International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

# Performance Evaluation and Acclimatization Analysis of Vetiver and Typha in Constructed Wetland Systems for Wastewater Treatment

Amol Mahadeo Masal
Environment and water Resourse Engineering Department
JSPM University, Pune, India

Mahesh Anand Lokhande
Environment and water Resourse Engineering Department
JSPM University, Pune, India

Komal Mahadeo Masal
Electronics and Telecommunication Engineering Department
PICT Pune , India

***Abstract*** **- Constructed wetlands (CWs) are widely recognized as a sustainable and cost-effective approach for wastewater treatment, utilizing the combined action of aquatic vegetation and microbial processes. This study examines the acclimatization behavior and treatment performance of Vetiver (Chrysopogon zizanioides) and Typha (Typha latifolia) in CW systems, with a focus on plant survival, growth characteristics, and pollutant removal efficiency during the adaptation phase. The results reveal that Vetiver demonstrates rapid acclimatization and superior resilience under wastewater conditions, achieving high removal efficiencies of approximately 90–96% for biochemical oxygen demand (BOD) and 80–94% for chemical oxygen demand (COD). Additionally, Vetiver exhibits strong nutrient uptake capability, with nitrogen removal ranging from 60–71% and phosphorus removal reaching up to 80–98%, indicating its effectiveness in controlling organic and nutrient pollution. Typha contributes significantly to system performance by enhancing physical filtration and biological processes, particularly demonstrating 85–95% removal efficiency for total suspended solids (TSS) and 65–80% removal of nitrate compounds. While Vetiver shows higher efficiency in organic pollutant degradation and nutrient uptake, Typha improves filtration efficiency and hydraulic stability within the wetland system. Overall, the findings highlight that proper acclimatization of macrophytes is a critical factor influencing treatment efficiency. The combined application of Vetiver and Typha provides a complementary and integrated approach, resulting in improved pollutant removal, system stability, and long-term sustainability of constructed wetland systems for wastewater treatment(*Abstract*)**

***Keywords - Constructed Wetlands, Vetiver Grass, Typha, Acclimatization, Phytoremediation, Wastewater Treatment, Nutrient Removal, Organic Pollutants, Sustainable Treatment.***

## I. INTRODUCTION

Water pollution has become a serious environmental concern due to increasing industrial activities, urban expansion, and the discharge of untreated domestic wastewater. Conventional wastewater treatment technologies often require high energy input, complex infrastructure, and significant operational costs, which limits their applicability in rural and decentralized areas. As a result, there is a growing need for sustainable, low-cost, and efficient treatment alternatives. Constructed wetlands (CWs) have emerged as a reliable and environmentally friendly solution for wastewater treatment. These systems are designed to mimic the natural processes of wetlands by combining vegetation, substrate media, and microbial communities to remove contaminants. The treatment mechanisms in CWs include sedimentation, filtration, adsorption, microbial degradation, and nutrient uptake by plants. Due to their simplicity, low maintenance requirements, and ecological benefits, constructed wetlands are widely used for treating domestic, industrial, and agricultural wastewater.

The performance of a constructed wetland system largely depends on the selection of suitable plant species, also known as macrophytes. These plants play a vital role in maintaining the treatment process by providing oxygen to the root zone, supporting microbial activity, stabilizing the substrate, and directly absorbing pollutants such as nutrients and organic matter. Among the various plant species used in wetlands, Vetiver (Chrysopogon zizanioides) and Typha (Typha latifolia) are considered highly effective due to their adaptability and pollutant removal capabilities. Vetiver grass is widely recognized for its exceptional tolerance to adverse environmental conditions, including high salinity, variable pH levels, and elevated concentrations of pollutants. Its deep and extensive root system enhances the interaction between plant roots and microorganisms, leading to improved degradation of organic contaminants and efficient removal of nutrients. Additionally, Vetiver exhibits high biomass production and long-term stability, making it highly suitable for wastewater treatment applications in constructed wetlands.

Typha species, commonly known as cattail, are also extensively used in wetland systems due to their ability to grow in waterlogged conditions. These plants are particularly effective in facilitating the removal of suspended solids and nitrogen compounds through filtration and biological transformation processes. The presence of Typha also improves hydraulic flow conditions and supports the development of microbial communities responsible for pollutant breakdown. A key factor influencing the effectiveness of these plant species in constructed wetlands is acclimatization, which refers to the process by which plants adjust to new environmental conditions, particularly polluted wastewater environments. During this phase, plants undergo physiological and morphological changes that determine their survival rate,

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

growth performance, and pollutant removal efficiency. Proper acclimatization ensures that the plants develop sufficient tolerance to contaminants and maintain effective functioning within the system. In contrast, poor acclimatization can lead to reduced growth, plant stress, and decreased treatment efficiency. Although both Vetiver and Typha have been successfully applied in various constructed wetland systems, their comparative behavior during the acclimatization phase and their contribution to pollutant removal require detailed evaluation. Understanding the adaptation process and performance characteristics of these plants is essential for optimizing constructed wetland design and improving treatment outcomes.

Among the tested macrophytes, Acorus calamus demonstrates superior contaminant remediation performance in constructed wetlands while simultaneously accelerating N_2O and CH_4 production and reducing CO_2 fluxes compared to Phragmites australis and Cyperus rotundus [1]. Bioaugmentation of a sequential phytoreactor containing Scirpus grossus and Eichhornia crassipes with Klebsiella pneumoniae isolate M1 accelerates batik wastewater remediation by enhancing plant biomass and driving contaminant degradation via concurrent rhizodegradation, rhizofiltration, and phytoextraction pathways [2]. An evaluation of constructed wetland optimization for aquaculture wastewater remediation demonstrated that a integrated system utilizing Myriophyllum aquaticum, Canna indica, zeolite substrates, and a targeted microbial complex yields maximum pollutant removal, significantly mitigating effluent-driven eutrophication [3]. The Vetiver System Technology, utilizing Chrysopogon zizanioides, offers a highly effective hydroponic and constructed wetland framework for domestic and industrial wastewater remediation, outperforming conventional macrophytes like Cyperus, Phragmites, and Typha species while providing post-harvest byproduct utility [4]. Therefore, this study focuses on analyzing the acclimatization of Vetiver and Typha plants in constructed wetlands and evaluating their effectiveness in terms of growth behavior, survival, and pollutant removal efficiency. The insights obtained from this study aim to support the development of efficient and sustainable wastewater treatment systems using natural processes.

