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Assessment of Phytorid Treatment System Efficacy for Irrigation Water Quality in Bindapur, South-West Delhi, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Constructed wetlands (CWs) offer an eco-friendly approach for treating diverse wastewaters, including sewage and industrial and agricultural effluents. This study evaluates the performance of a self-sustaining constructed wetland system using Phytorid treatment technology for decentralized wastewater treatment at Bindapur, South West Delhi. The government-operated system was monitored for twelve months (2022–2023), with inlet and outlet water samples collected fortnightly

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and analysed for irrigation water quality parameters. Key irrigation indices, such as Percent Sodium, Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Electrical Conductivity (EC), Kelly's Ratio (KR), Total Hardness (TH), Chloride-Bicarbonate Ratio (CB Ratio), Magnesium Hazard (MH), Permeability Index (PI), and Gibbs Ratio, were calculated to assess irrigation suitability. Results revealed that one inlet sample fell into the C4-S3 category (very high salinity, high sodium), while most samples were classified as C4-S2 (very high salinity, medium sodium). High EC and sodium levels indicated unsuitability for irrigation, particularly in poorly drained soils. The Wilcox Diagram confirmed most samples were unsuitable for irrigation due to high salinity. Diluting treated effluent with low TDS water (<500 mg/L) in a 2:1 ratio could improve suitability. This study provides insights to help policymakers and stakeholders manage treated sewage water for irrigation.

Keywords: Wastewater; irrigation; phytorid treatment; salinity.

1. INTRODUCTION

The increasing water stress due to environmental and climate changes is a growing global concern. As per data from 2018, approximately 2.3 billion people experienced water shortages (UNDP, 2021). Agriculture accounts for over 70% of a country's water consumption, while the demand for water in industries and energy production is also projected to rise sharply (UNESCO, 2019). Over the coming decades, the global demand for water resources is expected to increase significantly. Recycling wastewater offers a potential solution to address water scarcity. The pollution levels of untreated sewage water vary depending on location and season. The use of untreated sewage water for irrigation can lead to soil and groundwater contamination. However, treated sewage water from Phytorid Sewage Treatment Plants can be safely used for irrigation purposes (Balpande et al., 2017).

Across the globe, municipalities are increasingly utilizing constructed wetlands as a sustainable and eco-friendly method for treating sewage and wastewater. The treated effluent serves as an additional water resource, with approximately 90% being reused primarily for irrigation in water-scarce countries like Israel (Icekson-Tal et al., 2003), Kuwait (Alesia et al., 2019) and Spain (Jódar-Abellán, 2019). Additionally, some nations, including Singapore (Tortajada et al., 2020), Australia (ARMCAN, 2000), and Jordan (WHO, 2006), have also embraced wastewater reuse strategies. The reuse of wastewater in agriculture offers a cost-efficient disposal solution while also promoting environmental sustainability with minimal impact. The treatment standards required for irrigation are less rigorous compared to those needed for discharging into water bodies (Maria, 2003). Reclaimed water is extensively utilized across many countries for agricultural, industrial, municipal, and other purposes (Yang et al., 2014). Municipal wastewater is increasingly being used in agriculture particularly in regions such as the Middle East, North Africa, Australia, China, India, and Mexico (Fan et al., 2016). Beyond agricultural irrigation, reclaimed water is also employed for irrigating green spaces, including parks and green belts. The risk of pollution from reclaimed water irrigation is significantly lower compared to irrigation with untreated wastewater. Reclaimed water is rich in essential nutrients like nitrogen, phosphorus, and potassium, which support plant growth. Furthermore, using reclaimed water for irrigation can help reduce pollutant levels in aquatic environments (Chen et al., 2014; Feng et al., 2003). The use of reclaimed water for irrigation significantly reduces the burden on natural water bodies for self-purification. It also reduces treatment and operational costs while enabling the recovery of valuable by-products such as salts, nitrogen, and phosphorus during the reclamation process (Li et al., 2014; UNESCO, 2019).

