



Initial efficacy assessment of vertical subsurface flow constructed wetland as a nature-based solution for dairy plant wastewater treatment in the Philippines

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Abstract

This pilot study investigated the potential of vertical subsurface flow constructed wetlands (VSSF CWs) as a nature-based solution for treating wastewater from dairy processing plants. The study focused on the removal of key pollutants, including biochemical oxygen demand (BOD₅), total suspended solids (TSS), oil and grease, nitrate, and pH. These parameters are particularly significant for dairy product manufacturing industries and are regulated by the Philippine Department of Environment and Natural Resources (DENR) under Department Administrative Order (DAO) 2016-08 (PSIC code 105). The study investigated the removal of these pollutants in VSSF CWs under 7-day and 14-day hydraulic retention times. Four wetland systems were included: one unplanted control and three planted with *Dracaena sanderiana*, *Chrysopogon zizanioides*, and *Ipomoea aquatica* Forsk. While the lack of replication limits statistical comparisons between treatments, the results of this exploratory study suggest several trends. Pollutant removal tended to improve with a 14-day hydraulic retention time (HRT). *Dracaena sanderiana* appeared to exhibit the highest BOD₅ reduction from the initial concentration of 2680 to 42 mg L⁻¹ (98.43%), followed by *Chrysopogon zizanioides* from 2680 to 150 mg L⁻¹ (94.40%) and *Ipomoea aquatica* Forsk. from 2680 to 280 mg L⁻¹ (89.55%). Oil and grease concentrations generally fell below detectable limits (<1 mg L⁻¹) after 14 days, indicating effective removal. Nitrate levels remained below the DENR effluent standard (DAO 2016-08) throughout the study period at levels < 0.03. Finally, all systems' pH levels were reduced to near-neutral range (7.35–7.68) after a 14-day HRT. These preliminary findings suggest that VSSF CWs may be a viable nature-based solution for dairy wastewater treatment. Yet, further studies are needed to validate these observations and optimize system design.

Research Article

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1. Introduction

The issue of increasing demand for clean water is no longer a new concern [1]. For several years, communities worldwide have been facing this challenge [2]. It has been reported that approximately one-third of the world's population currently resides in water-stressed areas, with projections indicating that this number will rise to two-thirds by 2025 [3]. The primary drivers of this dilemma are the rapid industrialization and population growth that are occurring worldwide [4]. These factors have led to a significant rise in wastewater generation, resulting in severe environmental degradation and health-related consequences [5–7].

Among the major contributors to wastewater globally is the dairy industry. The dairy industry is particularly notable in the food sector for its high water consumption in producing products like fresh milk, milk powder, cheese, and yogurt [8]. Wastewater from this industry is known for its high levels of biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), and organic matter [9]. Bouanga Boudiombo et al. [10] report that dairy industries generate approximately 10 liters of wastewater per liter of drinking milk, containing significant levels of phosphorus and nitrogen.

While several treatment methods exist to address wastewater concerns, many are expensive and not always environmentally friendly [11]. Consequently, research has shifted toward alternative, cost-effective,

and eco-friendly solutions, such as phytoremediation. This process involves using plants and their associated microorganisms to remove, degrade, or immobilize pollutants in wastewater [12]. Depending on the contaminants present, phytoremediation can include phytodegradation, biodegradation, phytoextraction, phytostabilization, and phytovolatilization [13]. Constructed wetlands have emerged as a promising approach in this field [14, 15].

Constructed wetlands (CWs) are a form of green technology that harnesses the natural processes of wetlands to treat wastewater pollutants [16]. Numerous studies have shown that CWs significantly reduce pollutants [17–19]. As a nature-based solution, CWs offer sustainable, efficient, and cost-effective wastewater treatment, presenting an eco-friendly alternative to traditional methods.

Despite the growing recognition of the effectiveness of constructed wetlands, there are still gaps in their application, particularly in treating wastewater from milk processing plants. While extensive research exists on CWs for municipal or agricultural wastewater, the specific challenges of dairy processing wastewater have been less explored. Therefore, this pilot study aims to provide preliminary insights into the potential of VSSF CWs for treating wastewater from a dairy processing plant.

Among various plant species, macrophytes such as fortune plant (*Dracaena sanderiana*) [20, 21], Vetiver grass (*Chrysopogon zizanioides*) [22, 23], and water spinach (*Ipomoea aquatica* Forsk.) [24] have garnered attention for their remarkable capabilities in enhancing water quality by removing nutrients, heavy metals, and organic pollutants. These macrophytes not only contribute to wastewater purification but also promote biodiversity and ecosystem health in constructed wetlands and other aquatic systems. This pilot study investigated the effectiveness of the selected macrophytes in phytoremediation, exploring their potential roles in enhancing water quality using a vertical subsurface flow constructed wetlands (VSSF CW) prototype designed for treating wastewater from a dairy processing plant at the University of Science and Technology of Southern Philippines (USTP) Claveria, and providing initial insights into their application in sustainable wastewater management practices. Understanding the mechanisms and efficiencies of these plants can help develop more effective strategies to mitigate water pollution and promote environmental sustainability.

Moreover, the pilot study evaluated the efficiency of these plants in removing key pollutants in dairy processing wastewater, including BOD₅, total suspended solids, nitrates, oil and grease, and pH. These parameters are especially chosen considering that these are listed as significant parameters to be considered for industries that manufacture dairy products based on the Philippine Department of Environment and Natural Resources (DENR) Department Administrative Order (DAO) 2016-08, PSIC code 105 [25]. As such, the pilot study assessed whether the constructed wetland effluents tended to comply with the effluent standards set by the DENR. The

findings of this pilot study contribute to the initial design and operation considerations of VSSF CWs for the dairy industry. They also help identify potential plant species and operational conditions, laying the groundwork for more sustainable wastewater treatment solutions that are both environmentally friendly and cost-effective. It is important to emphasize that this is a pilot study and the findings presented here are exploratory and should be interpreted cautiously.

2. Method

2.1. Research Design

This pilot study employed a factorial experimental design with a completely randomized layout, integrating both developmental and experimental research components. The developmental component involved the design and construction of vertical subsurface flow constructed wetland (VSSF CW) prototypes. The experimental aspect evaluated the treatment efficiency of the VSSF CWs in reducing critical pollutants, including biochemical oxygen demand (BOD₅), total suspended solids (TSS), oil and grease, nitrates, and pH, from dairy processing plant wastewater. Two experimental factors were investigated: plant species (*D. sanderiana*, *C. zizanioides*, *I. aquatica* Forsk., and a control with no plant) and hydraulic retention time (7 days and 14 days), resulting in eight treatment combinations. Due to the absence of treatment replication, statistical analysis is limited and is focused primarily on descriptive statistics. Comparative analysis between plant species and retention times was limited and interpreted cautiously.

