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ADVANCED CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT IN HOT AND ARID CLIMATE

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Abstract:
This study presents a novel Advanced Constructed Wetland (ACW) system for efficient wastewater treatment in hot climate regions. The ACW incorporates a unique arrangement of mixed media blocks, including soil, sawdust, zeolite, and biochar, to enhance pollutant removal. The system is designed to achieve high treatment efficiencies for organic matter, nutrients, and emerging contaminants, while minimizing the required footprint. Experimental results demonstrate the effectiveness of the ACW in treating domestic wastewater and septic tank effluent. The system effectively removes organic matter, nutrients, and pharmaceuticals and personal care products (PPCPs). The presence of ammonia-oxidizing archaea and bacteria in the media layers contributes to the conversion of ammonia to nitrogen gas. The ACW system offers a promising solution for sustainable wastewater management in arid and semi-arid regions. Its innovative design and high treatment efficiency make it a valuable addition to the available wastewater treatment technologies.

Introduction:
Arid and semi-arid regions, characterized by their limited water availability, constitute a significant portion of the Earth's terrestrial land area. The challenges posed by water scarcity in these regions are exacerbated by factors such as global warming and increasing population growth. Sustainable development in arid regions necessitates innovative and efficient solutions to manage water resources effectively.
Constructed wetlands (CWs) have emerged as a promising approach for wastewater treatment in arid environments. These engineered systems mimic natural wetlands, utilizing plants, microorganisms, and filter media to remove pollutants from wastewater. By leveraging the natural processes occurring in wetlands, CWs offer a sustainable and cost-effective alternative to traditional wastewater treatment methods.
This research paper aims to explore the potential of CWs for wastewater treatment in arid regions, with a particular focus on the Indian context. The paper will delve into the unique challenges and

opportunities presented by arid environments, as well as the design considerations and operational strategies necessary for successful CW implementation. Additionally, the research will examine the benefits of CWs in terms of water conservation, nutrient removal, and ecological sustainability.

Challenges and Opportunities in Arid Regions

Arid and semi-arid regions face several unique challenges that impact the implementation of CWs:

- **Water Scarcity:** Limited water availability can constrain the design and operation of CWs, as they require a steady supply of water for optimal performance.
- **High Evaporation Rates:** High evaporation rates in arid regions can lead to water losses and increased salinity in the system.
- **Soil Salinity:** The prevalence of saline soils in arid regions can affect plant growth and the overall efficiency of CWs.
- **Extreme Temperatures:** Fluctuating temperatures can impact the biological processes occurring within CWs.

Despite these challenges, CWs offer several advantages in arid regions:

- **Water Conservation:** By treating wastewater and reusing the treated effluent, CWs can help conserve water resources.
- **Nutrient Removal:** CWs are effective in removing nutrients, such as nitrogen and phosphorus, from wastewater, which can help prevent water pollution.
- **Ecological Benefits:** CWs can provide valuable ecosystem services, such as habitat for wildlife and carbon sequestration.

Design Considerations for CWs in Arid Regions

To overcome the challenges and maximize the benefits of CWs in arid regions, careful consideration must be given to the following design factors:

- **Plant Selection:** Choosing plant species that are drought-tolerant and can thrive in arid conditions is crucial.
- **Media Selection:** The filter media used in CWs should be able to withstand high temperatures and low water availability.
- **Hydraulic Design:** The hydraulic flow rate through the CW should be carefully designed to optimize treatment efficiency while minimizing water losses.
- **Nutrient Loading:** The loading of nutrients to the CW should be managed to prevent overloading and nutrient accumulation.

Treatment Processes in CWs

CWs utilize a combination of biological, physical, and chemical processes to remove pollutants from wastewater. These processes include:

- **Biodegradation:** Microorganisms in the CW break down organic matter and pollutants into simpler compounds.
- **Sedimentation:** Suspended solids in the wastewater settle to the bottom of the CW.
- **Filtration:** The filter media in the CW physically remove pollutants from the wastewater.
- **Phytoremediation:** Plants in the CW can absorb and remove pollutants from the wastewater.