Reclaimed water holds significant potential in green space and agricultural irrigation. However, research indicates that it may also contain toxic trace substances, such as heavy metals, organic pollutants, and pathogens (Wang et al., 2017). These harmful substances can infiltrate soil and groundwater over time, leading to contamination that may pose environmental risks and threaten human health (Lyu et al., 2016). Reports suggest that the area irrigated with untreated wastewater is nearly ten times larger than that irrigated with treated wastewater (Scott et al., 2010). To mitigate these risks, it is crucial to monitor the quality of reclaimed water and implement strict regulations on its usage. Secondary treatment of municipal wastewater effectively removes biodegradable organic matter, offering substantial environmental and social benefits (Li et al., 2014; Li et al., 2018; UNESCO, 2019). Irrigation plays a crucial role in ensuring agricultural productivity and food security. As global food demand increases due to population growth, urbanization, and climate change, sustainable and efficient irrigation practices are gaining prominence. This study examines the suitability of water from the Bindapur Phytorid Treatment Plant for irrigation, emphasizing the importance of reusing treated sewage to address freshwater scarcity and groundwater depletion.

2. MATERIALS AND METHODS

The Phytorid treatment system in Bindapur, located in the southwest region of Delhi, India, is situated at a latitude of 28.611964° and longitude of 77.07361° (Fig. 1). According to the Master Plan of Delhi 2021, this area falls under ZONE K-II. As outlined in the Sewerage Master Plan for Delhi 2031, Bindapur is part of the Dwarka drainage zone, specifically sub-drainage zone Dwarka-2, with the nearest wastewater treatment plant (WWTP) being the Dwarka plant, which has a capacity of 20 MGD. The exact population of the Bindapur catchment area is not available from the 2011 census data.

2.1 Design and Components of the Phytorid Treatment System at Bindapur

The effectiveness of the Phytorid treatment system is primarily determined by its surface area, calculated as the length multiplied by the width. This surface area is crucial for the system's treatment capacity, while the cross-sectional area (width multiplied by depth) determines the maximum flow rate it can handle. For optimal performance, approximately 5 to 10 square meters of surface area per person equivalent is typically required. To ensure the treated water meets recreational quality standards as specified in Schedule VI of the Environmental Protection Act (EPA), the Phytorid Treatment System at Bindapur was designed with the components detailed in Table 1.

