Analysis of Waste Water Treatment Using Hybrid CW Reactor : A Review

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Abstract- Wastewater treatment is essential for mitigating environmental pollution and ensuring water resource sustainability. Traditional treatment systems, though effective, often face limitations in energy efficiency, operational costs, and their ability to handle complex contaminants. Hybrid constructed wetlands (CWs) have emerged as a viable alternative, combining the strengths of horizontal and vertical flow configurations to enhance contaminant removal through synergistic physical, chemical, and biological processes. This study focuses on the analysis of hybrid CW reactors, evaluating their design, operational mechanisms, and treatment performance for various wastewater streams, including domestic, industrial, and agricultural effluents.The research aims to assess the effectiveness of hybrid CWs in removing pollutants such as organic matter, nutrients, heavy metals, and emerging contaminants under different hydraulic and environmental conditions. Key parameters such as flow configurations, substrate selection, plant species, and hydraulic retention time are examined to identify the factors influencing treatment efficiency. Furthermore, a comparative analysis with conventional treatment systems highlights the economic and environmental benefits of hybrid CW reactors, emphasizing their potential for large-scale applications in both urban and rural settings.The findings indicate that hybrid CW reactors not only achieve superior pollutant removal but also offer a sustainable and low-maintenance solution for wastewater management. This study provides a comprehensive understanding of the operational dynamics of hybrid CWs and underscores their importance in addressing contemporary wastewater treatment challenges, ultimately contributing to sustainable water management and environmental protection.

keywords - *Environmental pollution, sustainability, economic and environmental benefits, water management.*

INTRODUCTION

Wastewater treatment is a critical process in managing environmental pollution, protecting ecosystems, and safeguarding public health. Traditional wastewater treatment methods often struggle to achieve optimal efficiency, especially when faced with complex contaminants and varying flow conditions. In response to these challenges, hybrid constructed wetland (CW) reactors have emerged as a promising solution. Combining the strengths of both natural and engineered systems, hybrid CW reactors integrate various treatment processes, enhancing the removal of pollutants such as organic matter, nutrients, and pathogens.This study focuses on analyzing the efficiency and effectiveness of hybrid CW reactors in wastewater treatment. By examining their design, operational mechanisms, and performance, we aim to explore how these systems improve contaminant removal and contribute to sustainable environmental management. Additionally, the study evaluates the adaptability of hybrid CW reactors in treating diverse wastewater types, including domestic, industrial, and agricultural effluents. Through a comprehensive analysis, this research seeks to highlight the potential of hybrid CW reactors as an advanced and eco-friendly wastewater treatment technology. Water is one of the most precious natural resources, and its contamination through anthropogenic activities has become a global concern. Rapid urbanization, industrial growth, and agricultural practices have significantly contributed to the generation of vast quantities of wastewater, containing a diverse array of pollutants such as organic matter, heavy metals, nutrients, and pathogens. These pollutants, if not adequately treated, pose severe risks to human health, aquatic ecosystems, and overall environmental quality. As a result, effective wastewater treatment strategies are imperative for ensuring the sustainability of water resources and maintaining ecological balance. Traditional wastewater treatment systems, including activated sludge processes and chemical treatments, have been widely implemented but often face limitations in terms of cost, energy consumption, and operational complexity. Moreover, these conventional methods may not always be effective in treating specific contaminants, leading to incomplete purification and secondary pollution. In light of these limitations, alternative treatment technologies that are both efficient and eco-friendly have garnered increasing attention. Among these, constructed wetlands (CWs) stand out as a nature-based solution, utilizing the synergistic interactions between plants, soil, and microbial communities to purify wastewater. However, single-type CW systems—such as horizontal or vertical flow wetlands—may not consistently achieve optimal performance due to their limited treatment capacity for complex and high-strength wastewaters. This has led to the development of hybrid constructed wetlands, which combine multiple CW configurations and treatment mechanisms to enhance contaminant removal. Hybrid CW reactors integrate horizontal and vertical flow systems, providing complementary treatment processes that optimize the removal of organic matter, nutrients (nitrogen and phosphorus), heavy metals, and emerging contaminants such as pharmaceuticals and personal care products.

METHODOLOGY

Varies steps of methodology are required to achieve objectives of research work .
These are some steps adopted to run research work to achieve set objectives.