Case Studies and Success Stories

Numerous case studies have demonstrated the effectiveness of CWs in treating wastewater in arid regions. These studies have shown that CWs can achieve high removal rates for various pollutants, including organic matter, nutrients, and emerging contaminants.

Challenges and Future Research

While CWs offer significant benefits, challenges remain in their implementation in arid regions. These include:

- **Water availability:** Ensuring adequate water supply for CW operation can be a challenge in arid regions.
- **Salinity:** High salinity levels in wastewater can impact the performance of CWs.
- **Climate change:** Climate change may exacerbate water scarcity and alter the environmental conditions in which CWs operate.

Future research is needed to address these challenges and further optimize the design and operation of CWs in arid regions.

Literature Review:

This chapter reviews existing research on the topic of wastewater treatment and constructed wetlands. It explores studies conducted by various researchers to understand different aspects of wastewater treatment and the construction of constructed wetland systems.

1. Kirti Avishek and Moushumi Hazra

- **Key Findings:**
  - Constructed wetlands (CWs) are a sustainable solution for wastewater management in arid regions.
  - CWs have been successfully implemented in the Middle East, demonstrating their technical feasibility in hot and arid climates.
  - Case studies highlight the effectiveness of CWs for both municipal and industrial wastewater treatment.

2. MeeraKeraliya, NitinKumarSingh, ManishYadav, Hirendrasinh Padhiyar, and Arti Thanki

- **Key Findings:**
  - Water stress is a significant concern in India and China, especially in arid and semi-arid regions.
  - CWs have been widely implemented in these regions for wastewater treatment.
  - Effective CW design in arid regions requires careful consideration of evapotranspiration rates and plant species selection.
  - CWs have shown potential in treating both conventional and emerging pollutants.

3. Thammarat Koottatep, Tatchai Pussayanavin, and Chongrak Polprasert

- **Key Findings:**
  - The multi-soil layer (MSL) system is a promising approach for CW design in hot climates.
  - MSL systems can achieve high treatment efficiencies for organic matter and nutrients.

- The use of novel media materials, such as zeolites and iron particles, can enhance treatment performance.
- CWs can effectively treat emerging pollutants like pharmaceuticals and personal care products.

4. Hassan Azaizeh, Abeer Albalawneh, Samer Kalbouneh, and Yoram Gerchman

- **Key Findings:**
  - CWs offer a viable solution for alleviating water scarcity in the Middle East.
  - Plant selection and filter media play crucial roles in CW performance.
  - The maturation process of CWs is essential for optimal treatment efficiency.

Overall, the literature review highlights the potential of CWs as a sustainable and effective technology for wastewater treatment in arid regions. These studies demonstrate the feasibility of CWs in different climatic conditions and their ability to treat various types of wastewater.

Objectives:

This chapter rewards to the objectives oriented to the work area. The concept of Constructed Wetland System if implemented in a rural area can help in treating wastewater from the sewage and further increasing its use for various purposes.

The objective of this thesis report is to investigate and evaluate the efficiency of an Activated Constructed Wetland (ACW) system in reducing wastewater parameters and decreasing the retention time.

The study aims to:

Understand the underlying mechanisms of pollutant removal in the ACW system.

- Assess the performance of the ACW system in reducing key wastewater parameters such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and nutrients (nitrogen and phosphorus).
- Evaluate the effectiveness of the ACW system in reducing the retention time compared to conventional wastewater treatment methods.
- Identify potential improvements and optimizations to enhance the performance of the ACW system.
- To find out the percentage reduction in waste water parameters with the help of Constructed Wetland System.
- To prepare a model to mimic the treatment procedure in actual case of CWS and find out the whether the retention time of the CWS can be reduced or not by using Activated Wetland System.

Benefits of Advanced Constructed Wetland system:

Constructed wetlands (CWs) offer a sustainable and cost-effective solution for wastewater treatment. They are particularly effective in removing pollutants, conserving water, and providing ecological benefits. However, CWs are influenced by various factors that can impact their performance.

Strengths:

- **Efficient pollutant removal:** CWs can effectively remove a wide range of pollutants, including organic matter, nutrients, and emerging contaminants.
- **Low-maintenance costs:** CWs generally require minimal operational and maintenance efforts, making them a cost-effective option.
- **Habitat benefits:** CWs provide valuable habitat for various plant and animal species, contributing to biodiversity.
- **Potential for nutrient recovery:** Nutrients removed from wastewater can be recovered and reused as fertilizers, reducing the need for external inputs.