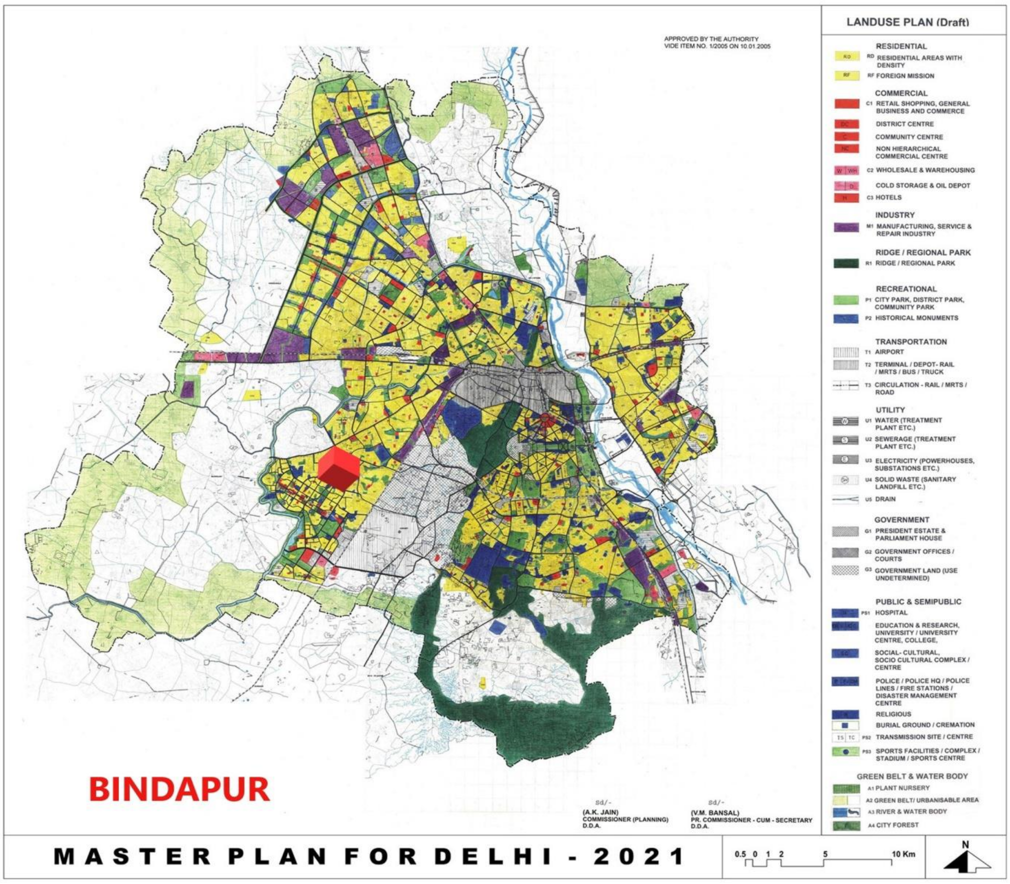

Fig. 1. Location of Bindapur in Delhi
(Source: DDA MPD 2021)

Table 1. Equipment Detail of Phytorid Treatment System at Bindapur

S. No.	Unit	Material of Construction	Capacity (M3)	Dimensions (Meter)	Qty
1	Screen Chamber	RCC *	2.1	3 X 1 X 0.7	01
2	Sump Well	RCC	37.33	3.5 X 3.68	01
3	Sedimentation Tank	RCC	276.76	17 X 4.4 X 3.7	01
4	Inlet launder	RCC	19.941	1 X 23.46 X 0.85	01
5	Phytorid Bed	RCC	997.6	19.96 X 22.7 X 2.2	01
6	Intermediate Collec. Tank	RCC	44.57	1 X 23.46 X 1.9	01
7	Hypochlorite Dosing Tank	HDPE**	NA	NA	01

** Reinforced Concrete Cement ** High Density Poly Ethylene*

2.2 Components of the Phytorid Treatment System at Bindapur

Key Components of the Phytorid Treatment System at Bindapur (Fig. 2) are as follows:

2.2.1 Screen chamber and sump well

Pre-treatment and primary treatment are critical for preventing blockages and ensuring smooth operation of the Phytorid system. The system includes components designed to handle incoming sewage/wastewater efficiently:

- Solid waste is removed using bar screens with aperture sizes of 5 mm and 3 mm.
- An oil and fat removal unit are integrated to enhance the performance of the collection and equalization tank (the sump).
- After initial separation, the sewage is pumped from the sump to the sedimentation tank for further processing.

2.2.2 Collection-cum-sedimentation tank

- The system includes six collection-cum-sedimentation tanks, each with a depth of 4 meters. Baffles within these tanks facilitate the settling of suspended solids while simultaneously achieving a significant reduction in BOD5 (more than fifty percent).
- An inlet cascade aerates the influent, promoting oxygen-dependent processes like BOD reduction and nitrification.
- To prevent leaching, the tank bed is lined with an impermeable material such as clay or geotextile.
- The design emphasizes a wide and shallow structure to maximize the flow path of water in contact with the roots of the vegetation, enhancing treatment efficiency.