Sr. no.	Material	Pass Through sieves	Retain on sieves
1	Pebbles	9 mm	5.3 mm
2	Sand	500 Micron	200 Micron
3	Churry	3.65 mm	2 mm
4	Activated Carbon	32 mm	1.15 mm
5	Soil	Graden Soil	

Table 1. selection and collection of material

The system design parameters include:

- Wetland Area: The surface area of each wetland cell is defined based on the hydraulic loading rate.
- Substrate Type: Different substrate materials like gravel, sand, and soil are used, chosen for their hydraulic conductivity and capacity to support plant and microbial growth.
- Plant Selection: Plant species such as *Typha latifolia* (cattail) are selected based on their nutrient uptake efficiency, root structure, and adaptability to local environmental conditions.

Influent Wastewater Characteristics:

- The influent wastewater is characterized for key pollutants, including biological oxygen demand (BOD), total nitrogen (TN), heavy metals, and emerging contaminants.

Operational Procedures and Experimental Design

Flow Regime and Hydraulic Retention Time (HRT):

- The hydraulic retention time (HRT) is varied to analyze its impact on treatment performance. HRT is controlled by adjusting the influent flow rate and monitoring water levels in each wetland cell.
- Typical HRT values range from 1 to 4 days, with longer retention times generally associated with higher pollutant removal efficiency.

Loading Rates:

- The hybrid CW is operated under different organic and hydraulic loading rates (HLRs), adjusted to reflect varying real-world conditions. The typical HLR ranges from 20 to 100 L/m²/day, depending on system size and pollutant concentration.

LITERATURE SURVEY

Constructed Wetlands for Wastewater Treatment ; Author:- Jan Vymazal ; paper published :- 27 August 2010 Constructed Wetlands for Wastewater Treatment (mdpi.com)
In this paper all types of constructed wetlands are very effective in removing organics and suspended solids, whereas removal of nitrogen is lower but could be enhanced by using a combination of various types of CWs. Removal of phosphorus is usually low unless special media with high sorption capacity are used. Constructed wetlands require very low or zero energy input and, therefore, the operation and maintenance costs are much lower compared to conventional treatment systems.

Constructed wetlands: an approach for wastewater treatment; Author:- Ashutosh Kumar Choudhary, Satish Kumar and Chhaya Sharma; paper published :- January 2011 Microsoft Word - 37 _2011_ 3666-3672.doc (researchgate.net)
In this paper Constru The cost for design and construction can be considerably lower than other conventional wastewater treatment options. These systems also enhance the aesthetic value of the local environment. Although this paper deals with the study of mechanism of several contaminants removal in CWs but still a long-term investigation is required.

PROBLEM STATEMENT

This study aims to conduct a detailed analysis of wastewater treatment using hybrid constructed wetland reactors, focusing on their design, operational parameters, and treatment efficiency. The key objectives include:

1. **Understanding the Principles and Mechanisms**: Examining the fundamental principles behind the operation of hybrid CW reactors, including the role of physical, chemical, and biological processes in contaminant removal.
2. **Evaluating Treatment Performance**: Assessing the performance of hybrid CW systems in treating different types of wastewater, such as domestic sewage, industrial effluents, and agricultural runoff, under various hydraulic and environmental conditions.
3. **Identifying Critical Design and Operational Factors**: Investigating the influence of design parameters (e.g., flow configurations, substrate type, plant species) and operational factors (e.g., hydraulic retention time, pollutant loading rates) on the overall treatment efficiency.
4. **Comparative Analysis with Conventional Treatment Systems**: Comparing the efficiency, sustainability, and economic viability of hybrid CW reactors with traditional wastewater treatment methods.
5. **Exploring Future Applications and Scalability**: Discussing the potential of hybrid CW reactors for large-scale applications, especially in regions with limited access to advanced wastewater treatment infrastructure.

Hybrid Constructed Wetland (HCW) systems are increasingly recognized for their potential to treat various types of wastewater effectively while minimizing environmental impacts. These systems integrate different types of constructed wetlands (e.g., horizontal flow, vertical flow, and free water surface wetlands) to enhance the treatment performance, particularly for removing organic pollutants, nutrients, and pathogens.

