.662
Nitrate	Pearson Correlation	0.200	-0.384	-0.401	-0.314	-0.041	-0.957	-0.996	-0.988	-0.895	-0.464	-0.464	-0.359	-0.506	1
	Sig. (2-tailed)	0.872	0.749	0.737	0.797	0.974	0.187	0.060	0.099	0.295	0.693	0.693	0.766	0.662	

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Soil Sample Collection and Analysis

Soil samples were collected from the selected rice fields from the surface soil (0-15cm). The samples were air-dried, ground, and sieved (2 mm) before analysis. Soil samples were analyzed for moisture content, pH, EC, organic C by dichromate oxidation method, Available N by Kjeldahl Method, P (Olsen method), Na, K (Flame Photometry), Ca and Mg (EDTA titration) following Kumar *et al*.[12] The sodium absorption ration was calculated using the following equation:

SAR= Na+ / √ ((Ca^{+2} +Mg^{+2})/2)

(The units of Ca^{+2}, Mg^{+2} and Na^{+} are milliequivalent/ liter)

Statistical Analysis

The data collected from soil and water analyses was subjected to statistical analyses (Correlation and ANOVA) using MS-EXCEL Spreadsheet.

Results and Discussion

Assessment of Water Quality

Water quality of samples used for irrigation from different sources was assessed based on various chemical properties and the results thus obtained were analyzed statistically through correlation analysis (Table 1).

pH, Electrical Conductivity and Total Dissolved Solids

In all the water samples (CN, TW and STP) the maximum and slightly alkaline pH values were observed in canal water samples and minimum and slightly acidic values were observed in STP samples. The pH was found to be significantly but negatively correlated with EC, TDS, Chloride, Alkalinity, Bicarbonate, Sulphate and Phosphate. STP samples had highest values of electrical conductivity followed by TW and CN. The EC values were significantly and positively correlated with TDS, Chloride, Alkalinity, Bicarbonate, Sulphate and Phosphate. Th STP samples also accounted for maximum values for total dissolved solids (1067mg/L) and CN samples accounted for minimum TDS (134mg/L). The TDS was significantly and positively correlated with EC, Chloride, Alkalinity, Bicarbonate, Sulphate and Phosphate.

Hardness, Calcium and Magnesium

The maximum values of all the three parameters (Hardness, Calcium and Magnesium) were observed in STP samples. The values of hardness were positively and significantly correlated with EC, TDS, Chloride, Alkalinity, Bicarbonate, Sulphate and Phosphate. Calcium values had positive and high correlation with Magnesium, Sodium and Potassium, however these were negatively yet significantly correlated with nitrate values. Similar relations were observed in Magnesium values.

Sodium and Potassium

Sodium and potassium content in all the three samples were very low and minimum was observed in TW and maximum in STP samples. The values of sodium and potassium were positively correlated with each other and negatively correlated with nitrate.

Alkalinity and Bicarbonate

As in case of other parameters, the STP samples accounted for highest values of alkalinity and bicarbonate concentration followed by TW and CN. Alkalinity and Bicarbonate was significantly and positively correlated with EC, TDS, Chloride, Hardness, Sulphate and Phosphate while negatively correlated with pH.

Sulphate and Phosphate

Sulphate and Phosphate content was observed to be maximum in STP samples followed by TW and CN. The values were highly correlated with EC, TDS, Chloride, Hardness, Alkalinity and Bicarbonate while negatively correlated with pH.

Chloride and Nitrate

The Chloride content was maximum in STP samples followed by TW and CN while nitrate content was maximum in TW followed by CN and STP. The values of chloride in water samples were significantly and positively correlated with EC, TDS, Hardness, Alkalinity, Bicarbonate, Sulphate and Phosphate. However, nitrate was negatively correlated with Calcium, Magnesium, sodium and Potassium.

The analysis of irrigation water sources revealed significant differences in water quality parameters among groundwater, canal water, and treated and disinfected sewage water. STP water exhibited higher electrical conductivity (EC) and total dissolved solids (TDS) followed by TW and CN, indicating higher salinity levels.[3] Additionally, STP water also had elevated concentrations of cations and anions specifically sodium, chloride, and sulphate, which are common constituents of saline water.