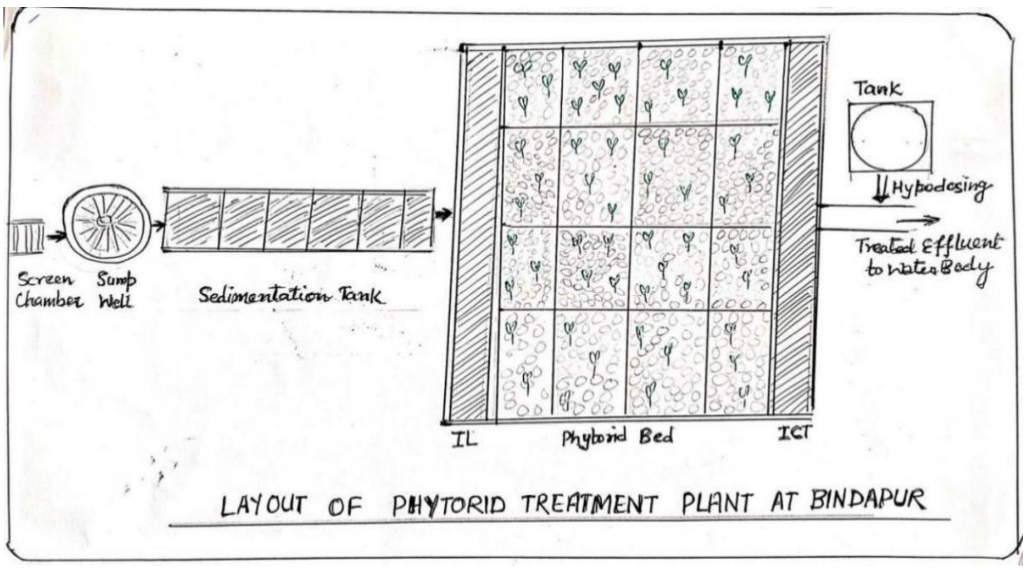

Fig. 2. Structural elements of the phytorid treatment system at bindapur

Fig. 3. Phytorid Bed with Canna indica at Bindapur

2.2.3 Phytorid beds with canna indica for phytoremediation

The Phytorid beds are filled with clean gravel (3–32 mm diameter) to a depth of 0.5–1 m, ensuring subsurface water flow at 5–15 cm below the surface and minimizing clogging. Canna indica, a resilient ornamental herb with deep roots and horizontal rhizomes, is planted on these beds. Native to tropical regions, Canna indica is effective in reducing pollutants such as BOD, COD, Total Suspended Solids (TSS), Total Phosphorus (TP), and Total Nitrogen (TN).

The plants, acclimatized to withstand wastewater with BOD of 300 mg/L and COD of 600 mg/L, sustain for at least 18 months. Additionally, the gravel bed system promotes pollutant removal through aerobic and anaerobic zones, achieving a fecal coliform reduction of over 99%. The system is energy-efficient, requiring minimal electricity and operational expertise, while matching or exceeding the performance of conventional STP processes.

2.2.4 Treated effluent disinfection

Post-treatment, the effluent is chlorinated using 10% sodium hypochlorite via a chlorine doser at the outlet launder. This ensures safe discharge into the Bindapur water body, contributing to its revival.

2.2.5 Sample collection and analysis

Samples were collected fortnightly from March 2022 to March 2023 at the inlet and outlet of the Phytorid system to evaluate treatment efficiency. Key parameters analyzed included turbidity, pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and ions such as sodium, potassium, calcium, and magnesium.

- **TDS and EC:** Indicators of ion concentration and water body health.
- **pH:** Reflects water acidity, influencing soil microbial activity and crop growth.

2.3 Different Indices for Irrigation Water Quality Assessment

To evaluate the suitability of irrigation water, various indices are calculated based on the concentration of ions and their influence on soil and plant health. These indices include:

2.3.1 Percent Sodium (%)

High sodium levels in irrigation water can reduce soil permeability and adversely impact plant growth. The **Soluble Sodium Percentage (SSP)** is calculated using the formula given by **(Todd and Mays).**

Soluble sodium percentage = [(Na + K) X100]/ (Ca + Mg +Na + K)

2.3.2 Sodium Adsorption Ratio (SAR)

The SAR measures the relative concentration of sodium compared to calcium and magnesium, influencing soil structure through clay particle dispersion or flocculation. It was calculated by this formula (Richards, 1954) The concentration of the ions was expressed in meq/L.

$$SAR = [\ Na+]/\ (1/2(Ca^{+}+Mg^{+2}))^{1/2}$$

2.3.3 Residual Sodium Carbonate (RSC)

RSC represents the excess of carbonate and bicarbonate over calcium and magnesium. Elevated RSC levels increase sodium hazards by precipitating calcium and magnesium ions. Formula (Eaton, 1950):

$$RSC\ Index = [HCO_3^- + CO_3^-] - [Ca^{2+} + Mg^{2+}]$$

A high RSC signifies reduced water suitability for irrigation (Bokhari & Khan, 1992).

2.3.4 Electrical Conductivity (EC)

EC measures the salinity hazard of irrigation water. Based on EC values, salinity hazard zones are categorized as (Richards, 1954):

Salinity Hazard	Category	EC Value (µS/cm)
Low	C1	<250
Medium	C2	250–750
High	C3	750–2250
Very High	C4	2250–5000

Saline water reduces soil productivity and plant efficiency in nutrient uptake.