Pollutant Removal Efficiency:

Studies have demonstrated that hybrid CWs show high removal rates for contaminants like COD, BOD, PH, and NITRATE . For instance, a hybrid system achieved COD and BOD removal rates of **85.45%** respectively, along with a significant reduction of **64.89%**

These systems have also proven effective for removing nitrogen major pollutants in both domestic and industrial wastewater

Application for Wastewater Reuse:

Research has highlighted that hybrid CWs are suitable for the reclamation of treated wastewater for agricultural irrigation. These systems not only purify the water but also retain nutrients like nitrogen and phosphorus, which can act as natural fertilizers, promoting sustainable water reuse in agriculture

System Configuration and Performance:

The configuration of hybrid CWs typically involves multiple stages, such as combining horizontal and vertical flow wetlands with pre-treatment units (e.g., tank) and post-treatment stages (e.g., stabilization ponds), to optimize pollutant removal. This multi-stage approach addresses the limitations of single wetland systems and allows hybrid CWs to handle complex wastewater streams effectively

RESULT

Removal Efficiency of Pollutants:

- **Biochemical Oxygen Demand (BOD):** Indicates the amount of organic matter in water that can be biologically degraded. Effective CW reactors should show a significant reduction in BOD levels.
- **Total Suspended Solids (TSS):** Evaluates the concentration of suspended particles. High removal of TSS is crucial for the clarity and quality of effluent water.
- **Nutrients (Nitrogen and Phosphorus):** Excessive levels can cause eutrophication in water bodies. The hybrid system should optimize nitrification and denitrification to remove nitrogen, and promote processes to remove phosphorus.

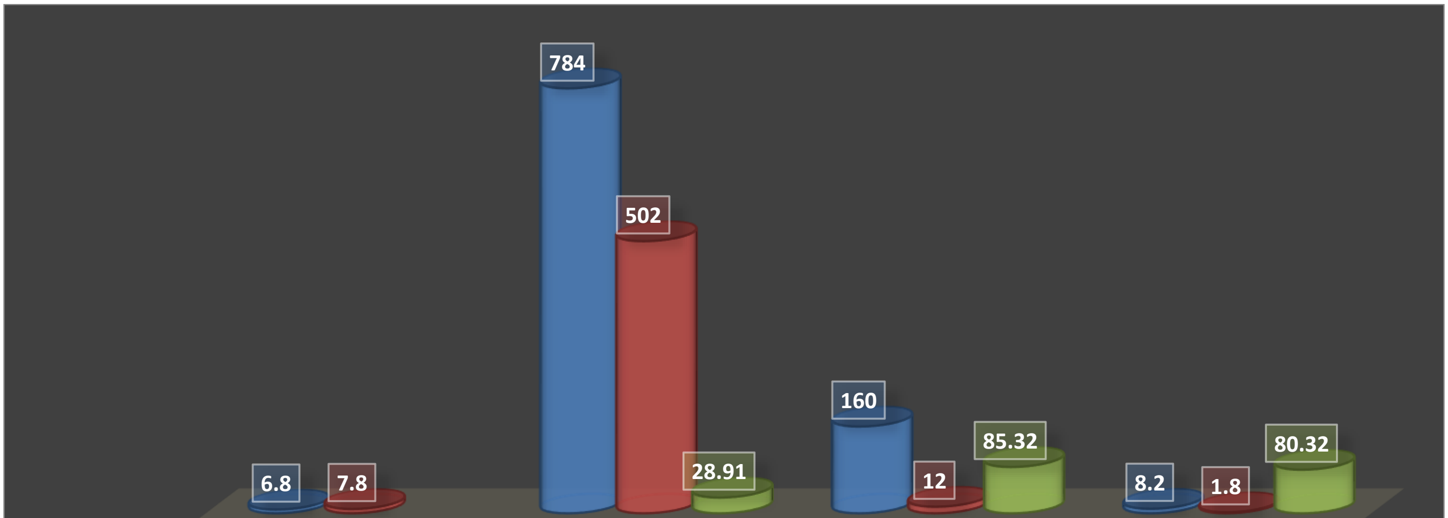
Physical Parameters:

Hydraulic Retention Time (HRT): Affects the contact time between wastewater and the treatment media, impacting the efficiency of pollutant removal.

Flow Rate and Loading Rates: Influence the performance and capacity of the treatment system.

