OPEN ACCESS
Kashf Journal of Multidisciplinary Research
Vol: 02 - Issue 2 (2025)
P-ISSN: 3007-1992 E-ISSN: 3007-200X
https://kjmr.com.pk

UTILIZATION OF PLANT LEAVES TO TREAT WASTEWATER FOR IRRIGATION PURPOSE

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DOI: https://doi.org/10.71146/kjmr262

Article Info

Abstract

This study focuses on the remediation of wastewater both grey and black water to be used in agricultural purposes in Pakistan, a country which is likely to suffer severe clean water shortage due to rapid growth of population caused by urbanization. It has become the need of time to remediate wastewater so that it can be used where applicable such as agriculture. Inadequate and unprocessed disposal of wastewater from homes and industries causes both health risks for humans as well as wildlife and environmental challenges. By conducting this study, we can observe the effectiveness of using macrophytes, specifically duckweed, in a bench-scale wastewater treatment model to reduce pollutants to concentrations allowable to be utilized in agriculture, in accordance with FAO directives. The study has been conducted in five experimental intervals with different Hydraulic Retention Times (HRTs) of 0, 3, 5, 7, and 10 days, measuring reductions in Electroconductivity (ECw), Sodium Adsorption Ratio (SAR), Dissolved Solids Concentration (TDS) and other key parameters. Recorded results and data showed drastic reductions across all characteristics, with TDS and ECw concentrations reduced by up to 35% and SAR by over 40% after 10 days of HR. The results suggest that 10-day hydraulic retention time with macrophytes especially Duckweed provides solution to various environmental challenges by carbon sequestration ultimately reducing the hazardous consequences of disposal of wastewater without any treatment. By implicating the methodologies conducted in this research, environmental policies and practices can be designed to overcome water shortage caused by use of freshwater or groundwater which is conventionally being used for irrigation purposes in Pakistan.

Keywords: *Wastewater Treatment, Phytoremediation, Duckweed, Macrophytes, Irrigation.*

Introduction

According to the findings by Planning and development department, Government of Pakistan, current population is projected to rise to 208 million by 2025.Such rapid growth of population faces extreme clean water shortage. Lack of infrastructure for proper disposal of wastewater of this large population leads to exposure of pathogens and disease-causing bacteria. This pollution pollutes ground and surface water, leading to waterborne diseases and potential health risks. The World Health Organization reported that around 5 million people die each year due to inadequate wastewater disposal facilities, with about 25 million lacking proper sanitation services (JMP WHO-UNICEF, 2012). To address this issue, wastewater treatment methods like oxidation ponds are recommended for developing countries like Pakistan. Waste Stabilization Ponds are the most economical and efficient method for treating domestic wastewater, as they are easy to operate and cost-effective. Pakistan's growing population and decreasing water availability resources are causing significant problems for the agricultural sector. Proper crop selection, soil conditions, and irrigation systems can help reduce health hazards. Low-level treatment is particularly significant in developing countries due to its low cost and complexity. Our research aims to determine the percentage reduction in wastewater parameters and evaluate the samples to determine their initial raw water value and treatment duration, and required hydraulic retention time for irrigation purposes. Agricultural irrigation accounts for 70% of global water usage, with treated municipal wastewater serving as a critical resource for upcycling and reutilize, particularly in Mediterranean areas and dry regions. The paper discusses the long-term effects on soils and plants (Pedrero et al., 2010). A pilot plant treated wastewater treatment effluent, irrigating an experimental plot with six ornamental species, showed effective bacteria removal and good plant growth. The refinery treatment, including filtration and disinfection, maintained nutrient content (Lubello et al., 2004). Treated wastewater (TW) boosts water resource utilization effecting on soil fertility, plants, and public health (Hashem and Qi, 2021). Utilizing treated effluent for eggplant irrigation revealed low heavy metal content, moderate irrigation restrictions, and high chlorophylla concentration (Al-Nakshabandi et al., 1997). A growth-irrigation scheduling model (GISM) was created for Eucalyptus plantations utilizing a lagoon sewage treatment system, accurately modelling height, and diameter growth useful for predicting tree growth and scheduling irrigations, understanding tree responses to environmental and water stress (Al-Jamal et al., 2001). The study in Murcia, Spain, assessed the impact of treated wastewater on citrus plants, finding that Cartagena's treated wastewater improved agronomic quality, but faced issues with high salinity and B accumulation. (Pedrero and Alarcón, 2009). A new mathematical model predicts a 16% increase in annual wastewater production from 2010 to 2025, affecting water demand and wastewater quantity in Logan, Utah (Ahmadi and Merkley, 2017). Using wastewater for irrigation raises soil pH, magnesium (Mg), potassium (K), calcium (Ca), total organic carbon (TOC), total nitrogen (TN), and cation exchange capacity (CEC), with cation exchange wastewater causing the most adverse effects. The study suggests that wastewater resources are valuable for improving soil fertility and crop growth (Abegunrin et al., 2016). Macrophytes improve wastewater quality by efficiently absorbing nutrients through their robust root systems (Sayanthan, Hasan and Abdullah, 2024). Purpose of our study is to evaluate the effectiveness of plants macrophytes in mitigating the hazardous effects of wastewater so that it can in utilized in irrigation purposes.