2.3.5 Kelly's Ratio (KR)

KR evaluates sodium excess in irrigation water. A KR value <1.0 is considered suitable, while values >1.0 or >2.0 indicate high sodium and unsuitability for irrigation (Kelley, 1963):

$$Kelly's\ Ratio\ (KR) = Na^+ \div (Ca^{2+} + Mg^{2+})$$

2.3.6 Total Hardness (TH)

TH measures the concentration of alkaline earth metals (calcium and magnesium) in water. Categories are as follows.

TH (mg/L)	Water Category
<75	Soft
75–150	Moderately hard
150–300	Hard
>300	Very hard

2.3.7 Chloride Bicarbonate Ratio (CB Ratio)

The CB Ratio assesses seawater intrusion based on the chloride and bicarbonate ion concentrations.

CB Ratio	Remarks
<0.5	Good
0.5–1.3	Slightly contaminated
1.3–2.8	Moderately contaminated
2.8–6.6	Highly contaminated
6.6–15.5	Extremely contaminated

2.3.8 Magnesium Hazard (MH)

MH indicates the impact of magnesium levels on soil structure. Higher MH values (>50%) can result in alkaline soils unsuitable for crops. It was calculated by given formula (Bokhari & Khan, 1992).

$$MH = Mg^{2+} / (Ca^{2+} + Mg^{2+}) \times 100$$

2.3.9 Permeability Index (PI)

PI assesses the impact of ion-rich water on soil permeability (Pillai & Khan, 2016). PI is calculated by using the given equation-

$$(Na+K+\sqrt{HCo_3})\ X\ 100\ /(Ca+Mg+Na+K)$$

2.3.10 Graphical assessment of irrigation water quality

2.3.10.1 USSL diagram

The **USSL diagram** evaluates irrigation water quality by plotting SAR against EC. It identifies the salinity and sodium hazards, helping predict their effects on soil and crops.

2.3.10.2 Wilcox diagram

The **Wilcox diagram** plots sodium percentage (Na%) against EC or total dissolved solids (TDS), classifying water based on salinity and sodium hazards.

These graphical tools are integral in assessing water quality, guiding soil salinity management, and ensuring sustainable agricultural practices.

3. RESULTS AND DISCUSSION

The suitability of irrigation water largely depends on the presence of dissolved salts, essential nutrients, and undesirable constituents (Haritash et al., 2016). To evaluate water quality for irrigation, various indices were calculated, including Percent Sodium, Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Electrical Conductivity (EC), Kelly's Ratio (KR), Total Hardness, Chloride-Bicarbonate Ratio, Magnesium Hazard (MH), Permeability Index (PI), and Gibbs Ratio. These indices, derived from cation and anion concentrations, help assess the suitability of treated effluent for irrigation and reuse.

Various ranges and interpretation of different irrigation water quality indices to treated effluent quality, are given as under (Table 2).

Table 2. Various ranges and interpretation of irrigation water quality indices

Parameter	Range/Threshold	Category	Treated Effluent Value	Effluent Category
% Na	<20: Excellent	20–40: Good	40–60: Permissible	47.26
SAR	0–10: Excellent	10–18: Good	18–26: Doubtful	<7.0
RSC	<1.25: Good	1.25–2.5: Doubtful	>2.5: Unsuitable	-0.86
EC (µS/cm)	<250: Excellent	250–750: Good	750–2250: Permissible	>2250
KR	<1.0: Suitable	>1.0: Excess Na	>2.0: Unsuitable	1.4
TH (mg/L)	<75: Soft	75–150: Moderately Hard	150–300: Hard	>550
CB Ratio	<0.5: Good	0.5–1.3: Slightly Contaminated	1.3–2.8: Moderately Contaminated	1.4
MH	<50: Suitable	>50: Harmful & Unsuitable	-	47.26
PI	>75: Suitable	25–75: Moderately Suitable	<25: Unsuitable	64.3

3.1 Sodium Percentage

Water quality based on sodium percentage is categorized as either safe or unsafe for agricultural use, with Na% > 60 considered unsafe and Na% < 60 deemed safe (Eaton, 1950; Ravikumar et al., 2011). During the study, the average sodium percentage was 62.7 for inlet samples and 57.8 for outlet samples. This indicates that while the inlet water is unsuitable for irrigation, the outlet water falls within the permissible limit, making it suitable for agricultural purposes.