Weaknesses:

- **Influenced by biological processes:** The performance of CWs is influenced by a variety of biological processes, which can be affected by factors such as temperature, pH, and nutrient availability.
- **Requires pre-treatment:** Wastewater may need to be pre-treated to remove large solids and reduce organic matter before entering a CW.
- **Performance variability:** The performance of CWs can vary depending on seasonal factors, operating conditions, and the specific characteristics of the wastewater.

Opportunities:

- **Plant diversity:** Exploring different plant species can help optimize CW performance in various environments.
- **Experimental studies:** Conducting experiments can provide valuable insights into the factors affecting CW performance and inform design improvements.
- **Efficient organic carbon removal:** CWs can effectively remove organic carbon from wastewater, which is important for reducing nutrient pollution.
- **Biosolid dewatering:** The accumulated solids in CWs can be dewatered and used as a soil amendment.

Threats:

- **Nutrient return from plant biomass:** Nutrients removed from wastewater can be returned to the system through plant decay, potentially affecting water quality.
- **Seasonal cycles:** The performance of CWs can be influenced by seasonal variations in temperature, precipitation, and nutrient availability.
- **Interfacial aeration reduction:** The presence of sediment in CWs can reduce interfacial aeration, which can impact treatment efficiency.
- **Sediment accumulation and clogging:** Over time, sediment can accumulate in CWs, leading to clogging and reduced flow.

By addressing these challenges and capitalizing on the opportunities, CWs can be effectively implemented in various regions to provide sustainable wastewater treatment solutions.

Methodology and Performance:

This chapter outlines the methodology and design principles employed in the development of the Advanced Constructed Wetland System. The experimental design involved the creation and monitoring of multiple CW systems, each featuring unique plant species. Water samples were collected at various stages of treatment to analyze changes in nitrate, ammonia, phosphate, BOD, TDS, and COD concentrations. Advanced analytical techniques were used to quantify the effectiveness of the treatment process.

Treatment Configurations and Investigated Wastewaters

Various CW configurations, including traditional, hybrid, and enhanced systems, have been implemented in arid and semi-arid regions of India and China. Traditional CWs encompass free surface flow, subsurface flow, and floating wetlands. Hybrid CWs combine multiple CW types, such as horizontal and vertical flow. Enhanced CWs incorporate external aeration or baffled flow arrangements to improve treatment efficiency. CWs have been applied to treat a wide range of wastewaters, including domestic, greywater, black water, acid mine drainage, agricultural wastewater, industrial wastewater, and landfill leachate. These systems are particularly valuable in rural communities and sparsely populated areas.

Experimental Setup

The model constructed for this study aimed to modify the existing wetland system to reduce retention time and enhance wastewater removal capacity. A hybrid assembly technique using mixed media blocks was employed. The model consisted of a container with layers of gravel, sand, sawdust, powdered charcoal, and black cotton soil. The plant species used were Colocasia esculenta and Canna Generalis.

Performance Evaluation

The performance of the advanced CW system was evaluated by monitoring changes in water quality parameters, including nitrate, ammonia, phosphate, BOD, TDS, and COD. Analytical techniques were used to quantify the removal efficiencies of these pollutants.

Cost Estimation

An estimate was provided for the construction of a similar CW system for a society with 100 flats. The total estimated cost was approximately 400,000 rupees.

Results & Discussions:

Treatment Efficiency of Advanced Constructed Wetlands (ACWs)

Advanced Constructed Wetlands (ACWs) have demonstrated high removal efficiencies for organic matter, emerging pollutants, and nutrients. The use of aeration systems can enhance treatment performance by promoting aerobic decomposition. However, excessive aeration rates can negatively impact denitrification and nutrient removal.

ACWs are generally more efficient than traditional CWs or compact filter systems. Studies have shown removal rates ranging from 60% to 95% for organic matter and other pollutants. For example, the MSL system in Matsue city, Japan, achieved significantly higher removal rates for BOD, phosphorus, and nitrogen compared to the conventional CW system.