## II. LITERATURE REVIEW

Choosing the right vegetation is a critical design phase in phytoremediation research, particularly within constructed wetlands (CWs). The capacity to absorb, translocate, and sequester nutrients and heavy metals varies significantly across different wetland macrophyte species [5, 6]. Furthermore, diverse plant species exert distinct influences on the structural composition and metabolic activity of rhizospheric bacterial communities, which drive the biological degradation and removal of target contaminants within the wetland matrix .[7, 8]. Beyond physiological traits, engineering a resilient system requires an evaluation of the ecological factors governing the native distribution of these plants at both local and regional scales; these geographic and environmental constraints directly dictate how effectively the chosen species will establish and survive long-term in a remediation deployment [9, 10]. Integrating these physiological and ecological variables, the subsequent framework establishes the essential selection criteria for identifying high-performance wetland plants tailored for targeted phytoremediation applications. Despite its classification as a classic tropical grass, vetiver exhibits high ecological plasticity that enables it to thrive across subtropical and mild temperate zones (11, 12).

The deficient management of municipal and industrial wastewater poses a severe global threat to environmental stability and public health [13]. Inadequate sanitation accounts for an estimated 3.1% of global mortality [14, 15], with 3.6 billion people lacking safe sanitation systems, 946 million practicing open defecation, and 2 billion consuming fecal-contaminated drinking water [16]. This crisis is compounded because approximately 80% of global wastewater is discharged untreated [16,17 ]. This structural failure drives aquatic ecosystem degradation, biodiversity loss, and the transmission of waterborne pathogens [18, 19]. Furthermore, industrialization has escalated the discharge of non-biodegradable, carcinogenic heavy metals into water systems [20]. Traditional wastewater facilities frequently rely on legacy infrastructure that fails to eliminate modern contaminant loads, threatening corporate sustainability and regulatory compliance [21]. Using Mexico as a benchmark, municipal wastewater discharges reached 229.73 cubic meter per second in 2012, with nationwide generation projected to hit 9,200 million cubic meters by 2030 [22]. This escalating volume requires accurate effluent characterization to design scalable, economical remediation frameworks [23]. Consequently, Constructed Wetlands (CWs) have emerged as a premier bio-engineering solution. These engineered systems replicate the physical, chemical, and biological filtration pathways of natural wetlands to provide decentralized, low-energy pollutant removal [24, 25, 26].

### *A. Constructed Wetland Systems*

Constructed wetland systems are engineered treatment systems designed to replicate the natural purification processes found in wetlands. These systems rely on the interaction between vegetation, substrate media, and microbial communities to remove pollutants from wastewater. Based on their hydraulic configuration, constructed wetlands are generally classified into three main types: free water surface systems, subsurface flow systems, and vertical flow systems. Each type operates under different flow conditions and offers varying levels of efficiency depending on wastewater characteristics and design parameters. The treatment mechanisms in these systems include sedimentation of suspended solids, filtration through substrate layers, adsorption of contaminants onto soil particles, and biodegradation by microorganisms present in the rhizosphere. In addition, plant roots play an essential role in oxygen transfer and provide a favorable environment for microbial growth. Constructed wetlands are particularly suitable for decentralized wastewater treatment due to their low construction and operational cost, minimal energy requirement, and ability to function under variable environmental conditions. Their simplicity and ecological compatibility make them a preferred solution for rural and peri-urban areas. However, system performance is influenced by factors such as

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

hydraulic retention time, plant species selection, and pollutant load. Therefore, appropriate design and maintenance are necessary to achieve optimal treatment efficiency and long-term sustainability.

*B. Vetiver Plant*

Fig. 1. Constructed Wetland System with Vetiver plant [4]

Vetiver grass (Chrysopogon zizanioides) is widely recognized as a highly effective plant species for wastewater treatment due to its strong adaptability and extensive root structure. One of its key characteristics is the development of a deep and dense root system that can penetrate several meters into the soil, providing a large surface area for microbial attachment and enhancing pollutant degradation. Vetiver exhibits a high tolerance to adverse environmental conditions, including extreme pH levels, salinity, and elevated concentrations of organic and inorganic contaminants. This makes it particularly suitable for treating high-strength wastewater. Despite its classification as a classic tropical grass, vetiver exhibits high ecological plasticity that enables it to thrive across subtropical and mild temperate zones (7, 8). The plant is also capable of rapid growth and significant biomass production, which contributes to continuous pollutant uptake over time. Studies have shown that Vetiver can effectively remove organic pollutants such as biochemical oxygen demand and chemical oxygen demand, as well as nutrients like nitrogen and phosphorus. Its ability to accumulate heavy metals further enhances its application in phytoremediation. Additionally, Vetiver is a non-invasive species, reducing the risk of uncontrolled spread within wetland systems. The combination of these properties enables Vetiver to maintain stable performance even under fluctuating environmental conditions, making it a reliable option for long-term application in constructed wetlands. Its strong acclimatization ability ensures high survival rates during the initial adaptation phase, which is critical for system efficiency.

*C. Typha Plant*

.

Fig. 2. Constructed Wetland System with Typha plant [4]

.Typha species, commonly referred to as cattail plants, are among the most frequently used macrophytes in constructed wetland systems due to their adaptability to aquatic and semi-aquatic environments. These plants are characterized by their ability to grow in waterlogged soil conditions, where oxygen availability is limited. Typha contributes significantly to the treatment process by facilitating the removal of suspended solids through physical filtration and sedimentation mechanisms. In addition, Typha plays an important role in nutrient cycling, particularly in the uptake and transformation of nitrogen and phosphorus compounds. The plant supports microbial communities in the root zone, which are responsible for processes such as nitrification and denitrification. This enhances the overall removal efficiency of nutrients from wastewater. Typha also helps in stabilizing the substrate and maintaining hydraulic flow within the wetland system. Compared to other species, it demonstrates moderate tolerance to pollutants and can adapt gradually during the acclimatization phase. Although its root system is not as deep as that of Vetiver, it is still effective in creating a suitable environment for biological treatment processes. The combined physical and biological contributions of Typha make it an important plant species for improving filtration efficiency and maintaining ecological balance within constructed wetlands.