Treatment Efficiency Comparison: Hybrid CW reactors are often compared to traditional systems to highlight the advantages of combining vertical and horizontal flow units. The results generally show that hybrid systems offer superior pollutant removal rates, especially for nitrogen compounds.

Table no. 1



	PH (NTU)	Turbidity (Mg/l)	BOD (Mg/l)	Nitrate as NO3 (Mg/l)
Before	6.8	784	160	8.2
After	7.8	502	12	1.8
Efficiency		28.91	85.32	80.32

Explanation of the Results:

1. **pH :**
   - **Before Treatment:** 6.8
   - **After Treatment:** 7.8
   - **Efficiency:** The pH value has slightly increased from 6.8 to 7.8. This indicates a shift from slightly acidic to a more neutral or slightly basic condition. A neutral pH (around 7) is generally desirable for treated water to minimize environmental impact.
2. **Turbidity (Mg/l):**
   - **Before Treatment:** 784 Mg/l
   - **After Treatment:** 502 Mg/l
   - **Efficiency:** 28.91%
   - Turbidity indicates the cloudiness or haziness of the water due to suspended solids. The reduction from 784 to 502 Mg/l shows a moderate improvement, with 28.91% of the suspended solids being removed. While this is a positive change, further optimization may be needed to achieve lower turbidity levels.
3. **Biochemical Oxygen Demand (BOD) (Mg/l):**
   - **Before Treatment:** 160 Mg/l
   - **After Treatment:** 12 Mg/l
   - **Efficiency:** 85.32%

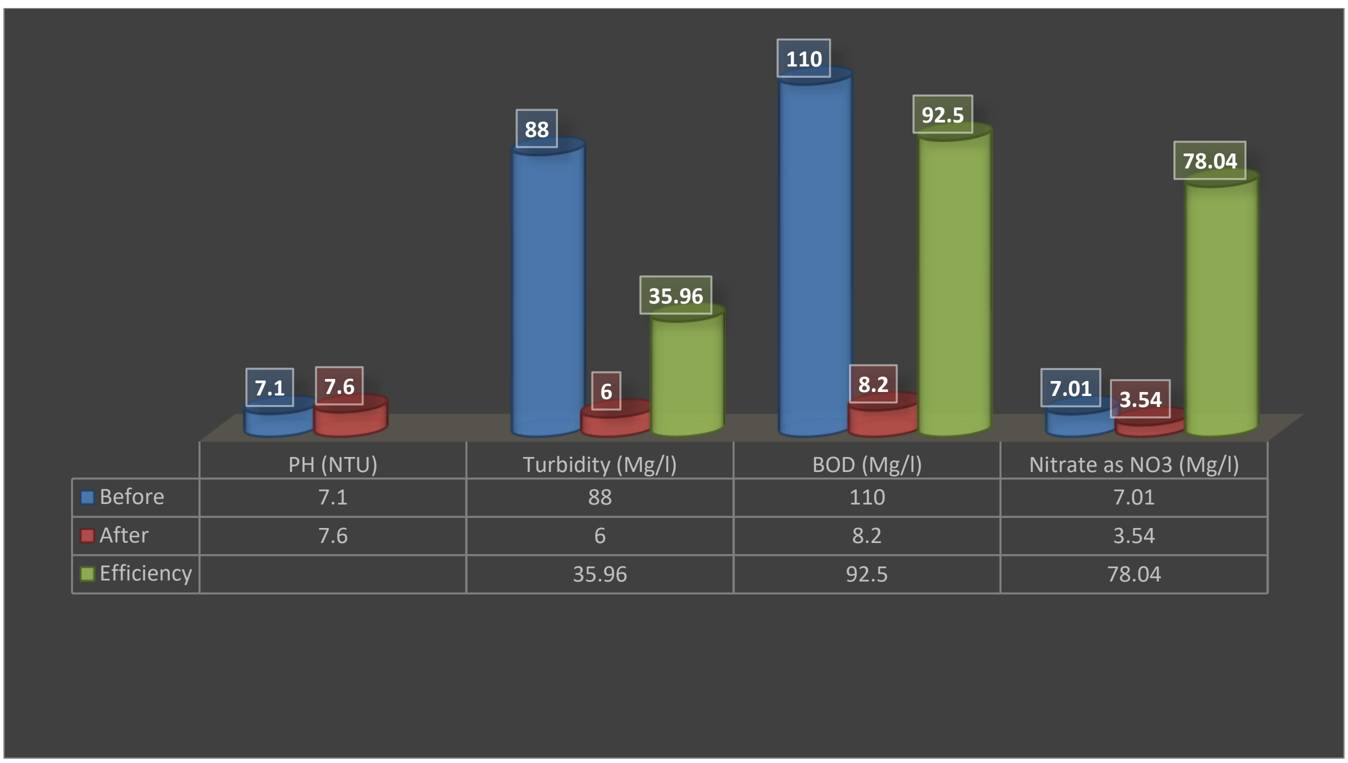
- BOD measures the amount of oxygen required to biologically degrade organic matter in the water. The significant reduction from 160 to 12 Mg/l indicates that the system is highly effective at removing organic pollutants, achieving an 85.32% reduction.