2.2. Preparation of the vertical subsurface flow constructed wetland

The constructed wetland prototype was designed to mimic the vertical subsurface flow constructed wetland system. Each unit consisted of a rectangular tank (0.6 m x 0.6 m x 0.7 m) filled with a mixture of local soil, gravel, and sand as the substrate material. The tank was divided into two compartments: an upper compartment for planting and a lower compartment for wastewater collection. A perforated pipe was installed at the top of the upper compartment to facilitate the even distribution of wastewater.

The VSSF-CW system was designed to operate under saturated conditions, with wastewater flowing vertically downward through the substrate material and plant roots. The system was fed with milk processing plant wastewater, which was pumped into the upper compartment at a controlled rate.

The inlet of the wastewater to the VSSF CW prototype was designed to distribute the influent around the cell evenly. The outlet was situated at the bottom. The plants selected for the laboratory model were aquatic plants, chosen based on their adaptability to the climate. The plants that were used for the model include fortune plant (*Dracaena sanderiana*), Vetiver grass (*Chrysopogon zizanioides*), and water spinach (*Ipomoea aquatica* Forsk.), which are locally available. The tray setup consisted of three layers of purification: gravel, sand

(sieved with a 1-4 mm sieve), and garden soil. Local soil, preferably loamy and containing silt and clay, was used for the constructed wetland. Each layer played a specific role in the purification process of the constructed wetland.

Table 1 shows the technical specifications that were used in this study with reference to related literature and studies, such as the Constructed Wetlands Manual of the United Nations Human Settlements Programme [26], the study of Tamang [21] and Flores & Adil [27]. Meanwhile, Figures 1, 2, and 3 show the cross-sectional, top, and isometric views of the VSSF CW.

Table 1. Technical Specifications of the Constructed Wetland Model

Operational Specifications	Value
CW Type	Subsurface Flow
CW Configuration	Vertical Flow
CW Substrate	Local Soil, Sand, Gravel
Type of Influent	Milk Processing Plant Wastewater
Tray Dimensions	0.6 m x 0.6 m x 0.7 m
Type of feeding	Intermittent
Plant Species	Fortune plant (<i>D. sanderiana</i>), Vetiver grass (<i>C. zizanioides</i>), and water spinach (<i>I. aquatica</i> Forsk.)
Depth of Gravel	20 cm
Depth of Sand	30 cm
Sand Sieve size	1-4 mm
Depth of Local Soil	10 cm
Slope of Setup	1%

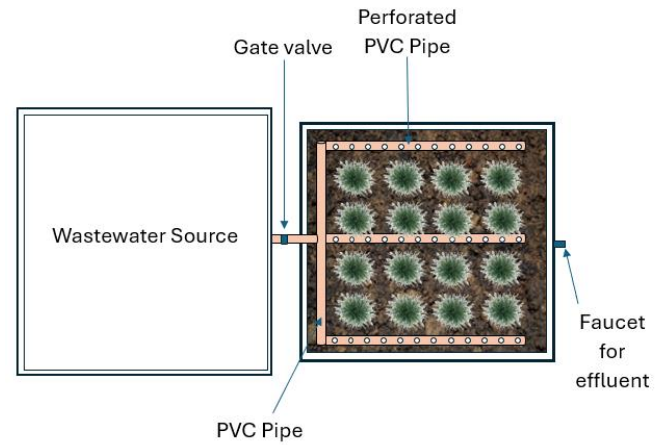


Figure 2. Top view of the VSSF CW setup

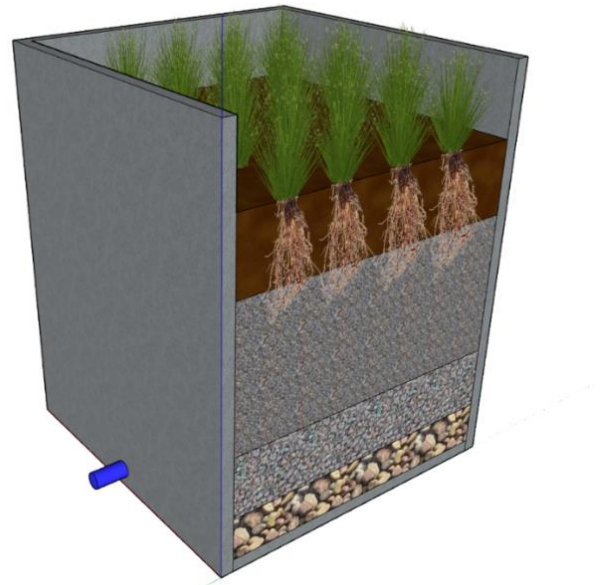


Figure 3. Isometric view of the VSSF CW setup

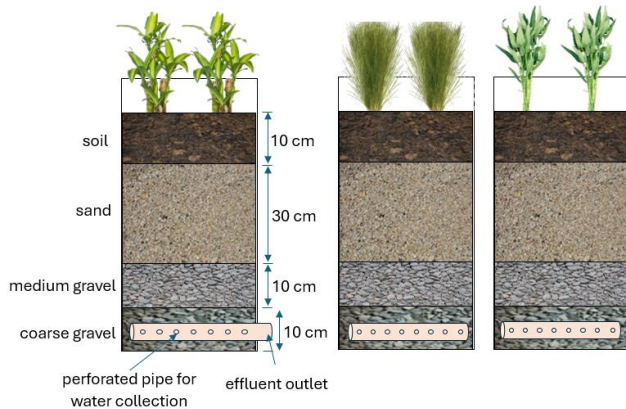


Figure 1. Cross-sectional view of the VSSF CW setup

Raw wastewater from the USTP Claveria Gatas 955 Milk Processing Plant was collected and stored in a sedimentation/settling tank designed to settle suspended solids in the wastewater and even out the flow rate of the wastewater influent that was fed into the vertical subsurface flow constructed wetland setup. The raw wastewater was then diluted at a 1:4 ratio (1 part raw wastewater to 3 parts water) so that the concentration of the feed wastewater was suitable for the constructed wetland system's design organic loading rate. The post-dilution feed wastewater was then characterized and used as the influent for the experimental systems. This dilution was applied as a necessary pre-treatment step to prevent rapid clogging of the substrate and ensure sustainable microbial activity, aligning the organic load with established VSSF CW design protocols.