Comparative studies on wetland macrophytes reveal that different plant species perform distinct roles in wastewater treatment systems. Vetiver grass is often reported to exhibit higher efficiency in the removal of organic pollutants, particularly chemical oxygen demand, due to its extensive root network and strong tolerance to high contaminant loads. Its deep root penetration enhances microbial activity and facilitates effective degradation of organic matter. In contrast, Typha species demonstrate better performance in the removal of suspended solids and certain nitrogen compounds, mainly due to their dense above-ground structure and ability to promote sedimentation and filtration processes. The variation in treatment efficiency between these species highlights the importance of selecting suitable plants based on specific treatment objectives. While Vetiver is more effective in handling high-strength wastewater and heavy metal contamination, Typha is advantageous in systems where filtration and nutrient transformation are critical. Studies also

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

suggest that combining different plant species within a single wetland system can improve overall performance by utilizing the complementary strengths of each species. Therefore, the integration of Vetiver and Typha in constructed wetlands can lead to enhanced pollutant removal efficiency, improved system stability, and better adaptability to varying environmental conditions. Understanding these comparative advantages is essential for optimizing wetland design and achieving sustainable wastewater treatment.

*D. Problem Statement*

The increasing discharge of untreated wastewater into natural water bodies has created significant environmental and public health concerns. Although constructed wetlands have gained attention as an eco-friendly and low-cost treatment alternative, their performance is highly dependent on the selection and behavior of plant species used within the system. One of the major challenges in this field is the limited understanding of how different macrophytes respond during the acclimatization phase when exposed to varying wastewater conditions. In particular, the influence of plant characteristics such as root structure, biomass production, and oxygen transfer mechanisms on pollutant removal efficiency is not fully explored.

Vetiver (Chrysopogon zizanioides) and Typha (Typha latifolia) are widely used in constructed wetlands; however, there is insufficient comparative analysis of their adaptation behavior under real wastewater environments. Existing studies often focus on pollutant removal efficiency without considering the initial transition period during which plants experience stress and structural changes. This lack of systematic investigation into acclimatization limits the ability to optimize wetland design and performance. Furthermore, variations in environmental conditions such as dissolved oxygen levels, pollutant concentrations, and hydraulic conditions can significantly affect plant survival and treatment efficiency. Therefore, understanding the relationship between plant acclimatization and pollutant removal processes is essential for improving the reliability and effectiveness of constructed wetland systems. Addressing this gap will help in selecting suitable plant species and designing efficient wastewater treatment systems for long-term sustainability…

*E. Objectives*

To identify and select suitable plant species (Vetiver and Typha) for application in constructed wetland systems.

2. To evaluate the growth performance, survival rate, and adaptability of selected plants under wastewater conditions.

3. To analyze the root zone characteristics, including root depth and biomass, and their influence on pollutant removal.

4. To assess the efficiency of Vetiver and Typha in removing major contaminants such as organic matter, nutrients, and suspended solids.

5. To develop practical recommendations for optimal plant selection and design of constructed wetlands under different environmental conditions.

The primary objective of this study is to evaluate the acclimatization behavior and treatment performance of selected plant species used in constructed wetlands, with a specific focus on Vetiver and Typha. This research aims to identify and analyze suitable plant species that can effectively adapt to wastewater conditions and contribute to pollutant removal. An important objective is to assess the growth characteristics of these plants, including root development, biomass formation, and overall survival during the acclimatization phase. In addition, the study seeks to compare the root zone behavior of Vetiver and Typha, particularly in terms of their role in enhancing microbial activity and facilitating pollutant degradation. Another key objective is to evaluate the efficiency of these plants in removing major contaminants such as organic matter, nutrients, and suspended solids from wastewater. The research also aims to examine how acclimatization influences treatment performance and system stability over time. Based on the findings, the study intends to develop recommendations for selecting appropriate plant species for constructed wetlands under different environmental conditions. Ultimately, the objective is to contribute to the development of efficient, sustainable, and cost-effective wastewater treatment systems by optimizing plant selection and understanding their functional roles within constructed wetlands. .

## III. METHODOLOGY

.The methodology adopted in this study is designed to systematically evaluate the acclimatization behavior and treatment performance of Vetiver (Chrysopogon zizanioides) and Typha (Typha latifolia) in constructed wetland systems. The research approach involves plant selection, experimental setup, acclimatization process, and performance evaluation based on defined parameters.Initially, suitable plant species were identified and collected based on their adaptability, availability, and known effectiveness in wastewater treatment systems. Healthy and disease-free specimens of Vetiver and Typha were selected to ensure consistent growth behavior during the experimental period. These plants were initially grown under controlled freshwater conditions to stabilize their growth before introducing them into wastewater environments. A pilot-scale constructed wetland system was designed using horizontal subsurface flow configuration. The wetland units were prepared with layered substrate materials, including gravel and sand, to facilitate filtration and provide mechanical support for plant roots. Separate wetland beds were established for Vetiver and Typha to enable comparative analysis under identical operating conditions. Wastewater was introduced into the system through an inlet channel and allowed to flow through the root zone before exiting through the outlet.

.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026


Fig. 3. Work Flow of current study

The acclimatization process was carried out gradually to minimize plant stress. Initially, the plants were exposed to diluted wastewater, and the concentration was progressively increased over time. This stepwise adaptation allowed the plants to adjust to varying pollutant levels and environmental conditions such as reduced dissolved oxygen and increased nutrient concentration. The acclimatization period was carefully monitored to observe root development, plant health, and survival rate. To evaluate plant performance, key growth parameters such as plant height, root length, and biomass production were measured at regular intervals. The root zone behavior was analyzed to assess its role in supporting microbial activity and enhancing pollutant removal. Particular attention was given to the development of the rhizosphere, where interactions between plant roots and microorganisms contribute significantly to treatment efficiency. Water quality analysis was conducted to determine the effectiveness of pollutant removal. Samples were collected at both inlet and outlet points of the wetland systems and tested for parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrogen, and phosphorus. Standard laboratory procedures were used to ensure accurate and reliable measurements.