Materials and Methods

Macrophytes play a crucial role in enhancing wastewater quality by efficiently absorbing nutrients through their robust root systems (Waste Stabilization Ponds) leading to employing treated wastewater for irrigation in compliance with the Food and Agriculture Organization (FAO) standards for Irrigation Water Quality. A compact bench-scale model was engineered and assembled at hydraulic lab of Bahauddin Zakariya University, Multan. The domestic wastewater was collected from university's domestic sewer. In our research, a specific Macrophytes Species Lemna called Duckweed was under study. Model was made with tempered glass of thickness 25mm with steel frame to protect outer surface of model and can be visualized in Figure 1.

Figure 1: Physical View of Model

To evaluate the treatment's removal efficiency, a Sampling methodology was devised and implemented, incorporating five trial runs with Hydraulic Retention Times (HRT) of 0, 3, 5, 7, and 10 days. For each specified HRT, three samples were collected and analysed according to the standards outlined by the American Public Health Association's Standard Methods for the Examination of Water and Wastewater and World Health Organization (WHO). Suitable number of Duckweeds were added to samples apparent in Figure 2 after retention began, forming sample containing model an artificial waste stabilization pond so that treatment by the under monitored macrophyte could be observed. Meanwhile this experiment, the average temperature was between 20^0C-25^0C, mostly 23°C. The Duckweeds covered between 81% and 92% of the surface area.

Figure 2: Duckweed (Lemna) added in sample

Parameters under examination

The wastewater parameters chosen for examination include pH, Fecal Coliform, Sodium adsorption ratio (SAR), the concentration of boron, sodium, chloride, bicarbonate, nitrate as well as Total Dissolved Solids (TDS) and Electrical Conductivity (ECw), all these directly affect water contamination and must be considered in-range as per FAO Irrigation Water Quality Guidelines for use in Agriculture. Following treatment at each HRT, samples of the treated wastewater were gathered from the aquatic model and analysed in the laboratory of the Pakistan Council of Research in Water Resources (PCRWR) in Multan.

Results and Discussion

The results of unrefined samples prior to the commencement of each trial are presented in Table 1. The standard ranges outlined in Table 1 are derived from the Irrigation Water Quality Guidelines provided by the Food and Agriculture Organization (FAO).