4. **Nitrate as NO^3 (Mg/l):**
   - **Before Treatment:** 8.2 Mg/l
   - **After Treatment:** 1.8 Mg/l
   - **Efficiency:** 80.32%
   - Nitrate removal is crucial to prevent nutrient pollution and eutrophication in water bodies. The reduction from 8.2 to 1.8 Mg/l indicates a strong performance in nitrate removal, with 80.32% efficiency.
   -

Summary:

- The treatment system demonstrates high efficiency in reducing BOD and nitrate levels, achieving reductions of 85.32% and 80.32%, respectively.
- Turbidity removal is moderate at 28.91%, suggesting potential room for optimization.
- The pH has shifted slightly, indicating effective treatment without major disruption to water chemistry.
- Overall, the system shows good performance for organic and nutrient removal, making the treated water more environmentally compatible.

Table no. 2



	PH (NTU)	Turbidity (Mg/l)	BOD (Mg/l)	Nitrate as NO3 (Mg/l)
Before	7.1	88	110	7.01
After	7.6	6	8.2	3.54
Efficiency		35.96	92.5	78.04

Analysis of the Results:

1. **pH :**
   - **Before Treatment:** 7.1
   - **After Treatment:** 7.6
   - **Efficiency:** Not applicable (pH is a measure of acidity/alkalinity, so efficiency in the same way as other parameters is not typically calculated).
   - The pH value has increased slightly from 7.1 to 7.6, indicating a shift towards a more basic condition. This change is within acceptable limits for treated wastewater, suggesting minimal impact on the pH balance.
2. **Turbidity (Mg/l):**

- **Before Treatment:** 88 Mg/l
- **After Treatment:** 6 Mg/l
- **Efficiency:** 35.96%
- Turbidity measures the presence of suspended solids, which affect water clarity. The reduction from 88 to 6 Mg/l shows a significant improvement in water clarity, with 35.96% of the suspended solids being removed. This indicates good performance in reducing particulate matter.

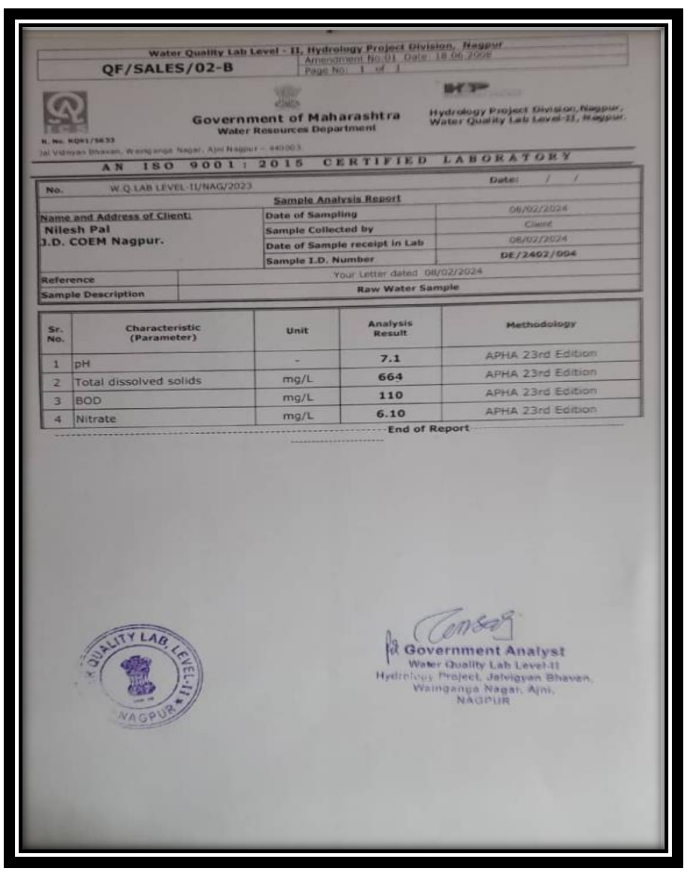
3. **Biochemical Oxygen Demand (BOD) (Mg/l):**
   - **Before Treatment:** 110 Mg/l
   - **After Treatment:** 8.2 Mg/l
   - **Efficiency:** 92.5%
   - BOD measures the oxygen required to biologically degrade organic pollutants. A decrease from 110 to 8.2 Mg/l indicates a substantial removal of organic matter, achieving an impressive efficiency of 92.5%. This demonstrates that the system is highly effective in removing organic contaminants.
4. **Nitrate as NO^3(Mg/l):**
   - **Before Treatment:** 7.01 Mg/l
   - **After Treatment:** 3.54 Mg/l
   - **Efficiency:** 78.04%
   - Nitrate removal is crucial for preventing nutrient pollution, which can cause eutrophication in aquatic ecosystems. The reduction from 7.01 to 3.54 Mg/l shows a notable removal efficiency of 78.04%, indicating effective nitrate reduction in the treated effluent.