Assessment of Soil Quality

pH and EC

The soil samples irrigated with Canal water were observed to have maximum pH (8.99) values followed by soil under TW and STP water. In all the three treatments, the values of pH decreased over the study period. These were higher before sowing the crop and gradually decreased with time and was minimum after the crop was harvested (Fig 1a). However, the differences were not significant. In case of electrical conductivity, soil irrigated with STP water showed maximum EC followed by CN and TW (Fig 1b). The EC values also presented a non-significant decreasing trend over the study period ($p<0.05$).

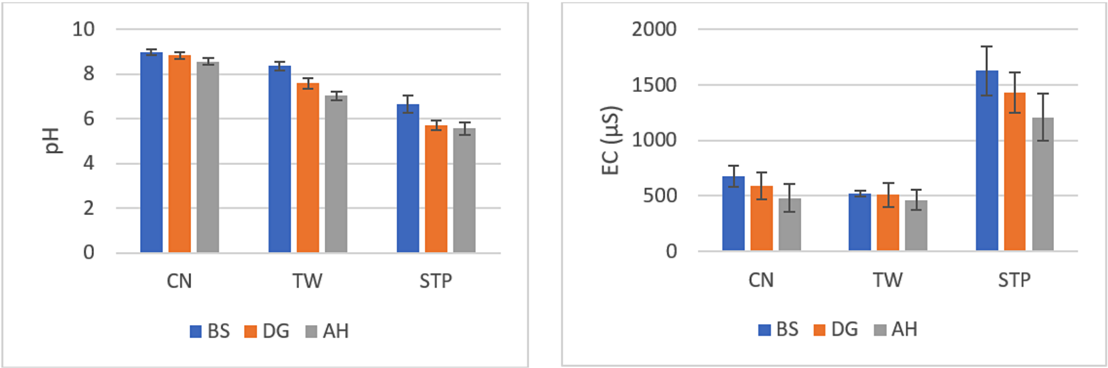

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Fig. 1a: Variations in pH and b. EC values of soil samples irrigated with different water samples

SOC and Available Nitrogen

STP-soil samples accounted for maximum Soil Organic Carbon (SOC) and available Nitrogen content. The minimum values of SOC and available nitrogen content were observed in TW-soil. The SOC content showed a gradual but non-significant increase over the study period (Fig 2a), however, a decline was observed in available nitrogen content in all the three treatments (Fig 2b).

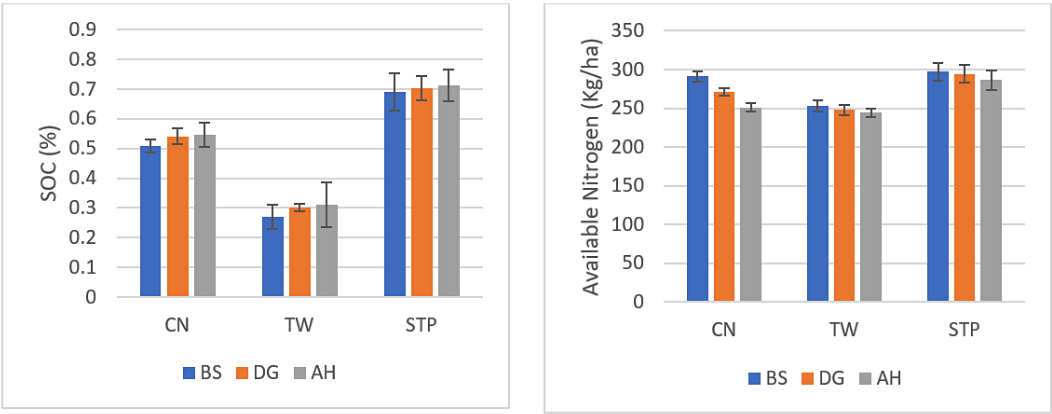

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Fig. 2a: Variations in SOC (%) and b. Available Nitrogen (Kg/ha) values of soil samples irrigated with different water samples

Potassium and Phosphorus

Potassium concentration was maximum in STP-soil while minimum in TW-soil. Maximum Phosphorus concentration was observed in CN-soil followed by STP-soil and TW-soil. Both the nutrients presented a significant decreasing trend over the study period (Fig 3a, b).