Table 1. Composition of Raw water along with Deviation from Standard Range

Parameter	Unit	Sample 1	Sample 2	Sample 3	Avg.	Standard Deviation	Permissible Standard Range
EC_w	ds/m	3.987	4.012	4.325	4.108	1.108	3
TDS	mg/L	2645	2345	2501	2497	497	2000
SAR	No.	6.49	5.81	4.89	5.73	2.73	0 - 3
Sodium	mEq/L	11.95	9.87	13.05	11.62	8.62	Less than 3
Chloride	mEq/L	11.82	10.46	10.78	11.02	0.98	4 -10
Boron	mg/L	5.01	4.76	5.24	5.00	2.00	less than 3
Nitrate	mg/L	37.24	36.25	34.11	35.86	5.86	less than 30
Bicarbonate	mEq/L	16.45	13.98	12.58	14.33	5.83	less than 8.5
pH	No.	8.86	7.91	8.95	8.57	0.17	6.5 to 8.4
Fecal Coliform	No./100mL	1345	1198	1250	1264	134	1130

The following tables present the average reduction in compositions after each Hydraulic Retention Time (HRT) across three experimental runs.

Table 2. Test outcomes of 1st Sample after HRT

Parameter	Unit	Raw water	Results of HRT				10 days HRT reduction rate
			3 days	**5 days**	**7 days**	**10 days**	
EC_w	dS / m	3.987	3.972	3.512	3.196	3.005	24.63 %
TDS	mg/L	2645	2495	2196	2035	1871	29.26 %
SAR	No.	6.49	5.86	4.91	4.23	3.78	35.49 %
Sodium	mEq/L	11.95	11.49	11.12	9.76	8.25	30.96 %
Chloride	mEq/L	11.82	11.06	9.74	8.78	8.06	31.81 %
Boron	mg / L	5.01	3.94	3.73	3.41	3.03	39.52 %
Nitrate	mg/L	37.24	33.91	32.67	30.28	26.05	30.04 %
Bicarbonate	mEq/L	16.45	14.04	13.10	11.56	7.98	51.48 %
pH	No.	8.86	8.10	7.85	7.28	6.65	24.94 %
Fecal Coliform	No./100mL	1345	1154	1023	810	705	47.58 %

After 10-day hydraulic retention time, results for sample 1 indicate substantial contaminant removal efficiency, yet Boron, Nitrate and Bicarbonate compositions are above the allowable range.

Table 3. Test outcomes of 2nd Sample after HRT

Parameter	Unit	Raw water	Result of HRT				10 days HRT reduction rate
			3 days	**5 days**	**7 days**	**10 days**	
EC_w	ds / m	4.012	3.287	2.919	2.725	2.648	33.99 %
TDS	mg/L	2345	2287	2124	1945	1710	27.07 %
SAR	No.	5.81	5.34	4.63	3.86	3.15	45.78 %
Sodium	mEq/L	9.87	9.01	8.13	7.24	6.99	29.17 %
Chloride	mEq/L	10.46	9.25	8.27	7.45	6.65	36.42 %
Boron	mg/L	4.76	3.67	3.27	2.97	2.54	46.63 %
Nitrate	mg/L	36.25	28.76	25.34	23.12	20.65	43.03 %
Bicarbonate	mEq / L	13.98	11.65	10.05	9.12	8.96	35.90 %
pH	No,	7.91	7.39	6.97	6.81	6.78	14.28 %
Fecal Coliform	No. / 100 mL	1198	1015	943	841	721	39.81 %

After 10-day hydraulic retention time, results for sample 2 indicate reduction in all properties except for Boron, Nitrate, Bicarbonate, Sodium that are still above the allowable range, and chloride being above the allowable range but satisfying the tolerant crops nutrient requirement.

