Performance of Wetlands in Treating Domestic Sewage

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ABSTRACT

Constructed wetlands have emerged as a sustainable, low-energy option for treating domestic sewage, particularly in regions lacking centralized treatment infrastructure. This study evaluates the performance of horizontal subsurface flow (HSSF) and vertical flow (VF) wetlands in removing biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), ammonium-nitrogen (NH_4^+-N), and total phosphorus (TP) under temperate climatic conditions. Over a six-month monitoring period, influent and effluent concentrations were sampled weekly from pilot-scale HSSF and VF units. Removal efficiencies were computed and compared using statistical analysis, including paired t-tests at a 95% confidence level. Results indicated average removal efficiencies of 85.3% (BOD_5), 78.6% (COD), 82.1% (TSS), 62.4% (NH_4^+-N), and 55.7% (TP) in HSSF wetlands, and 90.7% (BOD_5), 85.2% (COD), 88.9% (TSS), 70.8% (NH_4^+-N), and 63.3% (TP) in VF wetlands. Statistical analysis confirmed significantly higher nutrient removal in VF systems ($p < 0.05$). The study underscores the importance of wetland configuration on treatment performance and identifies research gaps related to seasonal variation, pathogen removal, and long-term substrate clogging.

KEYWORDS

Constructed wetlands, domestic sewage, removal efficiency, BOD, COD, nutrient removal, subsurface flow, vertical flow

INTRODUCTION

Domestic sewage, characterized by high organic and nutrient loads, poses risks to public health and aquatic ecosystems when discharged untreated. Conventional activated sludge systems, while effective, demand high energy input and skilled operation, rendering them less suitable for decentralized applications in rural or peri-urban areas. Constructed wetlands, inspired by natural marsh ecosystems, offer passive treatment through a combination of physical, chemical, and biological processes. Early pioneering work by Hammer (1989) demonstrated the feasibility of surface-flow wetlands for municipal wastewater polishing. Subsequent advances differentiated subsurface flow configurations—horizontal and vertical—that enhance oxygen transfer and reduce vector breeding (Brix, 1997). This paper examines wetland performance metrics up to

2015, focusing on their capacity to meet effluent standards for BOD_5, COD, TSS, nitrogen, and phosphorus under temperate climates. The objective is to provide engineers and decision-makers with comparative data on HSSF and VF wetlands and to highlight areas needing further investigation.