3.2 The Sodium Adsorption Ratio

The Sodium Adsorption Ratio (SAR) indicates the impact of sodium on soil structure, where higher SAR values reduce water suitability for irrigation by causing soil dispersion. (Ayers & Westcot, 1985; Suarez & Lebron, 1993). During the study, the average SAR for inlet and outlet samples was 6.78 and 6.82, respectively, reflecting excellent irrigation water quality despite potential concerns with excessive sodium affecting soil properties (Kelly, 1951).

3.3 Residual Sodium Carbonate (RSC)

RSC values <1.25 meq/L are safe for irrigation, 1.25–2.5 meq/L are marginally safe, and >2.5 meq/L indicate poor quality (Shil et al., 2019). High RSC can lead to sodium buildup, altering soil properties. During the study, average RSC values for inlet and outlet samples were -1.74 and -0.86, respectively, classifying all samples as safe for irrigation.

3.4 Electrical Conductivity (EC)

EC measures salinity hazard. In this study, EC values ranged from 2120 to 2755 µS/cm, with an average of 2409 µS/cm across all samples, indicating moderate salinity levels. High salinity in irrigation water can make it unsuitable for use, as it leads to soil salinization and reduces plants' ability to absorb nutrients efficiently. Based on salinity, all water samples in this study were classified as C4 (very high salinity), indicating their unsuitability for irrigation purposes.

3.5 Kelly’s Ratio

Kelly’s Ratio (KR) assesses excess sodium in irrigation water. This ratio is estimated by measurement of sodium against the total of calcium and magnesium ions. In this study, the average KR was 1.29 for inlet water (doubtful for irrigation) and 1.0 for outlet water (suitable for irrigation).

3.6 Total Hardness

Total Hardness (TH) indicates the concentration of alkaline earth metals in water. In this study, the average TH was 554 mg/L for inlet water and 564 mg/L for outlet water, classifying both as very hard and unsuitable for irrigation.

3.7 Chloride Bicarbonate Ratio (CB Ratio)

The CB Ratio helps assess seawater intrusion, with chloride dominant in seawater and bicarbonate in groundwater. In this study, average CB Ratio values were 1.83 for inlet and 1.4 for outlet samples, indicating moderate contamination and moderate suitability for irrigation.

3.8 Magnesium Hazard (MH)

MH values below 50% are suitable for agriculture, while values above 50% are harmful due to soil alkalinity. The average MH was 42 for inlet and 42.76 for outlet samples, deeming them suitable for irrigation.

3.9 Permeability Index (PI)

PI assesses the impact of ions on soil permeability. Class I water (PI >75) is highly suitable, Class II (PI 25–75) moderately suitable, and Class III (PI <25) unsuitable. PI values of 67.5 (inlet) and 64.3 (outlet) indicate moderate suitability for irrigation.

3.10 Classification of Water for Irrigation Suitability

The USSL diagram and the Wilcox diagram were plotted to quickly find the effectiveness of the Phytorid treatment system over a period of time and viability of the treated effluent for the irrigation purpose.

3.11 USSL Diagram

The USSL diagram assesses irrigation water quality by plotting Sodium Adsorption Ratio (SAR) on the Y-axis and Electrical Conductivity (EC) on the X-axis. SAR values measure sodium hazard, while EC indicates salinity hazard. Based on the study (March 2022–March 2023), the inlet and outlet SAR and EC values (Table 3) were categorized as follows.

Table 3. SAR and EC values of Inlet and the outlet samples

Months	EC/Inlet	SAR/Inlet	EC/Outlet	SAR/Outlet
Mar-22	2316	7.14	2338	7.228416
Apr-22	2184	6.55	2390	6.910137
May-22	2472	7.25	2339	7.35527
Jun-22	2292	6.74	2443	6.886581
Jul-22	2332	6.56	2120	6.652067
Aug-22	2361	6.67	2462	6.595453
Sep-22	2807	6.91	2580	6.892024
Oct-22	2294	6.52	2353	6.58597
Nov-22	5320	7	2755	6.892024
Dec-22	2352	6.55	2260	6.726812
Jan-23	2323	6.78	2290	6.837397
Feb-23	2329	6.65	2326	6.652067
Mar-23	2648	6.7	2668	6.519202