Table 4. Test outcomes of 3rd Sample after HRT

Parameter	Unit	Raw water	Result of HRT				10 days HRT reduction rate
			3 days	**5 days**	**7 days**	**10 days**	
EC_w	ds / m	4.325	4.157	3.715	3.354	3.009	30.42 %
TDS	mg/L	2501	2207	1912	1703	1412	43.54 %
SAR	No.	4.89	4.67	4.32	3.99	3.51	28.22 %
Sodium	mEq/L	13.05	11.14	9.35	8.17	7.22	44.67 %
Chloride	mEq/L	10.78	9.21	8.23	7.01	6.25	42.02 %
Boron	mg / L	5.24	5.01	4.64	4.28	3.66	32.47 %
Nitrate	mg/L	34.11	31.60	29.58	28.56	24.70	27.58 %
Bicarbonate	mEq/L	12.58	9.64	7.30	6.62	5.12	59.30 %

pH	No.	8.95	7.32	7.11	6.81	6.51	27.26 %
Fecal Coliform	No./ 100mL	1250	1123	907	735	698	44,16 %

Results for sample 3 show significant contaminant reduction in all parameters under study yet Sodium, Chloride, Boron, Nitrate, Bicarbonate levels are still slightly above the allowable range for the sample to be used in irrigation.

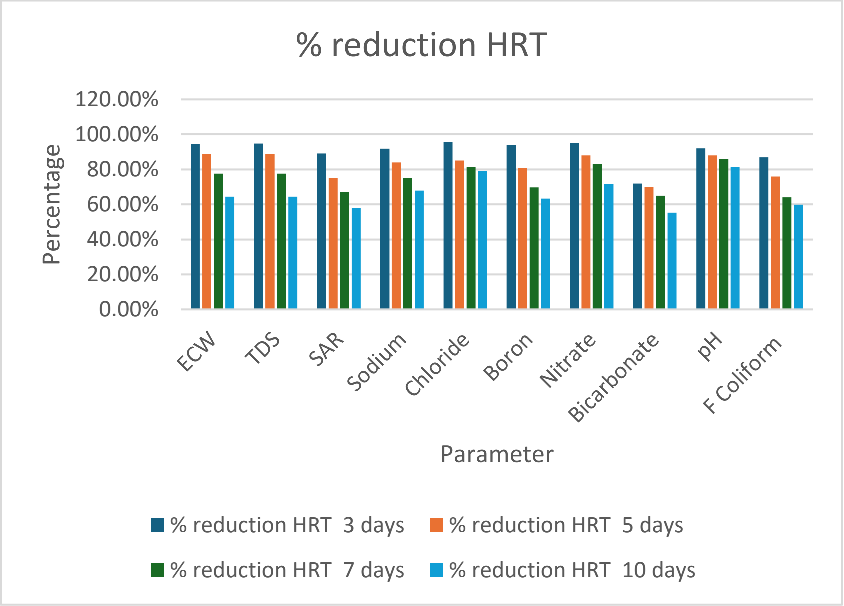

FIGURE 3: HRT REQUIRED FOR WASTEWATER CONSTITUENTS TO BE USED IN IRRIGATION

As depicted in Figure 3, the appropriate Hydraulic Retention Time (HRT) needed to meet the FAO Irrigation Water Quality Guidelines is 10 days.

Conclusions

This investigation reveals that a 10-day hydraulic retention time for macrophyte-based Waste Stabilization Ponds (WSP) reduced grey and black water pollutants to levels allowable for irrigation, meeting FAO guidelines. Key pollutant reductions achieved include 31.96% for ECw, 42.51% for SAR, and 41.39% for F. Coliforms. Extended retention time and temperatures between 20°C–25°C improve treatment efficacy, particularly for duckweed growth. By monitoring duckweed density, sufficient sunlight penetration can be ensured which enhances pond efficiency. Utilization of phytoremediation for wastewater treatment helps to minimize the dependency on non-renewable resources by implementing natural abilities of plants to clean water. This approach contributes to boosting energy efficiency and nutrient recycling, reducing chemical use and infrastructure investment. Further research on optimization of plant species and genetic engineering for carbon sequestration and climate change mitigation can facilitate policies for environmental protection.

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