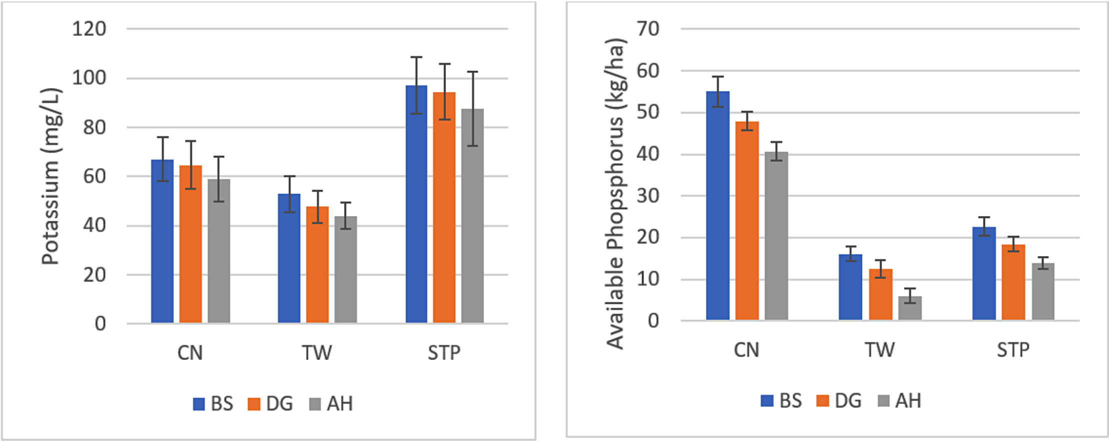

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Fig. 3a: Variations in Potassium (mg/L) and b. Available Phosphorus (Kg/ha) values of soil samples irrigated with different water samples

Calcium and Magnesium

Calcium and Magnesium contents were maximum in STP-soil. There was no significant difference in calcium content of CN-soil and TW-soil. The lowest magnesium content was observed in TW-soil. The decreasing trend was observed in the both the elements over the study period (Fig 4a, b).

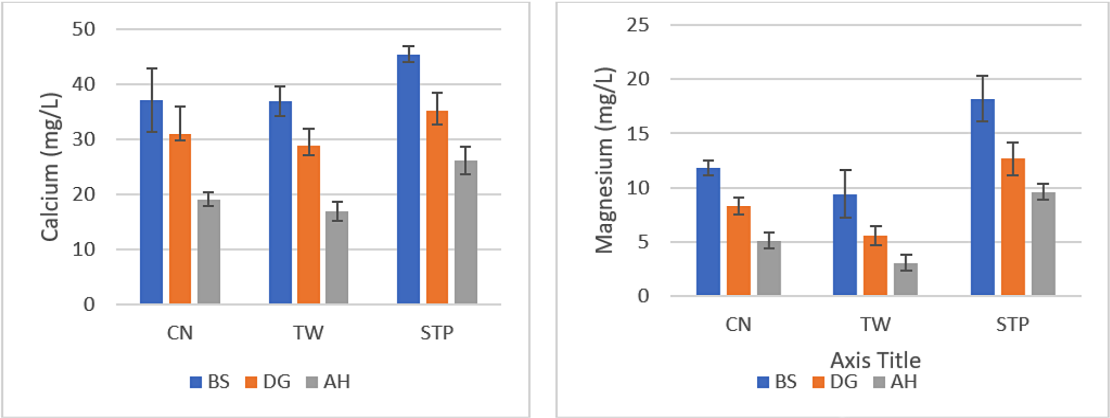

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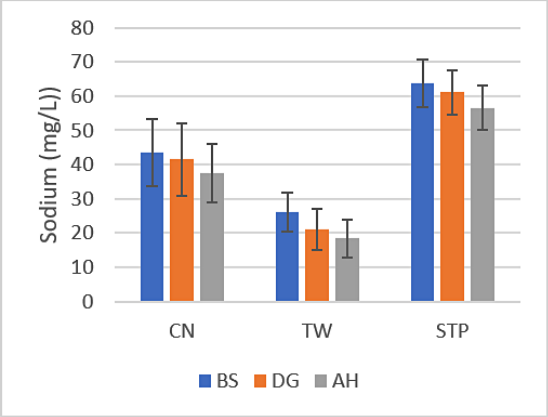
Fig. 4a: Variations in Calcium (mg/L) and b. Magnesium (mg/L) values of soil samples irrigated with different water samples

Sodium and Sodium Absorption Ratio

Sodium content was maximum in STP-soil followed by CN-soil and TW-soil. Sodium content also showed a gradual decreasing trend over the study period (Fig 5a). The sodium absorption ratio as calculated by mentioned equation for all samples was observed to be very low in range. Therefore, as per general criteria, it was inferred that all the soil samples at different times of sampling and irrigated with different water sources were in the class of low sodium (Fig 5b).