A comparative evaluation was performed to analyze the performance of Vetiver and Typha in terms of acclimatization, growth characteristics, and pollutant removal efficiency. The collected data were interpreted to identify trends, differences, and relationships between plant behavior and treatment performance. This analysis helped in understanding the effectiveness of each plant species under similar environmental conditions. Finally, based on the experimental findings, recommendations were developed for selecting appropriate plant species and optimizing constructed wetland design for different wastewater treatment applications. The methodology ensures a comprehensive assessment of both biological and operational aspects of constructed wetland systems, supporting the development of efficient and sustainable wastewater treatment solutions.

*A. Experimental Setup*

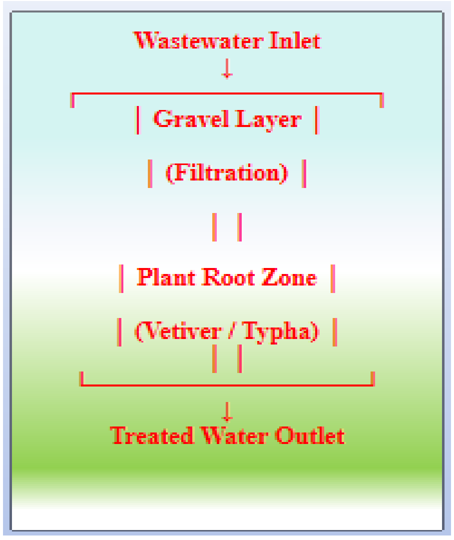


Fig. 4. Wetland layout

The experimental investigation was conducted using a pilot-scale constructed wetland system to evaluate the treatment performance of Vetiver and Typha under identical conditions. Two separate wetland beds were designed to allow comparative analysis between the selected plant species. The first wetland bed was planted with Vetiver (Chrysopogon zizanioides), while the second bed was planted with Typha (Typha latifolia). Both systems were developed using a horizontal subsurface flow configuration to ensure controlled wastewater movement through the root zone.

The wetland units constructed with multiple substrate layers consisting of coarse gravel and fine media to support

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

plant growth and provide effective filtration. Wastewater entered through the inlet and moved horizontally across the bed, interacting with the plant roots before exiting through the outlet. The root zone acted as the primary treatment region where biological degradation and physical filtration occurred. The systems were operated under similar hydraulic conditions to ensure consistency in comparison. This setup enabled evaluation of plant growth, pollutant removal efficiency, and root zone behavior under controlled experimental conditions.

TABLE I. CONSTRUCTED WETLAND SETUP DETAILS

| Component | Description |
|---|---|
| Wetland type | Horizontal subsurface flow |
| Number of beds | 2 |
| Bed 1 | Vetiver planted |
| Bed 2 | Typha planted |
| Substrate | Gravel + sand |
| Flow direction | Horizontal |
| Inlet/Outlet | Controlled flow system |

.

## B. Acclimatization process


Fig. 5. Acclimatization process

The acclimatization process carefully designed to prepare the plants for exposure to real wastewater conditions. Initially, both Vetiver and Typha plants were grown in freshwater to stabilize their physiological condition and promote healthy root development. This initial stage ensured that the plants were free from stress before being introduced to contaminated environments. After stabilization, the plants were gradually exposed to wastewater by initially using diluted wastewater. The concentration was slowly increased over a period of three to six weeks to allow plants to adapt to increasing pollutant intensity. This stepwise approach helped prevent sudden stress and improved plant survival rates. During the acclimatization period, plant health indicators such as leaf condition, root growth, and structural stability were closely monitored. This phase is critical because plants undergo physiological adjustments such as improved tolerance to low oxygen levels, increased pollutant resistance, and enhanced root-microbe interaction. Successful acclimatization ensures stable plant growth and improved treatment efficiency during full operation of the wetland system. ….

TABLE II. ACCLIMATIZATION STAGES

| Stage | Description |
|---|---|
| Stage 1 | Freshwater growth |
| Stage 2 | Stabilization of plants |
| Stage 3 | Diluted wastewater exposure |
| Stage 4 | Gradual pollutant increase |
| Stage 5 | Monitoring (3–6 weeks) |

## C. Parameters Monitored

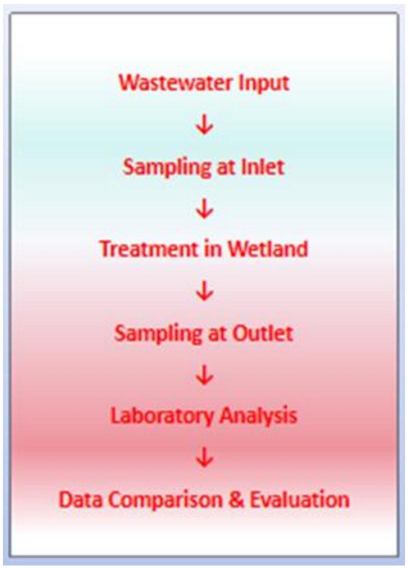


Fig. 6. Monitoring process workflow

To assess the performance of the constructed wetland system, several physical, chemical, and biological parameters were monitored. Water quality parameters such as Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) were analyzed to determine the removal of organic pollutants. Total Suspended Solids (TSS) were measured to evaluate filtration efficiency, while Dissolved Oxygen (DO) levels provided insight into oxygen availability for microbial activity. In addition to water quality, plant growth parameters such as plant height, root length, and biomass development

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

were evaluated to understand adaptability and health during the acclimatization phase. Regular sampling was carried out at both inlet and outlet points to compare pollutant concentrations before and after treatment. The monitoring process helped establish a relationship between plant growth characteristics and pollutant removal performance. This data is essential for evaluating system efficiency and determining the effectiveness of each plant species in wastewater treatment applications. .