SAR Classification:

- *S1 (Low): 0–10*
- *S2 (Medium): 10–18*
- *S3 (High): 18–26*
- *S4 (Very High): >26*

EC Classification:

- *C1 (Low): <250 µS/cm*
- *C2 (Medium): 250–750 µS/cm*
- *C3 (High): 750–2250 µS/cm*
- *C4 (Very High): 2250–5000 µS/cm*

Table 4. USSL Chart for explanation

Class	Explanation	Class	Explanation
C1-S1	Very good quality	C1-S3	Medium quality
C2-S1	good quality	C2-S3	Medium quality
C3-S1	Medium quality	C3-S3	Very Bad quality
C4-S1	Bad quality	C4-S3	Very Bad quality
C1-S2	good quality	C1-S4	Bad quality
C2-S2	good quality	C2-S4	Bad quality
C3-S2	Bad quality	C3-S4	Very Bad quality
C4-S2	Bad quality	C4-S4	Very Bad quality

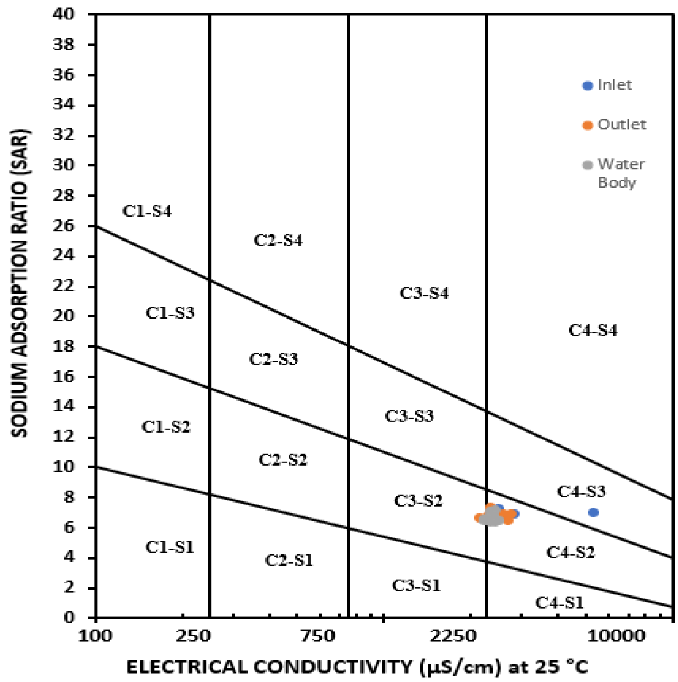

Fig. 4. USSL Diagram for Inlet and Outlet of phytorid treatment system at Bindapur

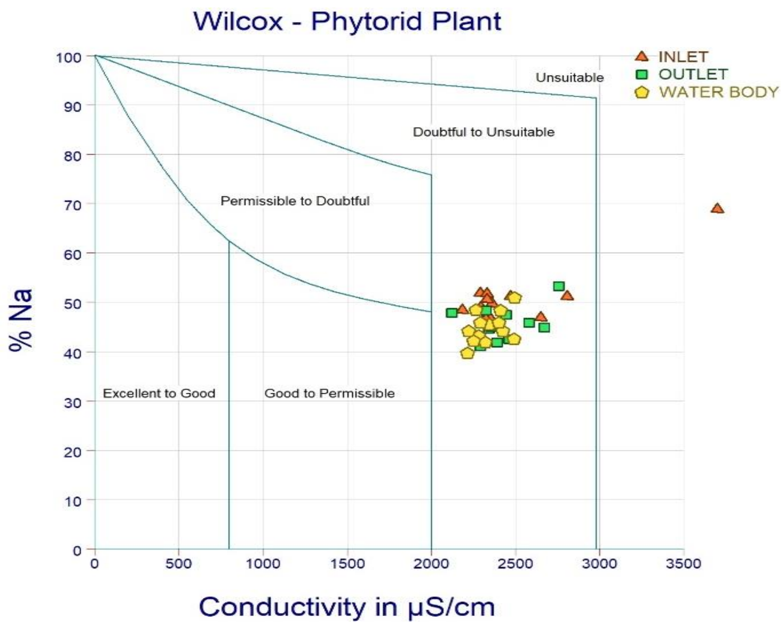

Fig. 5. Wilcox Diagram relating EC to % Sodium in Inlet/ and Outlet of Phytorid treatment

Based on the EC value (C1-C4) and the SAR values (S1-S4), the irrigation water quality can be described as per the criteria given in Table 4.