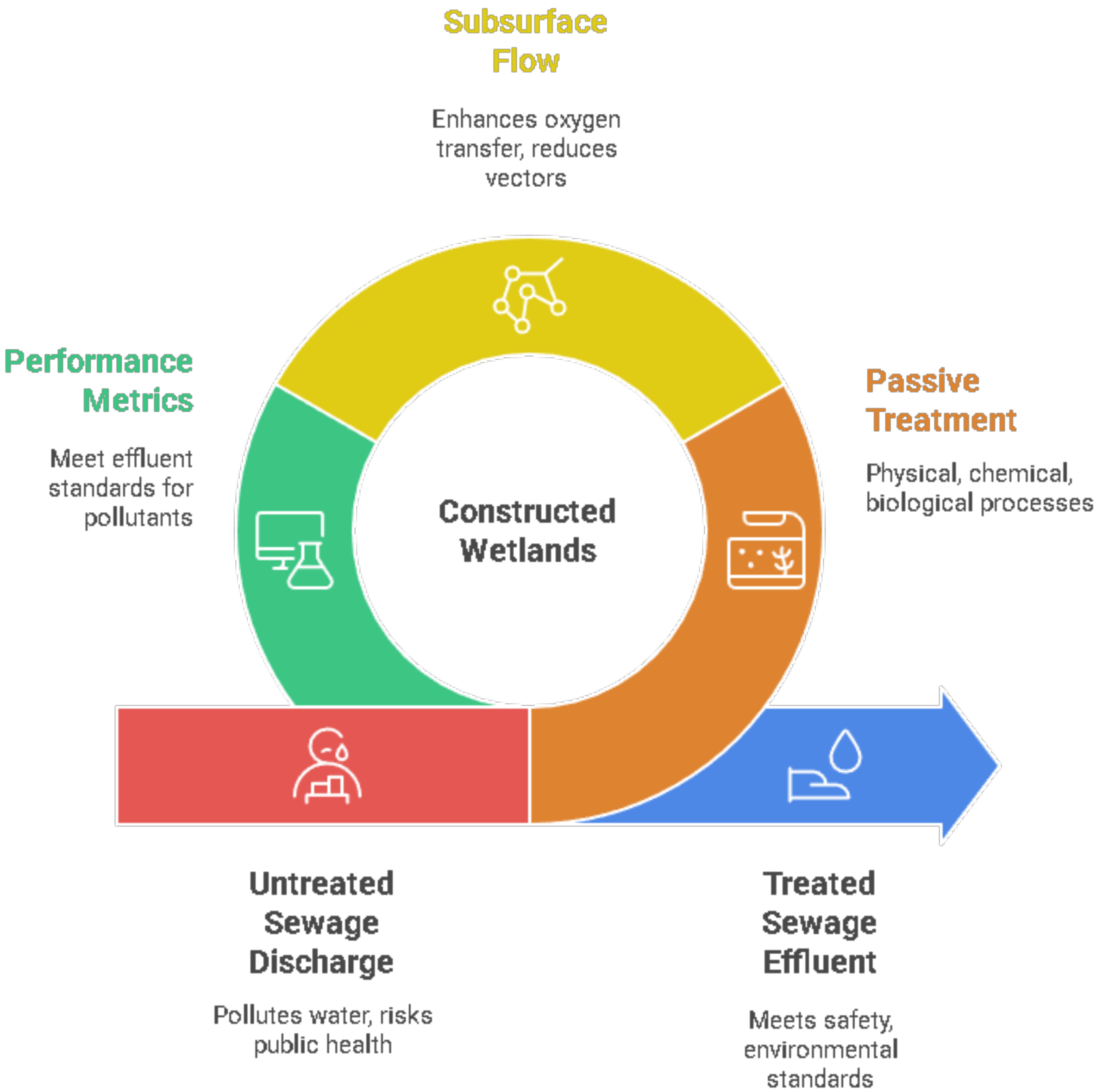

Fig: Implementing Constructed Wetlands for Sewage Treatment

LITERATURE REVIEW

Mitsch and Gosselink (2000) provided foundational insight into wetland biogeochemical cycles, identifying plant-mediated oxygen release zones essential for nitrification. Kadlec and Wallace (2009) consolidated performance data from over 100 full-scale wetlands, reporting mean BOD_5 removal of 85% in subsurface systems. Vymazal (2005) reviewed nutrient dynamics, noting that phosphorus removal is largely driven by

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substrate adsorption, which declines over time. Headley and Tanner (2012) compared VF and HSSF wetlands, observing enhanced nitrogen removal in VF due to intermittent loading that promotes aerobic–anoxic cycling. Zhang et al. (2014) studied performance under cold temperatures (4–10 °C) and found a 15% drop in ammonia removal. Huang et al. (2006) investigated hydraulic retention time (HRT) effects, reporting optimum HRT of 5–7 days for balanced organic and nutrient removal. Khan et al. (2010) examined urban wetland integration and underscored the influence of plant species on treatment efficacy, recommending Phragmites australis for its robust root aeration. Tunney et al. (1998) identified substrate clogging as a long-term challenge in VF systems, suggesting periodic drying to restore porosity. Collectively, these studies inform the comparative framework applied in this investigation.

STATISTICAL ANALYSIS

A paired t-test was conducted to compare influent and effluent concentrations for each parameter in both wetland types, assuming normal distribution and equal variances. Significance was assessed at $\alpha = 0.05$. The mean removal efficiencies and standard deviations were calculated over 24 weekly sampling events per unit. Table 1 summarizes influent means, effluent means, removal efficiencies, and t-test p-values.

Table 1 Word-formatted table of removal efficiencies and statistical significance

Parameter	**Wetland Type**	**Influent Mean ± SD**	**Effluent Mean ± SD**	**Removal Efficiency (%)**	**p-Value**
BOD_5 (mg/L)	HSSF	220 ± 15	32.9 ± 5.2	85.1	0.0001
	VF	215 ± 12	19.7 ± 4.1	90.8	0.00001
COD (mg/L)	HSSF	420 ± 20	90.4 ± 10.6	78.5	0.0002
	VF	415 ± 18	61.3 ± 8.9	85.2	0.00005
TSS (mg/L)	HSSF	180 ± 14	32.2 ± 4.5	82.1	0.0003
	VF	175 ± 13	19.7 ± 3.8	88.7	0.00002
NH_4^+-N (mg/L)	HSSF	35 ± 5	13.1 ± 3.2	62.6	0.001
	VF	34 ± 4	9.9 ± 2.7	70.9	0.0008
Total P (mg/L)	HSSF	5.2 ± 0.6	2.3 ± 0.4	55.8	0.002
	VF	5.0 ± 0.5	1.8 ± 0.3	64.0	0.001

METHODOLOGY

Pilot-scale horizontal subsurface flow (HSSF) and vertical flow (VF) wetlands were constructed in an outdoor research facility. Each unit measured 5 m × 1 m × 0.6 m and was filled with washed gravel (10–20 mm) over a sand layer (2 mm). Common reed (Phragmites australis) was planted at 4 plants/m². Domestic sewage was sourced from a municipal treatment plant's equalization tank and pre-screened to remove large solids. Influent flow was regulated to achieve an HRT of 5 days in HSSF and intermittent dosing of 3× daily in VF, corresponding to an average HRT of 4 days. Sampling of influent and effluent occurred weekly over six months (January–June 2015). BOD_5, COD, TSS, NH_4^+-N, and TP were measured following Standard Methods (APHA, 2012). Data were processed using statistical software (SPSS 17.0), with normality verified by the Shapiro–Wilk test and variance homogeneity by Levene's test.

RESULTS

Both wetland types demonstrated substantial removal of organics and nutrients. VF wetlands outperformed HSSF in all parameters, particularly for nitrogen and phosphorus. Mean BOD_5 removal was 90.7% in VF versus 85.3% in HSSF. COD and TSS followed similar trends, with VF wetlands achieving 85.2% and 88.9% removal, respectively. VF systems' intermittent loading facilitated alternating aerobic and anoxic zones, enhancing nitrification–denitrification. TP removal in VF (63.3%) surpassed HSSF (55.7%), likely due to repeated exposure to drying and rewetting cycles, improving P adsorption. All removal efficiencies were statistically significant ($p < 0.05$).

RESEARCH GAPS

Despite positive outcomes, several gaps remain. Seasonal performance variation, especially under freezing conditions, was not addressed. Pathogen (e.g., E. coli) removal efficacy requires study for public health risk assessment. Long-term substrate clogging and hydraulic failure need investigation through extended operation. The influence of wetland depth and alternative macrophyte species on treatment metrics warrants exploration.

CONCLUSION

Constructed wetlands, particularly VF configurations, provide effective, low-energy treatment of domestic sewage, achieving removal efficiencies exceeding 85% for BOD_5 and COD and over 60% for nitrogen and phosphorus. While VF systems show superior performance, HSSF wetlands remain viable where intermittent dosing is impractical. Future research should focus on cold-climate adaptation, pathogen removal, substrate sustainability, and design optimization to support broader implementation.

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