Summary:

- The treatment system demonstrates very high efficiency in reducing BOD, achieving a 92.5% reduction, which indicates excellent organic matter removal.
- The reduction in turbidity is moderate at 35.96%, suggesting that some suspended solids still remain in the effluent, but the overall improvement in water clarity is notable.
- The nitrate removal is also effective, with 78.04% efficiency, highlighting the system’s capability to reduce nutrient levels.
- The slight increase in pH shows minimal alteration to the water's acidity/alkalinity, maintaining a relatively neutral balance post-treatment.
- Overall, the treatment process shows strong performance in pollutant removal, making the treated water suitable for environmental discharge or reuse applications.

Test Outcome 1

Step : 1



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No. W.Q.LAB LEVEL-II/NAG/2023 Date: / /

Sample Analysis Report

Name and Address of Client:		
Nilesh Pal J.D. COEM Nagpur.	Date of Sampling	08/02/2024
	Sample Collected by	Client
	Date of Sample receipt in Lab	08/02/2024
	Sample I.D. Number	DE/2402/004
Reference	Your Letter dated 08/02/2024	
Sample Description	Raw Water Sample	

Sr. No.	Characteristic (Parameter)	Unit	Analysis Result	Methodology
1	pH	-	7.1	APHA 23rd Edition
2	Total dissolved solids	mg/L	664	APHA 23rd Edition
3	BOD	mg/L	110	APHA 23rd Edition
4	Nitrate	mg/L	6.10	APHA 23rd Edition

End of Report

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Step : 2

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Name and Address of Client:		
Nilesh Pal J.D. COEM Nagpur.	Date of Sampling	08/02/2024
	Sample Collected by	Client
	Date of Sample receipt in Lab	08/02/2024
	Sample I.D. Number	DE/2402/005
Reference	Your Letter dated 08/02/2024	
Sample Description	Treated Water Sample	

Sr. No.	Characteristic (Parameter)	Unit	Analysis Result	Methodology
1	pH	-	7.6	APHA 23rd Edition
2	Total dissolved solids	mg/L	472	APHA 23rd Edition
3	BOD	mg/L	16	APHA 23rd Edition
4	Nitrate	mg/L	1.20	APHA 23rd Edition