In this study, a hydraulic retention time of one (1) week and two (2) weeks were observed. This hydraulic retention time is adopted in the study of Flores & Adil [27], who studied the treatment of slaughterhouse wastewater in a subsurface flow constructed wetland, similar to the configuration that was used in this study.

The choice of vegetation and plant spacing plays a vital role in the performance of the constructed wetland system. For this study, fortune plant (*D. sanderiana*), Vetiver grass (*C. zizanioides*), and water spinach (*I. aquatica* Forsk.) were selected based on their known ability to tolerate wastewater conditions and their potential for phytoremediation. These plants were locally sourced from Claveria, Misamis Oriental, Philippines.

The spacing between plants was determined based on the growth characteristics of each species and the available area within the prototype. To ensure uniformity and consistency in the number of plants per constructed wetland system, each experimental setup consisted of 16 plants (arranged in a 4 x 4 grid) with a spacing of 0.15 m apart and a uniform margin of 0.075 m from the edges of the constructed wetland system on all sides. Furthermore, these plants were grown for three (3) months in a nursery before being transplanted to the constructed wetland system. To allow for adaptation to the new environment, the plants underwent a one-month acclimatization period, during which they were fed with clean water before wastewater introduction.

2.3. Research environment

The pilot study was conducted at the University of Science and Technology of Southern Philippines – Claveria Campus, Magsaysay St., Poblacion, Claveria, Misamis Oriental. Specifically, the pilot-scale constructed wetland system was put up at the back of the USTP Claveria Gatas 955 Milk Processing Plant.

Claveria, Misamis Oriental (8° 36' 36" N, 124° 53' 41" E), is characterized by a tropical climate with distinct wet and dry seasons. The area experiences a significant amount of rainfall throughout the year, with an annual average of approximately 2,500 mm. The wet season typically spans from June to December, bringing heavy rains and occasional typhoons, while the dry season extends from January to May. Average temperatures range from 22°C to 32°C, with the warmest months occurring from March to May.

2.4. Sampling procedure and data gathering

Wastewater samples were collected from the inlet and outlet of the constructed wetland system at regular intervals. The samples were collected in sterile containers and transported to the laboratory for analysis. The sampling procedure followed standard protocols to ensure the integrity and representativeness of the samples. Sampling was done after one (1) and two (2) weeks of retention time.

An influent sample was taken immediately to a Philippine Accreditation Bureau – Laboratory Accreditation Division (PAB-LAD) and Department of Environment and Natural Resources (DENR)-accredited third-party laboratory after the raw wastewater was screened prior to its introduction to the experimental cell. Effluent samples were analyzed every week for two weeks of detention time at the same identified laboratory. Specifically, the influent and effluent samples were analyzed for pH using the 4500 H+ B. Electrometric

Method, biochemical oxygen demand (BOD₅) using the 5210 B. 5-Day BOD Test, total suspended solids (TSS) using the 2540 D. Gravimetric method (dried at 103-105 °C), oil and grease using the 5520 B. Liquid-Liquid Partition-Gravimetric Method, and nitrate as NO₃-N using the US EPA 352.1 Colorimetric method with Brucine. After 14 days of retention time, sample plants were obtained to observe their root properties.

2.5. Data analysis

Due to the absence of treatment replication in this pilot study, the data analysis focused on descriptive statistics. Mean values and ranges were calculated for each water quality parameter in the influent and effluent. Changes in pollutant concentrations from influent to effluent within each treatment were assessed. However, comparisons between different plant species or retention times were limited to descriptive observations of trends and patterns, and no statistical tests were used for these comparisons.

3. Results and discussion

3.1. Characterization of the dairy processing plant wastewater

Table 2 presents the characteristics of the raw wastewater from the dairy processing plant that was used in this study. As earlier discussed, the parameters tested are based on the significant parameters for industries that manufacture dairy products as outlined in the Philippine Department of Environment and Natural Resources (DENR) DAO 2016-08 PSIC Code 105.

Table 2. Characteristics of the dairy processing plant wastewater

Parameters	Unit	Results
pH	-	3.84 @ 19.8 °C
Biochemical Oxygen Demand (BOD ₅)	mg L ⁻¹	2680
Total Suspended Solids	mg L ⁻¹	76
Oil and Grease	mg L ⁻¹	17
Nitrate as NO ₃ -N	mg L ⁻¹	< 0.03

The wastewater sample was acidic with a pH of 3.84, indicating a need for pH adjustment during treatment. The BOD₅ level of 2680 mg L⁻¹ suggests a high organic load, typical of dairy processing wastewater. The total suspended solids (TSS) concentration of 76 mg L⁻¹ is within the reported range for dairy effluents. The oil and grease content of 17 mg L⁻¹ is also consistent with literature values. The nitrate level was below the detection limit of 0.03 mg L⁻¹.

3.2. Treatment efficiency of VSSF CW with the different macrophytes

Table 3 presents the reduction of BOD₅, TSS, nitrate, oil and grease, and pH after 7 and 14 days retention time in a controlled experiment comparing the three plant species and a control system (no plant).

3.2.1. Biochemical oxygen demand (BOD₅)

The results indicate that all three plant species significantly enhanced BOD₅ removal compared to the control system after 7 and 14 days. *Dracaena sanderiana*

exhibited the highest BOD₅ reduction at 98.43% after 14 days, followed by *Chrysopogon zizanioides* at 94.40% and *Ipomoea aquatica* Forsk. at 89.55%.