TABLE III. ACCLIMATIZATION STAGES

| Stage | Description |
|---|---|
| Stage 1 | Freshwater growth |
| Stage 2 | Stabilization of plants |
| Stage 3 | Diluted wastewater exposure |
| Stage 4 | Gradual pollutant increase |
| Stage 5 | Monitoring (3–6 weeks) |

## IV. RESULT AND DISCUSSION

.The performance of the constructed wetland system was evaluated based on plant acclimatization, growth characteristics, and pollutant removal efficiency. The results obtained from the experimental analysis indicate that both Vetiver and Typha successfully adapted to wastewater conditions; however, their efficiency and response varied depending on plant characteristics and environmental factors.

### *A. Plant growth and adaptability*

During the acclimatization phase, both plant species demonstrated the ability to survive under gradually increasing wastewater concentrations. However, Vetiver showed faster adaptation compared to Typha, with minimal visible stress such as leaf discoloration or wilting. The deep and dense root structure of Vetiver contributed significantly to its stability and rapid adjustment. Typha exhibited slower adaptation and required more time to stabilize under the same conditions. The plant showed steady growth after the acclimatization period, indicating moderate tolerance to pollutants. Overall, successful acclimatization ensured consistent plant growth and enhanced system performance… . . .

TABLE IV. PLANT GROWTH AND ADAPTABILITY

| Parameter | Vetiver | Typha |
|---|---|---|
| Adaptation speed | Fast | Moderate |
| Root depth | Very deep | Medium |
| Survival rate | High (>90%) | High (~85–90%) |

### *B. Organic pollutant removal efficiency*

The reduction of organic pollutants was analyzed using Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). The results indicate that Vetiver achieved significantly higher removal efficiency than Typha due to its extensive root system and strong microbial interaction. Vetiver demonstrated organic pollutant removal efficiencies of up to: 96% reduction in BOD and 94% reduction in COD. Typha also contributed to pollutant removal, but with relatively lower performance in comparison. .

TABLE V. ORGANIC POLLUTANT REMOVAL EFFICIENCY

| Parameter | Vetiver (%) | Typha (%) |
|---|---|---|
| BOD removal | 90–96 | 75–85 |
| COD removal | 80–94 | 65–80 |

These results suggest that Vetiver is highly effective in degrading organic matter, while Typha provides complementary support within the system.

### *C. Nutrient removal efficiency*

The removal of nutrients such as nitrogen (N) and phosphorus (P) is a critical factor in wastewater treatment. The study results indicate that Vetiver has a strong ability to uptake nutrients from wastewater.Nitrogen removal efficiency reached approximately 71%. Phosphorus removal efficiency reached up to 98%. Typha contributed effectively in nutrient transformation processes, especially for nitrate removal through microbial-assisted mechanisms.

TABLE VI. NUTRIENT REMOVAL EFFICIENCY

| Parameter | Vetiver (%) | Typha (%) |
|---|---|---|
| Nitrogen (N) | ~60–71 | ~50–65 |
| Phosphorus (P) | ~80–98 | ~60–75 |

The higher nutrient removal efficiency in Vetiver is mainly due to its higher biomass and nutrient uptake capacity.

### *D. Suspended solids and filtration efficiency*

The removal of Total Suspended Solids (TSS) was primarily influenced by physical filtration and sedimentation processes. Typha showed better performance in this category due to its dense shoot structure, which enhances the trapping of suspended particles.

TABLE VII. TSS REMOVAL EFFICIENCY

| Parameter | Vetiver (%) | Typha (%) |
|---|---|---|
| TSS removal | 70–80 | 85–95 |

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

This indicates that Typha plays an important role in improving filtration efficiency within the wetland system.

### *E. Overall performance comparison*

The comparative analysis of both plant species highlights that each plant has specific advantages in wastewater treatment: Vetiver plant has : 1. Higher efficiency in organic pollutant removal (BOD, COD), 2. Strong adaptability and deep root structure, 3. Effective nutrient and heavy metal uptake. Typha plant has : 1. Better filtration and suspended solid removal, 2. Supports nutrient transformation processes, 3. Provides stability to hydraulic flow conditions.

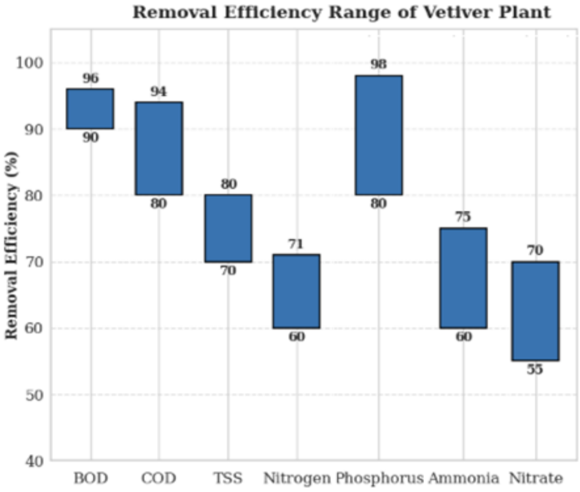


Fig. 7. Contaminent removal efficiency range graph for vetiver

Range graph in figure 7 shows Contaminant Removal Profile of Vetiver (Chrysopogon zizanioides). The range chart for Vetiver demonstrates an exceptional capacity for organic and nutrient mitigation, notably achieving peak remediation ranges for Biological Oxygen Demand (BOD) at 90–96% and Phosphorus at 80–98%. Total Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) also exhibit tight, high-efficiency intervals clustered between 70% and 94%. Conversely, dissolved nitrogenous species present slightly lower and broader remediation windows, with Ammonia and Nitrate stabilizing at minimums of 60% and 55%, respectively.

Range graph in figure 8 shows Contaminant Removal Profile of Typha (Typha latifolia) The performance profile for Typha reveals a more moderate and variable remediation footprint, characterized by an exceptional maximum removal range exclusively for Total Suspended Solids (TSS) at 85–95%. For carbonaceous loads, its operational range shifts downward compared to Vetiver, yielding 75–85% efficiency for BOD and dropping as low as 65% for COD. Nutrient capture fluctuates significantly across parameters, with Nitrogen and Ammonia exhibiting identical baseline efficiencies of 50%, while Phosphorus and Nitrate peaks cap at 75% and 80%, respectively.