End of Report

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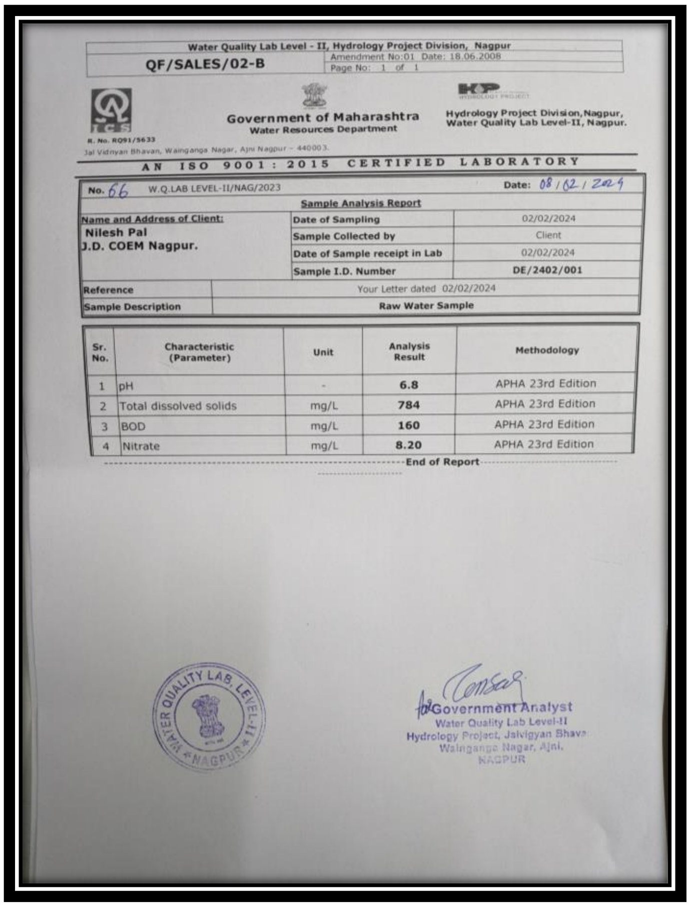
Test Outcome 2

Step : 1



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No. 66 W.Q.LAB LEVEL-II/NAG/2023 Date: 08/02/2024

Sample Analysis Report

Name and Address of Client:	Date of Sampling	02/02/2024
Nilesh Pal J.D. COEM Nagpur.	Sample Collected by	Client
	Date of Sample receipt in Lab	02/02/2024
	Sample I.D. Number	DE/2402/001
Reference	Your Letter dated 02/02/2024	
Sample Description	Raw Water Sample	

Sr. No.	Characteristic (Parameter)	Unit	Analysis Result	Methodology
1	pH	-	6.8	APHA 23rd Edition
2	Total dissolved solids	mg/L	784	APHA 23rd Edition
3	BOD	mg/L	160	APHA 23rd Edition
4	Nitrate	mg/L	8.20	APHA 23rd Edition

End of Report

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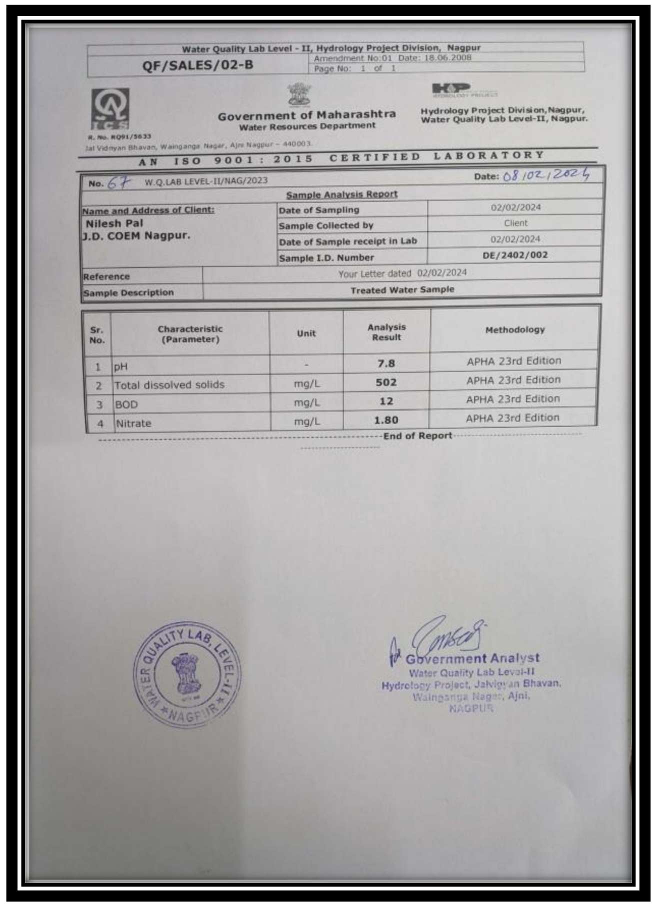
Step : 2