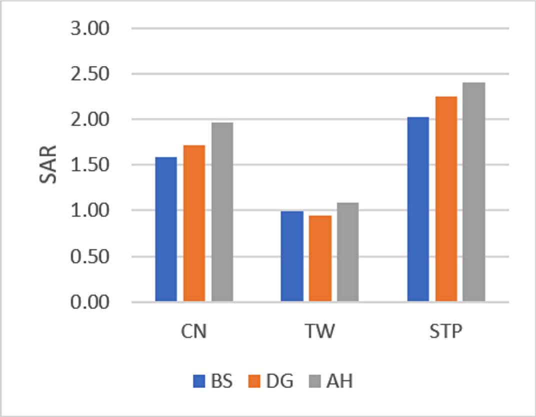


Fig. 5a: Variations in Sodium (mg/L) and b. Sodium Absorption Ratio values of soil samples irrigated with different water samples

The observed differences in soil quality parameters among rice fields irrigated with different water sources can be attributed to the variations in the chemical composition of the irrigation water. The analysis of soil samples revealed significant differences ($p>0.05$) in soil quality parameters among rice fields irrigated with different water sources. Rice fields irrigated with STP water had higher soil EC and sodium concentrations compared to those irrigated with canal or groundwater. The accumulation of salts and sodium in the soil can lead to soil salinization and sodicity, which can adversely affect soil structure, water infiltration, and nutrient availability.[13] Also, Soils with SAR values of 13 or above may be problematic as it causes an increased dispersion of organic matter and clay particles, reduced saturated hydraulic conductivity and aeration, and a general degradation of soil structure.[14] Also, fine-textured soils with SAR greater than 9 will have severe problems, however, the soils with SAR less than 3 are safe.[15] These soil quality issues can ultimately impact rice productivity and sustainability.

Also, the higher levels of calcium, magnesium, and bicarbonate in STP water seemed to influence the soil pH and cation concentrations in rice fields irrigated with canal water. While these factors may not pose immediate threats to soil quality, long-term irrigation with STP-water could potentially lead to soil alkalinization and nutrient imbalances.

Organic matter content and available macronutrient levels (nitrogen, phosphorus, and potassium) were generally higher in rice fields irrigated with STP water as compared to those irrigated with groundwater or canal water. This could be due to the potential contribution of organic matter and nutrients from sewage treatment plant.

Overall, it was observed that STP samples were high in their nutrient load. However, the EC of STP samples were quite high (2098μS). According to USDA scale, this water comes under class C3-S1 (EC 750 and 2250 μS/cm) and is qualified as water with high salinity.[16] However, the canal water sample was observed to have low salinity, and water samples from the tube-well and sewage treatment plant were moderately saline according to the general criteria given by DPIRD[17] based on EC and TDS values (Table 2). So, water with moderate or high salinity should only be used in well drained soils to avoid the problem of soil salinity. It can be inferred that the sewage water after chlorine treatment following primary and secondary treatment can effectively be used for irrigation purpose provided that proper monitoring and regular testing of the water is in place. This source of water can significantly reduce the pressure on groundwater, the availability of which for irrigation is a serious problem in an agriculture-based country like India.

Table 2: General salinity classification for water

EC (mS/cm, dS/m or mmhos/cm)	EC (mS/m)	Approximate total dissolved solids (mg/L or mg/L)	Status
0–0.80	0–80	0–456	Low salinity
0.80–2.50	80–250	456–1425	Moderately salty
2.50–5.00	250–500	1425–2850	Salty
>5.00	>500	>2850	Very salty