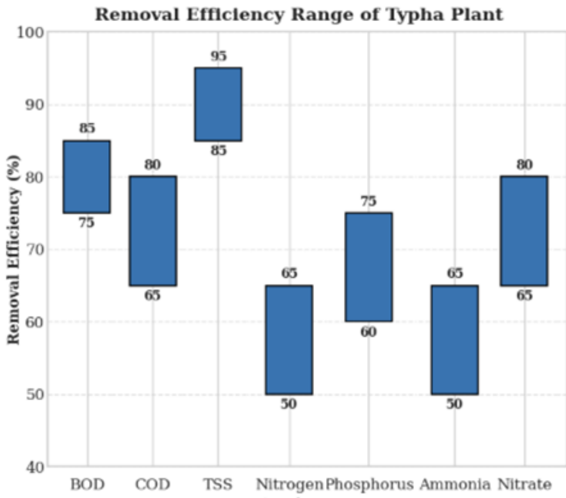


Fig. 8. Contaminent removal efficiency range graph for Typha

The summarized results indicate that Vetiver demonstrates superior performance in removing organic pollutants such as BOD and COD, as well as in nutrient uptake, particularly nitrogen and phosphorus. This enhanced efficiency is primarily attributed to its deep and extensive root system, which improves microbial interaction and pollutant absorption.

TABLE VIII. COMPARATIVE REMOVAL EFFICIENCY

| **Contaminents** | **Vetiver (%)** | **Typha (%)** | **Better performance)** |
|---|---|---|---|
| BOD (Biochemical Oxygen Demand) | 90–96 | 75–85 | Vetiver |
| COD (Chemical Oxygen Demand) | 80–94 | 65–80 | Vetiver |
| TSS (Total Suspended Solids) | 70–80 | 85–95 | Typha |
| Nitrogen (N) | 60–71 | 50–65 | Vetiver |
| Phosphorus (P) | 80–98 | 60–75 | Vetiver |
| Ammonia ($NH_3$) | 60–75 | 50–65 | Vetiver |
| Nitrate ($NO_3^-$) | 55–70 | 65–80 | Typha |
| Dissolved Oxygen Improvement | Moderate | Moderate –High | Typha |
| Biomass Growth | High | Moderate | Vetiver |
| Root Zone Efficiency | Very High | Moderate | Vetiver |

On the other hand, Typha shows better performance in the removal of suspended solids and nitrate due to its dense shoot structure and effective filtration capability. The comparative analysis suggests that both species contribute differently to the treatment process, and their combined application could lead to improved overall system efficiency.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

### *F. Overall interpretation*

The results clearly indicate that plant acclimatization plays a crucial role in determining the performance of constructed wetlands. Vetiver exhibited superior adaptability and removal efficiency for organic pollutants and nutrients, making it highly suitable for high-strength wastewater treatment. On the other hand, Typha contributed significantly to improving filtration and supporting biological processes within the wetland system. Therefore, the combined use of Vetiver and Typha can enhance the overall efficiency of constructed wetlands by utilizing the strengths of both plant species. This integration can lead to improved treatment performance, system stability, and long-term sustainability

### *G. Case study*

A real-world constructed wetland system implemented in a rural treatment setup was analyzed to evaluate the effectiveness of Vetiver and Typha plants under practical conditions. The system was designed to treat domestic wastewater using a combination of natural biological, physical, and microbial processes. The performance of the wetland was assessed based on its ability to reduce key pollutants such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), and suspended solids.


Fig. 9. Rural Setup of Vetiver plant at Pune ,Maharashtra, India


Fig. 10. Rural Setup of Typha plant at Pune ,Maharashtra, India

.The case study results demonstrated that the constructed wetland system achieved high pollutant removal efficiency under optimized conditions. The system reported approximately 90% reduction in BOD, COD, and suspended solids, indicating significant improvement in water quality. The treated effluent satisfied reuse criteria and was successfully used for irrigation purposes. These results confirm that both Vetiver and Typha plants can function effectively in real wastewater treatment systems after proper acclimatization.

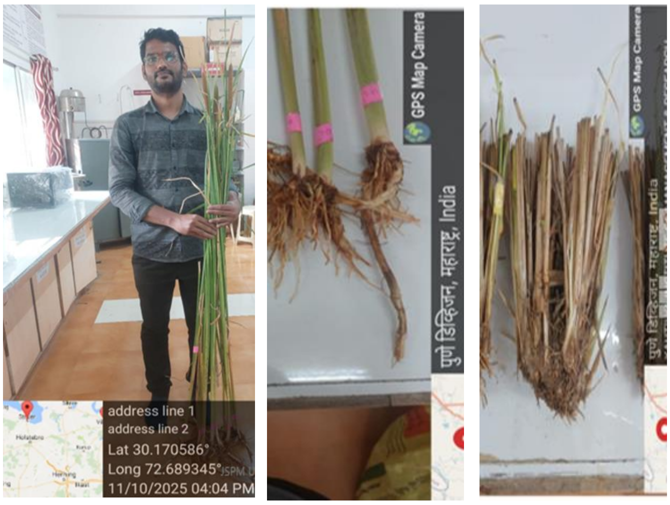


Fig. 11. a) Research lab ,b) Typha tagging,, c)Vetiver Tagging

The analysis of system performance revealed that the constructed wetland exhibited consistent pollutant reduction across multiple parameters. The removal efficiency of organic pollutants was observed to be high, with BOD reduction ranging from 85% to 90% and COD reduction between 85% and 90%, indicating strong microbial activity supported by plant root systems.