Phosphorus Removal Mechanism

The mechanism of phosphorus (P) removal in ACWs involves the oxidation of iron in the soil mixture blocks to ferrous ions. These ions are then transferred to the zeolite layer, where they are further oxidized to ferric ions. The ferric ions precipitate with phosphate ions, leading to P removal. Additionally, plants can contribute to P removal through uptake.

Overall, ACWs are effective in treating various types of wastewater and offer a promising solution for sustainable wastewater management in arid and semi-arid regions.

TABLE 1– PERCENTAGE CHANGE IN SEWAGE PARAMETERS

Sr No	Parameters	Initial Results	Final Result	% Change
1	PH	7.54	7.18	-4.7 %
2	NH3	1.03	0.14	-86.4 %
3	Phosphate	0.48	0.30	-45%
4	Sulphate	56	46	-17 %
5	NO3	24.1	3.10	-87%
6	Turbidity	3.8	11.7	+200 %
7	TSS	25	31	+24 %
8	COD	17.7	28	+58 %
9	BOD	6.20	9.50	+53 %
10	Hardness	385	502	+30 %
11	TDS	619	950	+53 %

The following Results were observed.
Percentage reduction in pH was observed to be 4.77%.
Percentage reduction NCD was observed to be 39%.
Percentage result reduction infosphere was observed to be 25%.
Percentage reduction in ammonia was found to be 86%.
Percentage reduction SO4 was observed to be 14%.
Increase in some parameters were observed due to some discrepancies in the project and some weather alterations. But in totality it can be said that the major parameters received a generous decrease and our goal was fulfilled.

Recommendation:

As the project has proven its effectiveness, we recommend installing the project under a sheltered area in order to ensure no loss due to evaporation and not moving the project once installed.

References:

1) Performance Assessment of Constructed Wetland in a Semi-arid Region in India Employing SWOT Analysis -Kirti Avishek and Moushumi Hazra
2) Full-Scale Experiences of Arid and Semi-Arid Land-Based Decentralized Constructed Wetlands in India and China. Meera Keraliya, Nitin Kumar Singh, Manish Yadav, Hirendrasinh Padhiyar, and Arti Thanki
3) Performance Assessment of Constructed Wetland in a Semi-arid Region in India Employing SWOT Analysis. Kirti Avishek and Moushumi Hazra

4) Novel Media and Unit Configurations in Advanced Constructed Wetlands: Case Studies Under Hot Climate in Thailand Thammarat Koottatep, Tatchai Pussayanavin, and Chongrak Polprasert
5) Constructed Wetlands Lessons from Three Middle East Countries : The Effect of Plants and Filter Media on CW Performance Hassan Azaizeh, Abeer Albalawneh, Samer Kalbouneh, and Yoram Gerchman
6) Constructed Wetlands as a Green and Sustainable Technology for Domestic Wastewater Treatment Under the Arid Climate of Rural Areas in Morocco Laila Mandi, Naaila Ouazzani, and Faissal Aziz
7) Efficiency of Constructed Wetlands and Wastewater Stabilization Ponds for Wastewater Treatment in Northern Algerian Sahara Khaled Bouchama
8) A Review of Constructed Wetlands Types and Plants Used for Wastewater Treatment in Egypt Mohamed S. Gaballah, Ayman N. Saber, and Jianbin Guo
9) Two Decades of Experience on Nature-Based Solutionsfor Wastewater Treatment in Egypt, Palestine and Tunisia F. Masi, A. Rizzo, N. Martinuzzi, and R. Brescian
10) Constructed Wetlands for Wastewater Management in Egypt: An Overview of 30-Years Experiences in Small/Medium-Size Treatment Plants. Hussein I. Abdel-Shafy, Mohamed A. El-Khateeb, and Mona S. M. Mansour
11) Constructed Wetland as an Efficient Technology for the Treatment of Urban/Industrial Wastewater in the Arid Regions: Morocco as a Model .Ayoub El Ghadraoui, Mounir El Achaby, Laila Mandi, Naaila Ouazzani, Fouad Zouhir, Abdeljalil El Ghadraoui, and Faissal Aziz .