SAR and EC values of Inlet and the outlet water samples for the study period were plotted in the graphical representation (Figs. 4 and 5).

Most samples fell into **C4-S2** (very high salinity, medium sodium), making them unsuitable for irrigation on soils with restricted drainage. Exceptions include:

- One inlet sample in **C4-S3** (very high salinity, high sodium), categorized as very bad quality.

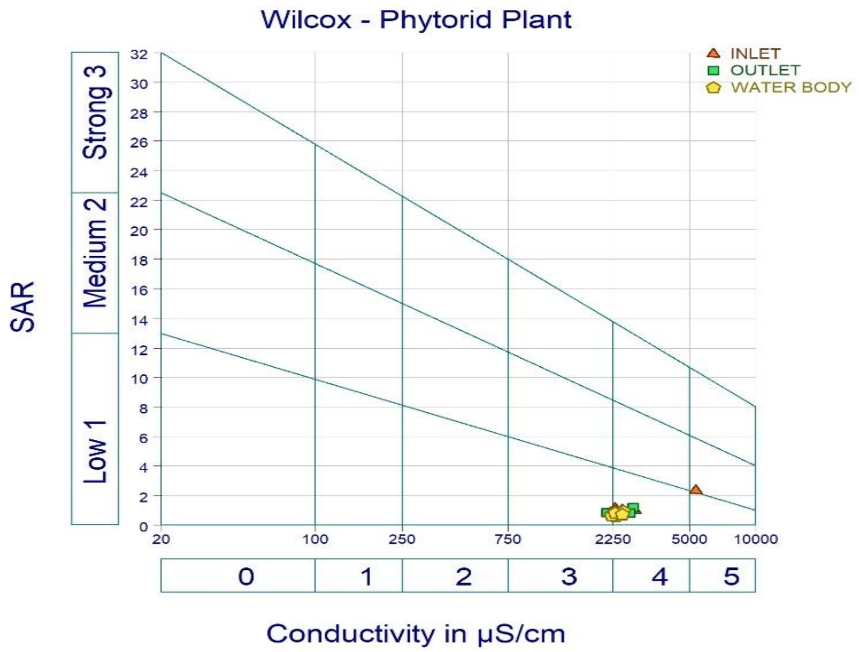

Fig. 6. Wilcox Diagram relating EC to Sodium Absorption Ratio (SAR) in Inlet/ Outlet of Phytorid

- One outlet sample in **C3-S2** (high salinity, medium sodium), of bad quality.

High EC results in saline soils, while high sodium levels lead to alkaline soil, further limiting irrigation use.

Wilcox Diagram: The Wilcox diagram classifies irrigation water by plotting EC against sodium percentage.

The average sodium percentage during the study was 62.7 for inlet samples and 57.8 for outlet samples, while the average electrical conductivity (EC) was 2618 µS/cm and 2405 µS/cm, respectively. Based on the analysis and the Wilcox diagram plotting EC against sodium percentage, all samples were classified in the doubtful to unsuitable category for irrigation purposes.

The Fig. 6 also emphasizes the earlier observation that the majority of samples fall into the category of low sodium hazard but high to very high salinity hazard. Based on the data and the Wilcox Diagram, which plots EC against % Sodium and SAR for 20 groundwater samples, most samples were classified as unsuitable for irrigation. However, one sample was categorized as good to permissible, and another as doubtful for irrigation use.

4. CONCLUSION

The evaluation of treated wastewater from Bindapur highlights significant concerns regarding its suitability for irrigation, primarily due to elevated salinity, sodium, and alkalinity levels. These issues threaten soil health, crop productivity, and long-term agricultural sustainability. To mitigate these risks, strategies such as blending treated water with low TDS sources or further treatment measures are essential. Proactive management of water quality is crucial for ensuring the sustainable use of reclaimed water in irrigation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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