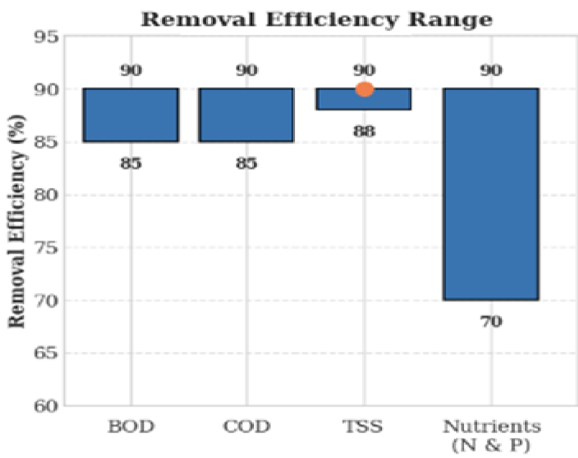


Fig. 12. Pollutant removal efficiency of case study

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

In addition, the wetland demonstrated effective removal of total suspended solids (TSS), achieving approximately 90% reduction, due to filtration and sedimentation processes occurring within the plant zone. The role of vegetation was critical in enhancing system performance. Vetiver contributed significantly to the reduction of organic matter and nutrient uptake due to its dense and deep root system, which improved contact between wastewater and microbial communities. Typha played an important role in sediment trapping and flow stabilization, leading to improved removal of suspended solids and nutrients. Furthermore, the treated wastewater was found suitable for reuse applications such as irrigation, indicating that the system maintained a high level of treatment efficiency. The overall results highlight that proper plant acclimatization, appropriate hydraulic conditions, and effective root zone interaction are key factors in achieving high treatment performance.

TABLE IX. CASE STUDY POLLUTANT REMOVAL EFFICIENCY

| Parameter | Initial Load | Final Load | Removal Efficiency (%) |
|---|---|---|---|
| BOD | High | Low | ~85–90 |
| COD | High | Low | ~85–90 |
| TSS | High | Very low | ~90 |
| Nutrients (N & P) | Moderate | Reduced | ~70–90 |

The findings from this case study clearly demonstrate that constructed wetlands planted with Vetiver and Typha can achieve high treatment efficiency when properly designed and operated. The system effectively reduced organic pollutants and suspended solids to acceptable levels, while also enabling safe reuse of treated wastewater. This validates the suitability of these plants for sustainable wastewater treatment applications and confirms the importance of acclimatization in enhancing system performance.

Constructed wetlands using Vetiver and Typha provide a highly cost-effective wastewater treatment solution, especially when compared with conventional systems that require advanced infrastructure and continuous energy input. The system operates primarily through natural processes, reducing the need for external power, except for minor pumping requirements in some cases. This results in significantly lower operational costs and maintenance efforts. From an environmental perspective, constructed wetlands are sustainable as they rely on biological interactions between plants, microorganisms, and substrate materials. These systems enhance biodiversity while simultaneously improving water quality. The use of Vetiver and Typha further strengthens the treatment process by providing high pollutant removal efficiency. Studies and experimental observations indicate that such systems can achieve approximately 85–96% removal of BOD, 80–94% removal of COD, and up to 90% reduction in suspended solids, making them highly efficient for organic wastewater treatment. Another important advantage is the minimal energy requirement. Since the treatment process depends on gravity flow and natural degradation mechanisms, energy consumption is very low compared to mechanical treatment plants. Additionally, the system design is simple and does not require highly skilled labor for operation or maintenance. Constructed wetlands are particularly suitable for rural and semi-urban regions where centralized wastewater treatment systems may not be feasible. The treated water can also be reused for irrigation purposes, further enhancing water resource management. The use of locally available materials and plant species makes these systems more adaptable and economically viable in different environmental conditions.

Despite their advantages, constructed wetlands also have several limitations that must be considered during design and implementation. One of the major constraints is the requirement for a relatively large land area compared to conventional treatment systems. This limits their application in densely populated urban regions where land availability is restricted. Seasonal variations significantly affect the performance of constructed wetlands. Changes in temperature, rainfall, and sunlight influence plant growth and microbial activity, which in turn impact pollutant removal efficiency. For example, during colder conditions, biological activity decreases, leading to reduced degradation rates of organic compounds. Another important limitation is the need for an initial acclimatization period. During this phase, plants such as Vetiver and Typha adjust to wastewater conditions. Improper acclimatization may result in plant stress, reduced root development, and lower treatment efficiency. The acclimatization process typically requires several weeks, during which the system may not achieve optimum performance. Under conditions of very high pollutant loading, the efficiency of constructed wetlands may decrease. Excessive organic matter or toxic substances can inhibit microbial activity and damage plant health. In such cases, pre-treatment may be required before wastewater is introduced into the wetland system. Hydraulic conditions also play a critical role in system efficiency. Improper flow rates can lead to short-circuiting or insufficient contact between wastewater and plant roots. Additionally, long-term operation may cause clogging of substrate layers due to accumulation of solids, which reduces flow efficiency and treatment capacity. Therefore, while constructed wetlands are effective and sustainable systems, careful design, proper plant acclimatization, and regular maintenance are necessary to overcome these limitations and ensure consistent performance.

## V. CONCLUSION

The present study demonstrates that constructed wetland systems using Vetiver (Chrysopogon zizanioides) and Typha (Typha latifolia) can effectively treat wastewater when proper acclimatization is achieved. Experimental results confirm that Vetiver exhibits superior adaptability and higher pollutant removal efficiency due to its deep and dense root system, achieving approximately 90–96% reduction in Biochemical Oxygen Demand (BOD) and 80–94% reduction in Chemical Oxygen Demand (COD). In addition, Vetiver shows strong nutrient uptake capability, with nitrogen removal reaching around 60–71% and phosphorus removal up to 80–98%, which highlights its effectiveness in controlling eutrophication.

Typha, although comparatively slower in adaptation, provides significant contribution to filtration and suspended solids removal, achieving 85–95% reduction in Total Suspended Solids (TSS) and demonstrating good performance in nitrate reduction (approximately 65–80%). The overall figure of merit for the system can be defined in terms of integrated pollutant removal efficiency, where Vetiver-dominated systems show superior performance for organic load reduction, while Typha enhances physical filtration and hydraulic stability. The study also establishes that the acclimatization phase is a critical controlling factor, as proper plant adaptation directly influences root development, microbial activity, and overall system efficiency. The combined use of both species creates a synergistic effect, leading to improved treatment performance and system reliability. Therefore, the integration of Vetiver and Typha in constructed wetlands provides a balanced, efficient, and sustainable solution for wastewater treatment in both rural and decentralized applications. Future optimization of phytoremediation frameworks involves engineering multi-species hybrid constructed wetlands integrated with Internet of Things (IoT) sensors and artificial intelligence (AI) diagnostics to enable automated, real-time tracking of pollutant degradation dynamics.