Table 3. Reduction of BOD₅, TSS, nitrate, oil and grease, and pH after 7 and 14 days retention time

Parameter	Treatment	Influent (mg L ⁻¹)	Effluent (mg L ⁻¹)		Reduction (Influent vs Effluent)	
			7 Days	14 Days	7 Days	14 Days
BOD ₅	Controlled (no plant)	2680	2520	500	5.97%	81.34%
	<i>Dracaena sanderiana</i>	2680	232	42	91.34%	98.43%
	<i>Chrysopogon zizanioides</i>	2680	59	150	97.80%	94.40%
	<i>Ipomoea aquatica</i> Forsk.	2680	532	280	80.15%	89.55%
TSS	Controlled (no plant)	76	12	14	84.21%	81.58%
	<i>Dracaena sanderiana</i>	76	4	9	94.74%	88.16%
	<i>Chrysopogon zizanioides</i>	76	10	13	86.84%	82.89%
	<i>Ipomoea aquatica</i> Forsk.	76	7	28	90.79%	63.16%
Nitrate	Controlled (no plant)	< 0.03	0.06	< 0.03	-	-
	<i>Dracaena sanderiana</i>	< 0.03	< 0.03	< 0.03	-	-
	<i>Chrysopogon zizanioides</i>	< 0.03	0.05	< 0.03	-	-
	<i>Ipomoea aquatica</i> Forsk.	< 0.03	< 0.03	< 0.03	-	-
Oil and grease	Controlled (no plant)	17	1	< 1	94.12%	> 94.12%
	<i>Dracaena sanderiana</i>	17	2	< 1	88.24%	> 94.12%
	<i>Chrysopogon zizanioides</i>	17	3	< 1	82.35%	> 94.12%
	<i>Ipomoea aquatica</i> Forsk.	17	1	< 1	94.12%	> 94.12%
pH	Controlled (no plant)	3.84	7.38	7.56	-	-
	<i>Dracaena sanderiana</i>	3.84	7.54	7.68	-	-
	<i>Chrysopogon zizanioides</i>	3.84	7.56	7.64	-	-
	<i>Ipomoea aquatica</i> Forsk.	3.84	7.35	7.42	-	-

These high removal rates are consistent with the reported effectiveness of constructed wetlands in treating wastewater with high organic loads. Studies have shown that *Dracaena sanderiana* can effectively remove organic pollutants like Bisphenol A [28]. *Chrysopogon zizanioides* has also demonstrated high BOD₅ removal efficiencies in various constructed wetland systems, including those treating dairy wastewater and other industrial effluents [23, 29–32]. The dense root system of *Chrysopogon zizanioides* provides a large surface area for microbial activity, which is crucial for BOD₅ degradation [32–34]. *Ipomoea aquatica* Forsk. is also known for its ability to remove organic matter from wastewater. The control system also showed a substantial BOD₅ reduction (81.34% after 14 days), indicating the contribution of the filter media and natural microbial activity.

3.2.2. Total suspended solids

All planted systems showed effective TSS removal after 7 days, with *Dracaena sanderiana* achieving the highest reduction at 94.74%. *Chrysopogon zizanioides* and *Ipomoea aquatica* Forsk. also performed well, with reductions of 86.84% and 90.79%, respectively. After 14 days, *Dracaena sanderiana* (88.16%) and *Chrysopogon zizanioides* (82.89%) maintained good TSS removal. However, *Ipomoea aquatica* Forsk. showed a decrease in TSS removal to 63.16% after 14 days, with an effluent concentration of 28 mg/L, higher than the 7 days retention time (3 mg/L). This increase could be due to

the sloughing off of root biomass or the release of fine particulate matter associated with the plant in the waterlogged conditions. The control system also demonstrated significant TSS removal (81.58% after 14 days), indicating the role of physical filtration by the substrate. *Dracaena sanderiana* has shown effectiveness in removing suspended solids. *Chrysopogon zizanioides* is also reported to be efficient in TSS removal in constructed wetlands. *Ipomoea aquatica* Forsk. has demonstrated high TSS removal rates in some studies.

3.2.3. Oil and grease

At the start of the study, the influent oil and grease concentration was 17 mg L⁻¹. In the unplanted system, this dropped to 1 mg L⁻¹ after 7 days and below 1 mg L⁻¹ after 14 days, indicating effective natural processes. *Chrysopogon zizanioides* reduced oil and grease to 3 mg L⁻¹ after 7 days and below 1 mg L⁻¹ after 14 days, aided by its dense, fibrous root system, enhancing microbial biodegradation [33, 35]. *Dracaena sanderiana* showed a similar trend, reducing concentrations to 2 mg L⁻¹ after 7 days and below 1 mg L⁻¹ after 14 days. *Ipomoea aquatica* Forsk. also achieved significant removal, reducing oil and grease to 1 mg L⁻¹ after 7 days and below 1 mg L⁻¹ after 14 days, despite its floating nature limiting sedimentation effects. The high removals are attributed to a combination of physical trapping of hydrophobic compounds by the substrate, and microbial biodegradation of fatty substances enhanced by aerobic microzones in planted systems [33, 35].

The extended retention time of 14 days enhanced oil and grease removal across all treatments, emphasizing the importance of optimizing hydraulic retention time for high pollutant removal efficiency.

3.2.4. Nitrate (NO₃-N)

The influent nitrate concentration initially was below 0.03 mg L⁻¹. In the control system without plants, nitrate levels rose to 0.06 mg L⁻¹ after 7 days, possibly due to nitrification or mineralization, but fell below 0.03 mg L⁻¹ after 14 days, indicating natural denitrification processes. Planted systems maintained nitrate concentrations below 0.03 mg L⁻¹ throughout. *Dracaena sanderiana* and *Ipomoea aquatica* Forsk. achieved near-complete nitrate removal, maintaining levels below detection limits (<0.03 mg L⁻¹) even at 7 days, highlighting plants' role in nitrogen uptake and rhizosphere oxygenation [36]. *Chrysopogon zizanioides* also effectively reduced nitrate, from 0.05 mg L⁻¹ at 7 days to below 0.03 mg L⁻¹ by 14 days, facilitated by its dense root system and microbial colonization.

Plants enhance nitrification and denitrification processes, with nitrifying bacteria converting ammonia to nitrite and nitrate, and denitrifying bacteria converting nitrate to nitrogen gas. The rhizosphere supports these microbial communities, leading to efficient nitrate removal [37]. Soil analysis revealed a nitrogen content of 0.268% using the Kjeldahl test, indicating potential nutrient leaching in control systems, mitigated by vegetation in planted systems. This underscores the importance of integrating vegetation in constructed wetlands to minimize nutrient leaching and enhance nitrate removal.