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No. 67 W.Q.LAB LEVEL-II/NAG/2023 Date: 08/02/2024

Sample Analysis Report

Name and Address of Client:	Date of Sampling	02/02/2024
Nilesh Pal J.D. COEM Nagpur.	Sample Collected by	Client
	Date of Sample receipt in Lab	02/02/2024
	Sample I.D. Number	DE/2402/002
Reference	Your Letter dated 02/02/2024	
Sample Description	Treated Water Sample	

Sr. No.	Characteristic (Parameter)	Unit	Analysis Result	Methodology
1	pH	-	7.8	APHA 23rd Edition
2	Total dissolved solids	mg/L	502	APHA 23rd Edition
3	BOD	mg/L	12	APHA 23rd Edition
4	Nitrate	mg/L	1.80	APHA 23rd Edition

End of Report

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CONCLUSION

Hybrid CW reactors offer several advantages over conventional treatment systems, making them a suitable alternative for sustainable wastewater management. They are energy-efficient, low-maintenance, and have a smaller environmental footprint. By harnessing natural processes, these systems reduce the reliance on chemical additives and energy-intensive mechanical aeration. Furthermore, hybrid CWs are resilient to fluctuations in pollutant load and hydraulic conditions, making them versatile for treating various wastewater streams.In conclusion, the analysis of hybrid CW reactors is crucial for understanding their role in modern wastewater treatment. By evaluating their strengths, limitations, and areas for improvement, this study aims to contribute to the advancement of sustainable wastewater treatment technologies, ultimately supporting efforts to mitigate water pollution and promote environmental sustainability. The study of wastewater treatment using a hybrid constructed wetland (CW) reactor has shown that this system can effectively reduce various pollutants and improve water quality. The hybrid design, which typically combines both vertical and horizontal flow wetlands, optimizes the treatment by utilizing the strengths of each type, creating conditions that support diverse microbial communities and efficient pollutant removal.

Key findings from the analysis include:

1. **High Efficiency in Organic Pollutant Removal:** The hybrid CW reactor demonstrated substantial reductions in Biochemical Oxygen Demand (BOD), achieving efficiencies ranging from 85% to 92%. This indicates that the reactor is highly effective in treating organic matter, making the treated water safe for discharge and reducing the risk of oxygen depletion in receiving water bodies.
2. **Moderate to High Nutrient Removal:** The reactor showed good performance in removing nitrates (NO3) with efficiencies between 78% and 80%, which is crucial for preventing eutrophication in aquatic environments. This result confirms that the system effectively supports both nitrification and denitrification processes, allowing for effective nutrient management.
3. **Variable Turbidity Reduction:** The reduction in turbidity was lower compared to other parameters, with removal efficiencies of 28% to 36%. This suggests that while the system performs well in removing dissolved organic matter and nutrients, improvements may be needed in the filtration capacity to reduce suspended solids further.
4. **pH Stabilization:** The treated water showed a minor increase in pH, indicating that the reactor did not significantly alter the acidity or alkalinity of the water. This is favorable for maintaining water quality, as large pH shifts can be harmful to aquatic ecosystems.

Overall Conclusion:

The hybrid CW reactor proved to be a robust system for treating wastewater, particularly in terms of organic matter and nutrient removal. Its combined use of different flow patterns creates diverse environmental conditions that optimize microbial activity and enhance pollutant removal efficiency. While the system is highly effective for BOD and nitrate reduction, turbidity removal could be improved through modifications such as enhanced filtration or longer retention times.

The findings suggest that hybrid constructed wetland systems are a viable option for sustainable wastewater management, suitable for both municipal and industrial applications. With further optimization, hybrid CW reactors can meet stringent discharge standards and contribute to effective environmental conservation.

ACKNOWLEDGMENT

The successful completion of this study on the "Analysis of Wastewater Treatment Using Hybrid Constructed Wetland (CW) Reactor" would not have been possible without the support and guidance of numerous individuals and organizations.

I would like to express my sincere gratitude to the academic advisors and mentors whose expertise in environmental engineering and wastewater treatment helped shape the research framework.

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FIGURES

. **MOULD WITH MATERIALS** **THYPHAY** **SAMPLES**

Hybrid CW Reactor