In terms of soil analysis, it was observed that almost all the parameters except soil organic carbon followed a decreasing trend from initial (before sowing) to final sampling (after harvesting). The decrease in pH can be attributed to leaching effect in case of excessive irrigation, where basic cations are removed from the soils leaving the acidic cation in the soil, decomposition of organic matter that releases acidic compounds on the soil surface, and uptake of basic cations by the crops. The leaching effect can also account for the decrease in EC of the soil whereby the irrigation promotes leaching of salts due to flocculation of soil having dispersed soil matrix and improvement in hydraulic conductivity.[18] The leaching and uptake of nutrients from the soil by the crop roots for their growth and metabolism is responsible for gradual decrease in nutrient concentration in the soil in all the three treatments over the entire study period. Decomposition of organic matter is a continuous ongoing process in the ecosystem that keeps on adding the carbon in soil. Therefore, a gradual increase was observed in the soil organic carbon in all the three treatments. Further, it was observed that the soils of the field receiving effluent of sewage treatment plant as irrigation water were generally high in their nutrient concentration except phosphorus (maximum in CN treated soil) as compared to the soils of other two treatments. Beneficial changes in the physico-chemical and biological properties have been observed in the soils under Beta vulgaris crop in India19. Significant increases in total N, absorbable P and absorbable K of soil in of rice field irrigated with wastewater has been reported by.[20] The results of the present studies are in confirmation with various other studies worldwide[21-24] that supports the use of treated sewage water, municipal or domestic water for irrigation in agricultural fields.

The results highlighted the importance of considering irrigation water quality in agricultural practices and the need for appropriate water management strategies to maintain soil quality and ensure sustainable rice production in the region.

Conclusion

This study investigated the impact of different irrigation water sources on soil quality in rice fields in Kurukshetra, Haryana, India. The results revealed significant variations in soil quality parameters among rice fields irrigated with groundwater, canal water, and STP water highlighting the critical role of irrigation water quality in maintaining soil health and productivity.

Rice fields irrigated with STP water exhibited higher soil electrical conductivity and sodium concentrations, indicating potential risks of soil salinization and sodicity. These soil quality issues can adversely affect soil structure, water infiltration, and nutrient availability, ultimately impacting rice productivity[3,7] Further, slightly higher soil pH and higher levels of calcium and magnesium can potentially result in soil alkalinization and nutrient imbalances over the long term.[3]

Notably, rice fields irrigated with STP water exhibited higher organic matter content and available macronutrient levels, potentially due to the contribution of organic matter and nutrients from the sewage treatment plant. However, careful management of organic loads and potential contaminants is essential to maintain soil quality and environmental sustainability.

The findings of this study highlight the importance of considering irrigation water quality in agricultural practices and the need for appropriate water management strategies to maintain soil quality and ensure sustainable rice production in the region. Continuous monitoring and evaluation of irrigation water sources and their impact on soil properties are crucial for developing site-specific management practices.

For groundwater irrigation, strategies such as conjunctive use of surface and groundwater, implementation of efficient irrigation methods, and periodic leaching of salts from the soil may be necessary to mitigate the risks of soil salinization and sodicity.[25]

For canal water irrigation, periodic monitoring of water quality and soil parameters is recommended to detect any signs of soil alkalinization or nutrient imbalances. Appropriate amendments or management practices may be required to maintain optimal soil conditions.

Despite having a large number of rivers and water bodies, India faces a severe shortage of water resources for irrigation. Water availability is highly variable across different regions and seasons, and many areas suffer from droughts and water scarcity. Further, the quality of irrigation water in India is often poor, with high levels of salts, pesticides, and other contaminants. This can lead to soil salinity, reduced crop yields, and environmental problems. Irrigation techniques practiced in India are also often inefficient such as flood irrigation where large amounts of water are being wasted due to inefficient irrigation systems, poor water management, and overuse of groundwater resources. Climate change is expected to further exacerbate the water scarcity problem in India, with changing rainfall patterns and increased variability in water availability. There is a need to bring the unused sources of water such as effluents of sewage treatment plants under use for irrigation purpose to reduce the excessive pressure on ground and surface water. This can offer two-way benefits in terms of providing water loaded with nutrients to lower down the use of chemical fertilizers in crop fields along-with providing an alternative source for irrigation. STP water irrigation can be beneficial for soil fertility, but intensive care should be taken to manage the organic loads and any potential contaminants

Overall, this study contributes to the understanding of the relationship between irrigation water quality and soil quality in rice fields and provides valuable insights for developing sustainable agricultural practices in Kurukshetra and other similar rice-growing regions. Implementing appropriate water management strategies and monitoring soil quality will be crucial for ensuring long-term productivity and environmental sustainability in the region.

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Conflict of Interest

The authors declare that there are no conflicts of interest

Data Availability Statement

The manuscript incorporates all datasets produced or examined throughout this research study

Ethics Statement

Not Applicable.

Authors' Contribution

PA designed the study, performed field sampling, analysed the data and wrote the manuscript. NR and AA executed the laboratory work.

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