Although nitrate concentrations in the influent wastewater were found to be below detection limits (<0.03 mg L⁻¹), the plant growth and pollutant removal performance observed in planted constructed wetland systems suggest that alternative nitrogen sources supported plant development. Dairy wastewater is known to contain high levels of organic nitrogen compounds, such as proteins and amino acids, which can be mineralized by microbial communities into ammonium (NH₄⁺) and subsequently into nitrate through nitrification processes [38–40]. Plants in constructed wetlands can efficiently utilize ammonium as a nitrogen source, in addition to nitrate, thereby sustaining growth even under conditions of low inorganic nitrate availability [41]. Recent studies highlight the critical role of microbial-driven nutrient cycling within the wetland substrate, particularly in systems treating stormwater or agricultural runoff, where microbial communities adapt to fluctuating nutrient loads and redox conditions to maintain nitrogen transformations [38–40]. For instance, microbial taxa such as *Nitrosomonadaceae* and *Nitrospira* have been shown to persist even during seasonal nitrification failures, suggesting functional redundancy in nitrogen cycling pathways [42, 43]. Additionally, small-scale constructed wetlands (<8 hectares) demonstrate sustained synergistic removal of nitrogen and phosphorus over 3–12 years, emphasizing the long-term stability of these systems [39]. The

integration of plant uptake and microbial activity in constructed wetlands ensures efficient phytoremediation, even when inorganic nitrogen forms are scarce [39, 41].

3.2.5. pH stabilization

The level of pH is very important to be controlled before being discharged to the environment [44]. In the control treatment, pH levels increased to 7.38 after 7 days and surged to 7.56 by the 14th day, likely due to the buffering capacity of the wetland substrate. In contrast, systems with plants exhibited more consistent pH stabilization through various biological and chemical processes.

Ipomoea aquatica Forsk. was particularly effective, maintaining a pH of 7.35 after 7 days and 7.42 after 14 days, in line with its known abilities in environmental remediation [24]. The *Dracaena sanderiana* kept the pH at 7.54 after 7 days and 7.68 after 14 days, which can be attributed primarily to root exudates and microbial activity. Similarly, *Chrysopogon zizanioides* stabilized the pH at 7.56 after 7 days and 7.64 by the 14th day.

These planted treatments outperformed the control in pH stabilization, showcasing the crucial role of vegetation and microbial interactions in maintaining near-neutral pH levels, which are essential for protecting aquatic ecosystems. The constructed wetland system effectively raised the pH from an acidic influent of 3.84 to near-neutral levels (7.35–7.68), highlighting the importance of vegetation in enhancing pH stabilization.

Among the plants tested, water spinach emerged as the most effective in maintaining neutral pH, making it a promising candidate for treating acidic wastewater in constructed wetlands.

3.3. Effects of retention time

This pilot study explored the effects of retention time on the treatment efficiency of vertical subsurface flow constructed wetlands (VSSF CW) planted with three macrophyte species: *Dracaena sanderiana*, *Chrysopogon zizanioides*, and *Ipomoea aquatica* Forsk. As shown in Figure 4, a general trend of improved removal performance for BOD₅ and TSS was observed with an increase in retention time from 7 to 14 days. *Dracaena sanderiana* consistently exhibited the highest treatment efficiency, achieving approximately 91% and 98% BOD₅ removal at 7 and 14 days, respectively, along with 95% and 88% TSS removal. *Chrysopogon zizanioides* also demonstrated strong performance, particularly for BOD₅ removal (around 98% at 7 days and 94% at 14 days); however, a slight decrease was noted in TSS removal with extended retention. In contrast, *Ipomoea aquatica* Forsk. showed lower removal efficiencies, especially for TSS, where removal rates decreased markedly from about 91% at 7 days to approximately 63% at 14 days. It is important to note that although BOD₅ removal for *Ipomoea aquatica* Forsk. improved with longer retention, the variability in TSS performance suggests potential limitations related to plant type or system stabilization over time.

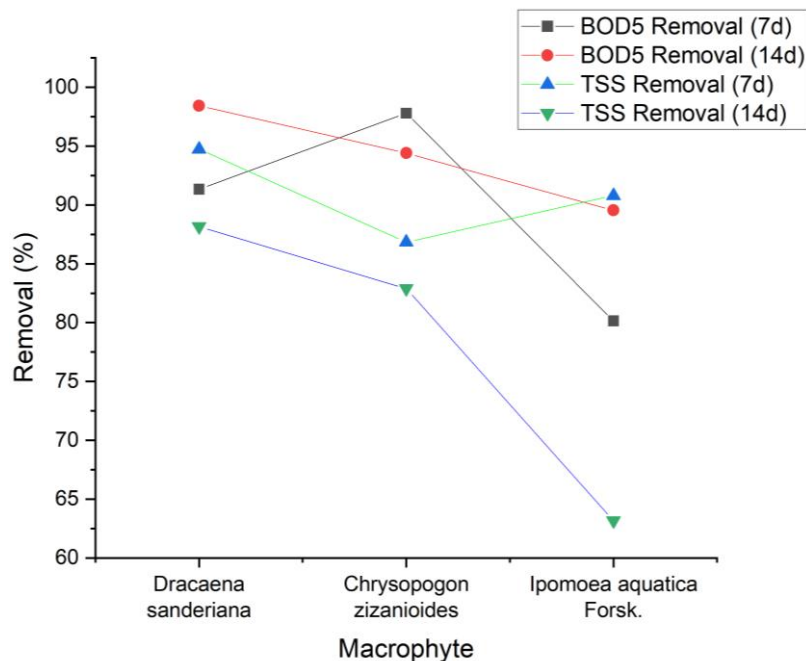


Figure 4. Removal efficiencies of BOD₅ and TSS after 7- and 14-day retention times in pilot-scale VSSF CW planted with different macrophyte species

Additional water quality parameters, presented in Table 3, offer further insights but should be interpreted cautiously given the preliminary nature of the investigation. Nitrate levels in the influent were very low ($<0.03 \text{ mg L}^{-1}$), making it difficult to assess significant treatment effects across different macrophytes and retention times. For oil and grease, all treatments—including the unplanted control—achieved high removal efficiencies, exceeding 88% after 7 days and surpassing 94% after 14 days, indicating that both biological and physicochemical processes may be contributing substantially to treatment outcomes. The observed neutralization of pH, from an initial highly acidic value (pH 3.84) to values near neutrality (pH 7.35–7.68) across all planted and unplanted treatments, further supports the potential of VSSF CWs for effluent stabilization.

While these preliminary results are promising, they must be interpreted within the context of the study's limitations, including the controlled conditions and relatively short operational period typical of pilot-scale systems. Further long-term studies, under variable environmental conditions and operational scales, are necessary to validate these findings and fully establish the reliability and robustness of the observed treatment performances. Nevertheless, the current data suggest that both retention time and macrophyte selection are critical factors influencing the efficacy of VSSF CWs and warrant continued investigation.

3.4. Removal Mechanisms in the Vertical Subsurface Flow Constructed Wetlands

The overall high pollutant removal observed in all four systems is a result of complex, synergistic mechanisms occurring within the VSSF CW system. The high BOD₅ removal efficiency demonstrated by the

unplanted control system, 81.34% confirms that physical filtration/sedimentation and microbial degradation within the gravel and sand substrate are the dominant and primary removal processes. Plant presence provides a critical enhancement mechanism, particularly in systems that achieved $>95\%$ BOD₅ removal. Large solids (TSS) and oil/grease are primarily removed via filtration by the sand and gravel medium and subsequent sedimentation in the bed. Heterotrophic bacteria attached to the substrate particles aerobically oxidize organic pollutants (BOD₅) and nitrify ammonium (NH_4^+). Oxygen is provided by the intermittent loading scheme and is enhanced by the plants' root systems (rhizosphere). The significant change in pH (from 3.84 to neutral) promotes the precipitation of heavy metals and phosphorus compounds as insoluble salts, trapping them within the substrate matrix.

Furthermore, the macrophytes provide several crucial functions, primarily in the nutrient uptake into the plant biomass, root matrix stabilization to prevent clogging and increase porosity, and crucially, the transport of oxygen from the leaves to the rhizosphere, creating a highly oxygenated micro-zone that significantly boosts aerobic microbial degradation and facilitates the final, critical percentage of BOD₅ and TSS removal.

3.5. Compliance with the Philippine DENR effluent standards

The effluent quality of the vertical subsurface flow constructed wetland (VSSF CW) systems was evaluated against the effluent standards established by the Department of Environment and Natural Resources (DENR) under DAO 2016-08. Considering the classification of the water bodies near the USTP Claveria

Gatas 955 Milk Processing Plant, comparisons were made based on the standards for Class C and Class D water bodies. Class C waters are intended for fisheries, recreation, and agricultural use, while Class D waters are designated for navigational and transport purposes. Tables 4 and 5 summarize the effluent quality results following 7 and 14 days of retention time, respectively.

At 7 days of retention, the biochemical oxygen demand (BOD₅) concentrations in the effluents from *Dracaena sanderiana*, *Chrysopogon zizanioides*, and *Ipomoea aquatica* Forsk. treatments exceeded the Class C standard of 50 mg L⁻¹. Only the effluent from *Chrysopogon zizanioides* complied with the Class D limit of 120 mg L⁻¹. After 14 days, a substantial reduction in BOD₅ was observed, with *Dracaena sanderiana* achieving full compliance with both Class C and Class D standards. In contrast, effluents from *Chrysopogon zizanioides* and *Ipomoea aquatica* Forsk. remained above the allowable

BOD₅ thresholds. These findings suggest that longer retention time is critical for effective organic pollutant removal. However, it must be emphasized that these results stem from pilot-scale experiments and should be interpreted cautiously pending validation under full-scale and long-term operational conditions.

For total suspended solids (TSS), all treatments consistently achieved compliance with the DENR standards across both retention times. TSS concentrations remained well below the Class C (100 mg L⁻¹) and Class D (150 mg L⁻¹) thresholds, ranging from 4 to 10 mg L⁻¹ after 7 days and from 9 to 28 mg L⁻¹ after 14 days. These results highlight the capacity of the VSSF CW systems to effectively remove suspended solids through sedimentation and filtration mechanisms supported by the substrate and plant root networks. Nonetheless, sustained monitoring is necessary to ensure long-term system performance.

Table 3. Effluent quality of VSSF CW planted with *Dracaena sanderiana*, *Chrysopogon zizanioides*, and *Ipomoea aquatica* Forsk. compared with the DENR DAO 2016-08 effluent standard for Class C and Class D after 7 days retention time

Parameter	Unit	Results			DAO 2016-08	
		<i>Dracaena sanderiana</i>	<i>Chrysopogon zizanioides</i>	<i>Ipomoea aquatica</i> Forsk.	Class C *	Class D *
pH	-	7.54	7.56	7.35	6.0-9.5	5.5-9.5
BOD ₅	mg L ⁻¹	232	59	532	50	120
TSS	mg L ⁻¹	4	10	7	100	150
Nitrate	mg L ⁻¹	< 0.03	0.05	< 0.03	14	30
Oil and Grease	mg L ⁻¹	2	3	1	5	15

* Water body classification according to beneficial use

Table 4. Effluent quality of VSSF CW planted with *Dracaena sanderiana*, *Chrysopogon zizanioides*, and *Ipomoea aquatica* Forsk. compared with the DENR DAO 2016-08 effluent standard for Class C and Class D after 14 days retention time

Parameter	Unit	Results			DAO 2016-08	
		<i>Dracaena sanderiana</i>	<i>Chrysopogon zizanioides</i>	<i>Water spinach</i>	Class C *	Class D *
pH	-	7.68	7.64	7.42	6.0-9.5	5.5-9.5
BOD ₅	mg L ⁻¹	42	150	280	50	120
TSS	mg L ⁻¹	9	13	28	100	150
Nitrate	mg L ⁻¹	< 0.03	< 0.03	< 0.03	14	30
Oil and Grease	mg L ⁻¹	< 1	< 1	< 1	5	15

* Water body classification according to beneficial use

Effluent concentrations of oil and grease also fell within the allowable limits (5 mg L⁻¹ for Class C and 15 mg L⁻¹ for Class D) for all treatments. At the 14-day retention time, concentrations were below the detectable limit (<1 mg L⁻¹) across all systems, suggesting effective removal processes, possibly through substrate adsorption and microbial degradation. However, given the short duration and controlled conditions of the study, further investigation under varied influent characteristics is warranted.

Nitrate removal was consistently high across all treatments, with effluent concentrations remaining below detection limits (<0.03 mg L⁻¹) or showing only minimal presence, and consistently meeting DENR standards (14 mg L⁻¹ for Class C and 30 mg L⁻¹ for Class D). While these results indicate effective nitrogen removal mechanisms such as microbial denitrification and plant uptake, the low nitrate concentration in the influent limits the full assessment of system nitrogen removal capacity.

Effluent pH values across all treatments were within the acceptable ranges of 6.0–9.5 for Class C and 5.5–9.5 for Class D. The pH increased from the initial acidic condition (3.84) to near-neutral values (7.35–7.68) after treatment, indicating effective pH stabilization.

The preliminary findings from this pilot-scale study demonstrate that the VSSF CW systems planted with *Dracaena sanderiana*, *Chrysopogon zizanioides*, and *Ipomoea aquatica* Forsk. achieved consistent compliance with DENR standards for TSS, oil and grease, nitrate, and pH. However, BOD₅ reduction varied among species and was significantly influenced by retention time. Among the species tested, *Dracaena sanderiana* demonstrated the most consistent performance in achieving full regulatory compliance after 14 days of treatment. Further studies under extended operational periods and field-scale conditions are necessary to validate these initial observations and to optimize system design and plant selection for robust performance.

4. Conclusion

This study examines the effectiveness of vertical subsurface flow constructed wetlands (VSSF CW) in treating milk processing plant wastewater in terms of various significant parameters, as outlined in DENR DAO 2016-08, PSIC Code 105, regarding the manufacture of dairy products. Furthermore, this study also compared the performance of three plants—*Dracaena sanderiana*, *Chrysopogon zizanioides*, and *Ipomoea aquatica* Forsk.—in terms of their phytoremediation potential in application to the VSSF CW. Results revealed notable differences in their pollutant removal efficiencies. Each plant demonstrated unique strengths in handling specific contaminants, underscoring the importance of selecting the right plant for optimal wetland performance. These findings highlight the role of constructed wetlands as an effective and environmentally friendly wastewater treatment solution. By leveraging the inherent capabilities of the selected plants, this study contributes valuable insights into sustainable water management practices. The promising effluent quality demonstrates the potential of VSSF CWs to help local dairy industries achieve compliance with the Philippine DENR DAO 2016-08 effluent standards, thereby promoting sustainable and nature-based industrial wastewater management.

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Author contributions

Val Irvin F. Mabayo: Conceptualization, Methodology, Investigation, Data curation, Writing-Original draft preparation **Felisa E. Gomba:** Supervision, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

References

- Karakas, I., & Kizil, S. (2024). A critical study on the treatability of metal plating industry wastewater and real scale adaptation. *Turkish Journal of Engineering*, 8(3), 427–435. <https://doi.org/10.31127/tuje.1406437>
- Erdem, F. (2022). Risk assessment with the fuzzy logic method for Ankara OIZ environmental waste water treatment plant. *Turkish Journal of Engineering*, 6(4), 268–275. <https://doi.org/10.31127/tuje.975623>
- EL-Tawabty, M. O., Samn, A. A. M., AbouTaleb, E. M., Ghanem, M. H., & Noura, A. (2022). Minimize environmental impact of dairy production through improve the life cycle. Part 1: Pollution load from Dairy wastewater in 6 of October Industrial City. *Egyptian Journal of Chemistry*, 65(9), 201–209. <https://doi.org/10.21608/EJCHEM.2022.94800.4463>
- Ubuza, L. J. A., Padero, P. C. S., Nacalaban, C. M. N., Tolentino, J. T., Alcoran, D. C., Tolentino, J. C., ... Arazo, R. O. (2020). Assessment of the potential of duckweed (*Lemna minor* L.) in treating lead-contaminated water through phytoremediation in stationary and recirculated set-ups. *Environmental Engineering Research*, 25(6), 977–982. <https://doi.org/10.4491/eer.2019.258>
- Mabayo, V. I., & Orale, R. (2023). Agricultural-based Biomass as an Efficient Adsorbent in the Removal of Dyes in Dye-contaminated Wastewater: A Mini Review. *Current Applied Science and Technology*, 24(1), e0257011. <https://doi.org/10.55003/cast.2023.257011>
- Quimada, N. E., Sioson, A. S., Sutopo, F., & Mabayo, V. I. F. (2024). Response surface optimization of the efficiency of ZnCl₂-impregnated activated carbon from residual coffee grounds in the removal of Eriochrome Black T dye-contaminated wastewater. *Biomass Conversion and Biorefinery*, 14(6), 7555–7567. <https://doi.org/10.1007/s13399-023-04090-3>
- Saleh, M., Yalvaç, M., Sime, F., & Mazmanci, M. A. (2019). Study the Effect of Hair Style Products on the Quality of Domestic Wastewater-Wax As Case Study. *Turkish Journal of Engineering*, 3(2), 97–101. <https://doi.org/10.31127/tuje.451173>
- Kaur, N. (2021). Different treatment techniques of dairy wastewater. *Groundwater for Sustainable Development*, 14(July), 100640. <https://doi.org/10.1016/j.gsd.2021.100640>
- Bolognesi, S., Cecconet, D., & Capodaglio, A. G. (2020). Agro-industrial wastewater treatment in microbial fuel cells. *Integrated Microbial Fuel Cells for Wastewater Treatment*. INC. <https://doi.org/10.1016/B978-0-12-817493-7.00005-9>
- Bouanga Boudiombo, J. S., Madden, D. G., Cusack, B., Cronin, P., & Ryan, A. (2023). State of the art and prospects of zeolites and metal organic frameworks (MOFs) for nitrogen and phosphorus removal in dairy wastewater. *Chemosphere*, 329(October 2022), 138531. <https://doi.org/10.1016/j.chemosphere.2023.138531>
- Savcı, S. (2017). Treatment of Biodiesel Wastewater Using Yellow Mustard Seeds. *Turkish Journal of Engineering*, 1(1), 11–17. <https://doi.org/10.31127/tuje.315927>
- Kafle, A., Timilsina, A., Gautam, A., Adhikari, K., Bhattarai, A., & Aryal, N. (2022). Phytoremediation: Mechanisms, plant selection and enhancement by natural and synthetic agents. *Environmental Advances*, 8(February), 100203. <https://doi.org/10.1016/j.envadv.2022.100203>
- Dickinson, N. (2016). Phytoremediation. *Encyclopedia of Applied Plant Sciences*, 3, 327–

331. <https://doi.org/10.1016/B978-0-12-394807-6.00016-2>
14. Mateo-Díaz, N. F., Sandoval Herazo, L. C., Zurita, F., Sandoval-Herazo, M., Nani, G., Fernández-Echeverría, E., ... Martínez-Reséndiz, G. (2023). Remediation of River Water Contaminated with Whey Using Horizontal Subsurface Flow Constructed Wetlands with Ornamental Plants in a Tropical Environment. *Water (Switzerland)*, 15(19), 1–17. <https://doi.org/10.3390/w15193456>
15. Dabrowski, W., Karolinczak, B., Malinowski, P., & Boruszko, D. (2019). Modeling of pollutants removal in subsurface vertical flow and horizontal flow constructed wetlands. *Water (Switzerland)*, 11(1). <https://doi.org/10.3390/w11010180>
16. Vymazal, J. (2019). Constructed Wetlands for Wastewater Treatment. In *Encyclopedia of Ecology* (Vol. 1, pp. 14–21). Elsevier. <https://doi.org/10.1016/B978-0-12-409548-9.11238-2>
17. Alateeqi, M., Khajah, M., Abu-Arabi, M., & AlMansour, H. (2023). Greywater treatment using vertical subsurface flow constructed wetland system. *Journal of Engineering Research (Kuwait)*, 11(3), 7–12. <https://doi.org/10.1016/j.jer.2023.100052>
18. Perdana, M. C., Sutanto, H. B., & Prihatmo, G. (2018). Vertical Subsurface Flow (VSSF) constructed wetland for domestic wastewater treatment. *IOP Conference Series: Earth and Environmental Science*, 148(1). <https://doi.org/10.1088/1755-1315/148/1/012025>
19. Minakshi, D., Sharma, P. K., Rani, A., Malaviya, P., Srivastava, V., & Kumar, M. (2022). Performance evaluation of vertical constructed wetland units with hydraulic retention time as a variable operating factor. *Groundwater for Sustainable Development*, 19(August), 100834. <https://doi.org/10.1016/j.gsd.2022.100834>
20. Yuan, J. J., Dong, W. Y., Sun, F. Y., Zhao, K., & Li, P. (2016). Enhanced heavy metal removal by wetland vegetations and its significance for vegetation-activated sludge process configuration. *Desalination and Water Treatment*, 57(52), 25153–25160. <https://doi.org/10.1080/19443994.2016.1150885>
21. Tamang, R. (2023). Nutrient And Heavy Metal Accumulation In A Lab-Scale Vertical Subsurface Flow Constructed Wetland Planted With Selected Plants Species. *Science International (Lahore)*, 35(3), 235–238.
22. Teixeira, D. L. (2022). Influence of plants on the salinity of constructed wetlands effluents. *Water Science and Technology*, 85(5), 1648–1657. <https://doi.org/10.2166/wst.2022.075>
23. Velasco, P. P., Dala, P. S., Sundo, M. B., De Padua, V. M. N., & Madlangbayan, M. S. (2024). Effect of varying retention times and feeding schemes on the performance of vertical constructed wetlands planted with vetiver grass in treating dairy wastewater in the Philippines. *Environmental Quality Management*, 33(3), 173–181. <https://doi.org/10.1002/tqem.22103>
24. Osa, J. R. F., & Apuan, D. A. (2018). Water spinach (*Ipomoea aquatica*) as potential macrophytes to remediate acid mine drainage (AMD). *International Journal of Biosciences (IJB)*, 13(05), 161–167. <https://doi.org/10.12692/ijb/13.5.161-167>
25. Denr. (2016). Department of Environment and Natural Resources (DENR) Administrative Order No. 2016-08 on Water Quality Guidelines and General Effluent Standards of 2016. Philippines. Retrieved from <http://water.emb.gov.ph/wp-content/uploads/2016/06/DAO-2016-08-WQG-and-GES.pdf>
26. Un-Habitat. (2008). *Constructed Wetlands Manual*. Nepal, Kathmandu: UN-HABITAT Water for Asian Cities Programme Nepal, Kathmandu. Retrieved from <https://www.unhabitat.org>
27. Flores, R., & Adil, J. (2019). Treatment of Slaughterhouse Wastewater Utilizing Cogon Grass (*Imperata cylindrica*) in a Subsurface Flow System Constructed Wetland in Zamboanga City, Philippines. In *16th International Conference on Environmental Science and Technology*. Rhodes, Greece.
28. Saiyood, S., Vangnai, A. S., Thiravetyan, P., & Inthorn, D. (2010). Bisphenol A removal by the *Dracaena* plant and the role of plant-associating bacteria. *Journal of Hazardous Materials*, 178(1–3), 777–785. <https://doi.org/10.1016/j.jhazmat.2010.02.008>
29. Hassan, I., Chowdhury, S. R., Prihartato, P. K., & Razzak, S. A. (2021). Wastewater treatment using constructed wetland: Current trends and future potential. *Processes*, 9(11), 1–27. <https://doi.org/10.3390/pr9111917>
30. Ayres, J., Awad, J., Walker, C., Page, D., van Leeuwen, J., & Beecham, S. (2022). Constructed Floating Wetlands for the Treatment of Surface Waters and Industrial Wastewaters. https://doi.org/10.1007/978-3-031-18412-3_3
31. Dorafshan, M. M., Abedi-Koupai, J., Eslamian, S., & Amiri, M. J. (2023). Vetiver Grass (*Chrysopogon zizanioides* L.): A Hyper-Accumulator Crop for Bioremediation of Unconventional Water. *Sustainability (Switzerland)*, 15(4). <https://doi.org/10.3390/su15043529>
32. Nguyen, M. K., Hung, N. T. Q., Nguyen, C. M., Lin, C., Nguyen, T. A., & Nguyen, H. L. (2023). Application of vetiver grass (*Vetiveria Zizanioides* L.) for organic matter removal from contaminated surface water. *Bioresource Technology Reports*, 22(April), 101431. <https://doi.org/10.1016/j.biteb.2023.101431>
33. Aregu, M. B., Soboksa, N. E., & Kanno, G. G. (2021). High Strength Wastewater Reclamation Capacity of Vetiver Grass in Tropics: The Case of Ethiopia. *Environmental Health Insights*, 15.

- <https://doi.org/10.1177/11786302211060162>
34. Chukwumati, J. A., & Kamalu, O. J. (2021). Capability of Vetiver (*Vetiveria Zizanioides*), Guinea Grass (*Panicum Maximum*) and Organic Manures to Remove Total Hydrocarbon and Heavy Metals from Crude Oil Contaminated Soil in Port Harcourt. *Advances in Research*, 22(3), 18–29.
<https://doi.org/10.9734/air/2021/v22i330301>
 35. Grinberga, L., Lauva, D., & Lagzdins, A. (2021). