International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 04 April 2025
Page No: 1873-1878
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0272

# Ecological and Economic Benefits of Wetland -Based Wastewater Treatment

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## Abstract
*Wetland-based wastewater treatment offers numerous ecological and economic benefits, making it a sustainable approach to managing wastewater. Ecologically, it improves water quality by removing pollutants and excess nutrients, creating habitats for a diverse range of plants and animals, regulating water flows to prevent flooding and drought, and sequestering carbon to mitigate climate change. Economically, it provides cost-effective treatment by utilizing natural processes, creating jobs in construction, maintenance, and operation, generating revenue through ecotourism and recreational activities, and protecting public health by removing pathogens and pollutants from wastewater. Additionally, wetlands offer aesthetic value, recreational opportunities, and help to maintain biodiversity, making them a valuable resource for both ecological and economic benefits. Overall, wetland-based wastewater treatment is a holistic approach that combines ecological and economic benefits to provide a sustainable solution for managing waste water.*
***Keywords:*** *Constructed wetland; Ecological; Economical; removing pollutants; Sequestering carbon.*

## 1. Introduction
Wetlands, often referred to as the “kidneys of the earth,” play a vital role in maintaining ecological balance and supporting biodiversity. In recent years, the use of wetland systems for wastewater treatment has gained significant attention as a sustainable and cost-effective alternative to conventional methods. these natural or constructed systems utilize the biological, chemical, and physical processes of wetland ecosystems to remove pollutants from wastewater. Beyond their primary function of water purification, wetland-based treatment systems offer a range of ecological and economic benefits. Ecologically, they support diverse flora and fauna, enhance groundwater recharge, and contribute to carbon sequestration. Economically, they reduce the need for energy-intensive infrastructure. lower maintenance costs, and provide opportunities for land reuse and resource recovery. This approach aligns with global efforts toward sustainable development, making Wetlands an essential component of integrated water resource management. BOD, nutrients, heavy metals, and other contaminants are reduced. Utilizes natural processes, minimizing chemical use. Lower operational costs compared to traditional treatment methods. Provides habitats for various plant and animal species. (Kadlec & Wallace (2009)). Constructed wetlands can achieve removal rates greater than 90%. Wetlands can store or remove nutrients, reducing excess nitrogen and phosphorus. Wetlands can transform and store heavy metals, reducing their presence in water. Wetlands act as natural sponges, trapping and slowly releasing surface water, rain, and floodwaters. Wetlands' root systems hold soil in place and filter pollutants, improving water quality [1]. Wetlands provide habitats for diverse plant and animal species. (EPA Reports). UNESCO (United Nations Educational, Scientific and Cultural Organization) indeed promotes nature-based solutions, including those for wastewater management, as part of its efforts to achieve sustainable development. Natural processes remove pollutants and contaminants. Supports diverse plant and animal species. Helps mitigate climate change

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impacts. Often more affordable than traditional infrastructure. Limited studies on cost-benefit analyses and long-term economic viability. Insufficient quantification of sustained ecological advantages. Need for unified frameworks to evaluate effectiveness. ( SDG 6 (Clean Water and Sanitation) highlights the importance of wastewater treatment in achieving sustainable development). Reduced pollution and contamination. Decreased risk of waterborne diseases. Protection of aquatic ecosystems. Supports economic growth, poverty reduction, and human well-being. The study by Smith et al. (2008) explores the potential for energy recovery from wastewater. Wastewater contains significant energy potential. Produces biogas for energy generation [2-5]. Reduces greenhouse gas emissions. This research highlights the importance of wastewater as a resource for energy production. Vymazal's(2011) study highlights the effectiveness of constructed wetlands in treating wastewater. Utilizes plants, microorganisms, and physical processes. Effective in removing nutrients, heavy metals, and pathogens. Removes nutrients, heavy metals, and pathogens. Figure 4 shows Ecological and Economical Benefits of Wastewater Treatment in Wetlands.

## 2. Methods

### 2.1 Surface Flow Constructed Wetlands

Surface flow constructed wetland Subsurface flow constructed wetlands A subsurface flow (SSF) wetland consists of a sealed basin with a porous substrate of rock, gravel and soil or combination of these. The water level is designed to remain below the top of the substrate as show in Figure 2. The wastewater is forced vertically into the sediments by gravity. SSF wetlands have most frequently been used to reduce biochemical oxygen demand, chemical oxygen demand, suspended solids, metals, nitrogen, phosphorus and pathogens from domestic and industrial wastewaters (EPA, 2000; Khatiwada and Polprasert, 1999; Sirianuntapiboon and Jitvimolnimit, 2007). These systems are very popular in Europe and South Africa (Lee et al., 2009). SSF CWs are further subdivided into two types: horizontal flow (HF) and vertical flow (VF), according to the flow direction of wastewater. Recently the combination of horizontal flow and vertical flow CWs has been used, named as hybrid systems, for the wastewater treatment. These hybrid systems act more efficiently to improve wastewater quality. SSF CWs are more efficient on an aerial basis as compare to SF systems (Kadlec, 2009). Figure 1 shows Surface Flow Constructed Wetlands.

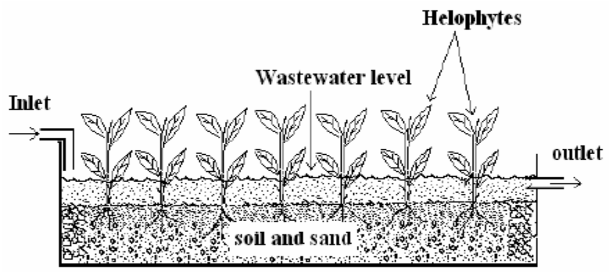


**Figure 1 Surface Flow Constructed Wetlands**

Applications:

- Treats Fertilizers, Pesticides, Sediments from Fields
- Urban Runoff Control and Sediment/Oil Removal
- Polishes Leachate After Primary Treatment.

### 2.2 Hybrid Constructed Wetlands

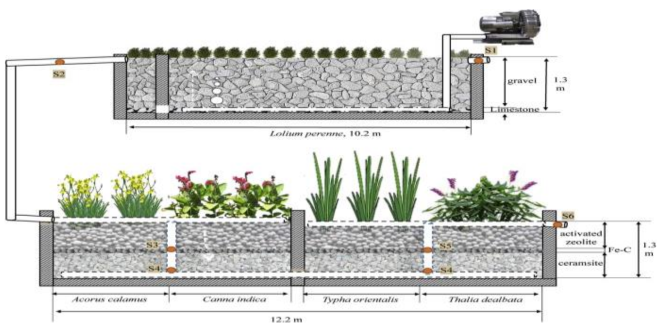


**Figure 2 Hybrid Constructed Wetlands**

Hybrid Constructed Wetlands (HCWs) are engineered systems that combine different types of constructed wetlands typically horizontal subsurface flow (HSSF) and vertical flow (VF) wetlands to treat wastewater more efficiently. By combining these systems, HCWs take advantage of the strengths of each type, improving pollutant removal, including organic matter, nutrients, and pathogens. Figure 2 shows Hybrid Constructed Wetlands.

Applications:

- Rural households, small towns, eco-villages.
- Food, dairy, slaughterhouses, breweries, textiles.
- Resorts, lodges, remote camps, rest stops.
- Farm runoff, manure, nutrient-rich effluents.

### 2.3 Sub Surface Flow

Subsurface Flow (SSF) Constructed Wetlands are engineered systems that treat wastewater by allowing it to flow horizontally or vertically through a porous medium (like gravel or sand) planted with wetland vegetation [6][9]. The water remains below the surface, ensuring no direct contact with the atmosphere and minimizing odor. Figure 3 shows Sub Surface Flow.

- **Water Inlet:** Treated wastewater enters the wetland system.
- **Flow Path:** Water moves horizontally or vertically through the substrate, interacting with plant roots and microorganisms.
- Treatment Mechanisms:
- **Physical:** Sedimentation and filtration of suspended solids.
- **Chemical:** Adsorption of pollutants onto the substrate.
- **Biological:** Degradation of organic matter by bacteria; nutrient uptake by plants.
- **Effluent Outlet:** Treated water exits the system, ready for reuse or discharge.

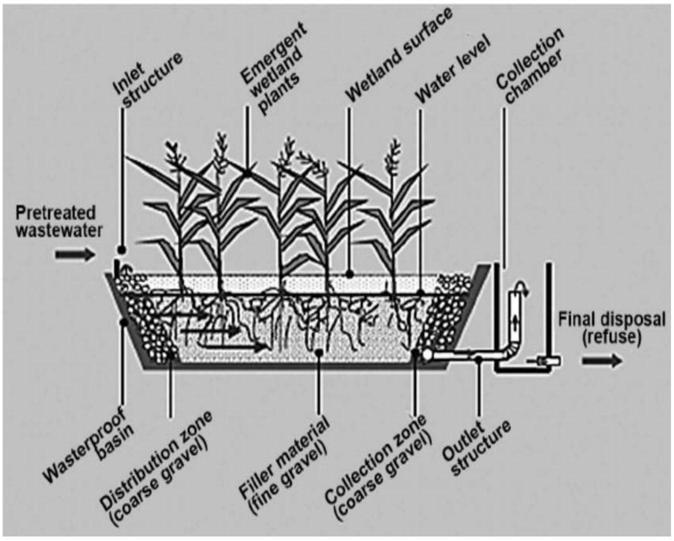


Figure 3 Sub Surface Flow

Applications:

- Low energy and maintenance requirements.
- No mosquito breeding (since water is below surface)
- Natural, eco-friendly wastewater treatment
- Long lifespan with proper maintenance

## 3. Figures

Figure 5 shows Spectrum Representation of Wastewater Treatment Benefits.

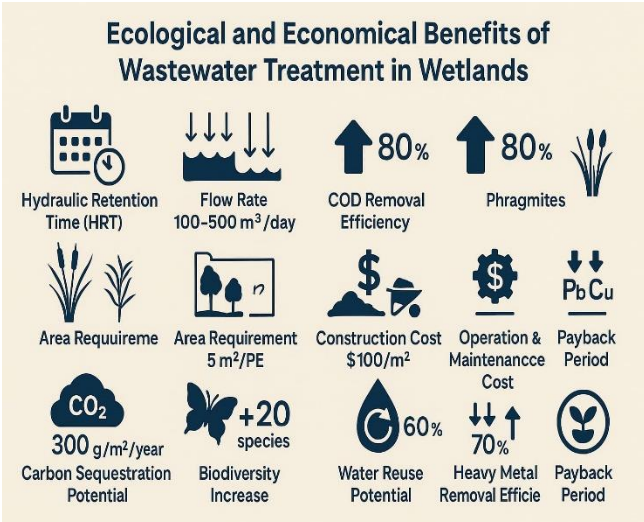


Figure 4 Ecological and Economical Benefits of Wastewater Treatment in Wetlands

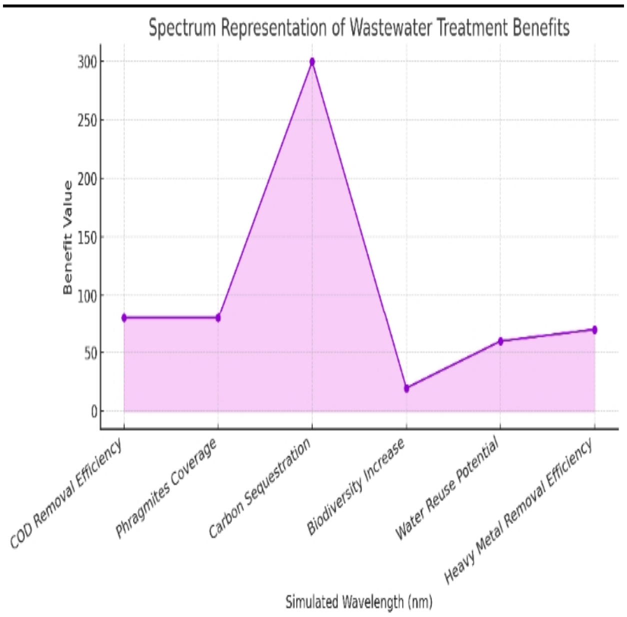


Figure 5 Spectrum Representation of Wastewater Treatment Benefits

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## 4. Tables

**Table 1 Ecological/Economical Benefit**

| Parameter | Units | Example Value | Ecological/Economical Benefit |
|---|---|---|---|
| Hydraulic Retention Time (HRT) | Days | 5–10 | Longer HRT allows more effective pollutant removal |
| Flow Rate | $m^3$/day | 100–500 | Determines system size and treatment capacity |
| BOD Removal Efficiency | % | 70–95 | Indicator of organic matter reduction |
| COD Removal Efficiency | % | 60–90 | Measures total oxidizable pollutants removal |
| Total Nitrogen Removal | % | 40–80 | Reduces eutrophication in water bodies |
| Total Phosphorus Removal | % | 30–70 | Prevents algae growth and supports biodiversity |
| Plant Species Used | - | *Phragmites australis, Typha spp.* | Improve pollutant uptake, biodiversity |
| Area Requirement | $m^2$ per PE (person equiv.) | 3–10 | Determines land cost and spatial planning |
| Construction Cost | USD/$m^2$ | 50–200 | Initial economic investment |
| Operation & Maintenance Cost | USD/$m^2$/year | 5–20 | Ongoing expenses for functionality and labor |
| Carbon Sequestration Potential | g C/$m^2$/year | 100–500 | Climate regulation through $CO_2$ capture |
| Biodiversity Increase (species) | Species count | +10–30 | Enhances ecological value and conservation |
| Water Reuse Potential | % | 50–80 | Saves costs in irrigation and non-potable uses |
| Heavy Metal Removal Efficiency | % | 50–90 | Reduces soil and water contamination risk |
| Payback Period | Years | 5–10 | Financial return through cost savings in treatment and reuse |

## 5. Results and Discussions

**Hydraulic Retention Time (HRT):** A typical HRT of 5–10 days enhances the contact time between wastewater and wetland biota, leading to more effective pollutant breakdown.

**Flow Rate (100–500 $m^3$/day):** This range ensures adequate treatment capacity for small to mid-sized communities. Stable flow supports consistent treatment performance.

**COD Removal Efficiency (~80%):** Constructed wetlands demonstrate high COD (Chemical Oxygen Demand) removal through microbial degradation and plant uptake.

**Phragmites (Common Reed) Utilization:** Species like Phragmites australis play a vital role in nutrient uptake, root oxygenation, and microbial habitat formation.

**Area Requirement (5 $m^2$/PE):** Land requirements are modest compared to conventional systems. This spatial efficiency makes wetlands feasible for decentralized rural or peri-urban areas [7].

IRJAEH

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**Construction Cost (~\$100/m²):** Initial capital investment for wetland systems is relatively low compared to mechanical treatment plants.

**Operation & Maintenance Cost (Low, \$5–20/m²/year):** Minimal energy use and no need for skilled operators reduce O&M costs.

**Heavy Metal Removal Efficiency (~70%):** Wetlands effectively immobilize or absorb heavy metals like Pb and Cu through sedimentation, adsorption, and uptake by plants.

**Water Reuse Potential (~60%):** Treated effluent can be reused for irrigation, aquaculture, or landscaping, reducing pressure on freshwater sources.

**Carbon Sequestration (~300 g/m²/year):** Wetlands act as carbon sinks, capturing $CO_2$ through plant growth and sedimentation. Figure 5 shows Ecological and Economical Benefits of Wastewater Treatment in Wetlands.

**Ecological and Economical Benefits of Wastewater Treatment in Wetlands**

| Ecological Benefits | Economical Benefits |
|---|---|
| Pollutant removal | Cost-effective technology |
| Nutrient retention | Reduced energy use |
| Carbon sequestration | Long-term operation |
| Biodiversity support | Lower maintenance costs |
| Habitat provision | Resource recovery |
| Hydrological regulation | Flood mitigation |
| Water quality improvement | Water reuse |
| Groundwater recharge | Avoided costs of flooding |
| Erosion control | Improved property value |
| Climate change adaptation | Job creation |

**Figure 5 Ecological and Economical Benefits of Wastewater Treatment in Wetlands**

## Conclusion

### Ecological Benefits

- **Improves Water Quality** – Wetlands naturally filter and remove pollutants, nutrients, and sediments from wastewater.
- **Enhances Biodiversity – They provide** habitats for a wide range of plant and animal species.
- **Reduces Pollution Impact** – Wetlands act as a buffer, reducing the flow of contaminants into natural water bodies.
- **Promotes Ecosystem Balance** – Supports ecological processes and restores degraded environments.
- **Carbon Sequestration** – Wetland plants capture and store carbon, helping mitigate climate change.

### Economic Benefits

- **Low Construction and Maintenance Cost** – Compared to conventional treatment plants, wetlands are more affordable to build and operate.
- **Energy Efficient** – They require little to no external energy for operation.
- **Minimal Operational Skills Needed** – Wetlands can be managed with basic training, reducing labor costs.
- **Long-term Cost Savings** – Less need for chemical treatments and mechanical systems leads to savings over time.
- **Suitable for Rural Areas** – Offers an effective solution in places with limited infrastructure and financial resources.

## Acknowledgement

We would like to express our sincere gratitude to all individuals and organizations that contributed to the understanding and promotion of wetland-based wastewater treatment systems. We acknowledge the valuable contributions of environmental researchers, ecologists, and engineers whose studies have highlighted the ecological advantages of wetlands in enhancing water quality, supporting biodiversity, and restoring natural ecosystems. Their work has provided a strong foundation for recognizing the environmental importance of this sustainable approach [8][10]. We also extend our appreciation to policymakers, economists, and development planners who have demonstrated the economic viability of constructed wetlands as a cost-effective alternative to conventional wastewater treatment systems. Their efforts have made it possible to implement such systems in rural and resource-

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limited settings, ensuring both affordability and environmental protection. Finally, we thank all communities and stakeholders actively participating in the implementation and maintenance of wetland systems. Their commitment reinforces the long-term success and benefits of this green technology for future generations.

## References

[1]. Vymazal, J. (2011). Constructed wetlands for wastewater treatment: five decades of experience. Environmental Science & Technology, 45(1), 61-69. Discusses efficiency, ecological sustainability, and low operational cost.

[2]. Kadlec, R. H., & Wallace, S. D. (2008). Treatment Wetlands (2nd ed.). CRC Press.A comprehensive book outlining design, performance, ecological, and economic benefits.

[3]. Brix, H. (1997). Do macrophytes play a role in constructed treatment wetlands? Water Science and Technology, 35(5), 11-17. Covers the ecological role of vegetation in nutrient removal.

[4]. Zhang, D. Q., Jinadasa, K. B. S. N., Gersberg, R. M., Liu, Y., Ng, W. J., & Tan, S. K. (2014). Application of constructed wetlands for wastewater treatment in tropical and subtropical regions (review). Journal of Environmental Science, 26(5), 920–928. Includes cost-efficiency and climate-specific performance.

[5]. Ghermandi, A., van den Bergh, J. C. J. M., Brander, L. M., de Groot, H. L. F., & Nunes, P. A. L. D. (2010). The economic value of wetland conservation and creation: A meta-analysis. Ecological Engineering, 37(1), 145-158. Explores economic valuation of wetlands, including wastewater services.

[6]. Mitsch, W. J., & Gosselink, J. G. (2015). Wetlands (5th ed.). Wiley.A key textbook covering both ecological functions and economic perspectives.

[7]. Rousseau, D. P. L., Lesage, E., Story, A., Vanrolleghem, P. A., & De Pauw, N. (2008). Constructed wetlands for water reclamation. Desalination, 218(1-3), 181-189.Economic feasibility and ecological benefits in water reuse.

[8]. Scholz, M. (2006). Wetland Systems to Control Urban Runoff. Elsevier.Focuses on stormwater and greywater treatment with cost-effective wetland solutions.

[9]. Wu, S., Wallace, S., Brix, H., Kuschk, P., Kirui, W. K., Masi, F., & Dong, R. (2015). Treatment of industrial effluents in constructed wetlands: challenges, operational strategies and overall performance. Environmental Pollution, 192, 245-262.Ecological treatment of complex wastewater and cost analyses.

[10]. Langergraber, G., & Muellegger, E. (2005). Ecological sanitation—a way to solve global sanitation problems? Environment International, 31(3), 433–444. Includes wetlands as part of sustainable sanitation systems.