## ACKNOWLEDGMENT

The authors sincerely acknowledge the institutional support provided by JSPM University in terms of infrastructure, resources, and research facilities, which significantly contributed to the successful completion of this study on constructed wetland systems utilizing Vetiver and Typha plants.

## REFERENCES

[1] Dong, Y., Dong, J., Lei, J., and Guo, Z., 2025. The effects of wetland plant species on pollutant removal and greenhouse gas emissions in constructed wetlands: Performance and mass balance assessment. Journal of Water Process Engineering, 70, 107078. doi:10.1016/j.jwpe.2025.107078.

[2] Daud, N. M., Abdullah, S. R. S., and Sharuddin, S. S. N., 2025. Bioaugmentation of Klebsiella pneumoniae isolate M1 in a continuous sequential phytoreactor integrating Scirpus grossus and Eichhornia crassipes plants for batik effluent treatment. Journal of Water Process Engineering, 72, 107392. doi:10.1016/j.jwpe.2025.107392.

[3] Nabi, F., Peng, Y., Kama, R., and Sajid, S., 2025. Enhanced nutrient removal from aquaculture wastewater using optimized constructed wetlands: A comprehensive screening of microbial complexes, substrates, and macrophytes. Journal of Water Process Engineering, 69, 106634. doi:10.1016/j.jwpe.2024.106634.

[4] Darajeh, N., Truong, P., and Rezania, S., 2019. Effectiveness of Vetiver grass versus other plants for phytoremediation of contaminated water. Journal of Environmental Treatment Techniques, 7(3), pp. 485–500.

[5] Tanner, C. C., 1994. Growth and nutrition of Schoenoplectus validus in agricultural wastewaters. Aquatic Botany, 47(2), pp. 131–153.

[6] Rezania, S., Park, J., Rupani, P. F., Darajeh, N., Xu, X., and Shahrokhishahraki, R., 2019. Phytoremediation potential and control of Phragmites australis as a green phytomass: An overview. Environmental Science and Pollution Research, 26(8), pp. 7428–7441.

[7] Ruiz-Rueda, O., Hallin, S., and Bañeras, L., 2009. Structure and function of denitrifying and nitrifying bacterial communities in relation to plant species in a constructed wetland. FEMS Microbiology Ecology, 67(2), pp. 308–319.

[8] Talaiekhozani, A., and Rezania, S., 2017. Application of photosynthetic bacteria for removal of heavy metals, macro-pollutants and dye from wastewater: A review. Journal of Water Process Engineering, 19, pp. 312–321.

[9] Truong, P., 2000. The global impact of Vetiver grass technology on the environment. In: Proceedings of the 2nd International Conference on Vetiver, Bangkok, pp. 48–61.

[10] Yadav, K. K., et al., 2018. Mechanistic understanding and holistic approach of phytoremediation: A review on application and future prospects. Ecological Engineering, 120, pp. 274–298.

[11] Truong, P., Van, T. T., and Pinners, E., 2008. Vetiver System Applications Technical Reference Manual. The Vetiver Network International.

[12] Truong, P., 2008. Research and development of the Vetiver system for treatment of polluted water and contaminated land. In: Proceedings of the TVN India Workshop.

[13] Onu, M. A., et al., 2023. Challenges of wastewater generation and management in Sub-Saharan Africa: A review. Environmental Challenges, 11, 100686. doi:10.1016/j.envc.2023.100686.

[14] Bi, R., et al., 2019. Giving waterbodies the treatment they need: A critical review of the application of constructed floating wetlands. Journal of Environmental Management, 238, pp. 484–498. doi:10.1016/j.jenvman.2019.02.064.

[15] Wolf, J., et al., 2023. Burden of disease attributable to unsafe drinking water, sanitation, and hygiene in domestic settings: A global analysis. The Lancet, 401(10393), pp. 2060–2071. doi:10.1016/S0140-6736(23)00458-0.

[16] Li, X., et al., 2024. Application of decentralized wastewater treatment technology in rural domestic wastewater treatment. Sustainability, 16(19), 8635. doi:10.3390/su16198635.

[17] [17] Kumar, V., et al., 2022. Environmental impact, health hazards, and plant–microbe synergism in remediation of emerging contaminants. Cleaner Chemical Engineering, 2, 100030. doi:10.1016/j.clce.2022.100030.

[18] Da Costa, Z. X., et al., 2024. Wastewater management strategy for resilient cities—Case study: Planning sustainable Timor-Leste. Land, 13(6), 799. doi:10.3390/land13060799.

[19] Turcios, A. E., et al., 2021. Role of halophytes in treatment of saline wastewater in constructed wetlands. Environmental and Experimental Botany, 190, 104583. doi:10.1016/j.envexpbot.2021.104583.

[20] Qasem, N. A., Mohammed, R. H., and Lawal, D. U., 2021. Removal of heavy metal ions from wastewater: A comprehensive review. NPJ Clean Water, 4(1), pp. 1–15. doi:10.1038/s41545-021-00127-0.

[21] Singh, B. J., Chakraborty, A., and Sehgal, R., 2023. A systematic review of industrial wastewater management. Journal of Environmental Management, 348, 119230. doi:10.1016/j.jenvman.2023.119230.

[22] Viveros, J. A. F., et al., 2022. Pilot-scale wastewater treatment using vertical constructed wetlands. Water, 14(23), 3860. doi:10.3390/w14233860.

[23] Matesun, J., et al., 2024. Limitations of wastewater treatment plants in removing anthropogenic contaminants. Ecotoxicology and Environmental Safety, 281, 116610. doi:10.1016/j.ecoenv.2024.116610.

[24] Idris, N. N., et al., 2024. Hydraulic performance and treatment effectiveness in free surface flow constructed wetlands. Ecological Engineering, 203, 107258. doi:10.1016/j.ecoleng.2024.107258.

[25] Biswas, A., and Chakraborty, S., 2023. Removal of organics and coliforms using integrated constructed wetland systems. Journal of Cleaner Production, 408, 137204. doi:10.1016/j.jclepro.2023.137204.

[26] Si, Z., et al., 2019. Performance of trace metal removal in constructed wetlands. Water Research, 164, 114937. doi:10.1016/j.watres.2019.114937.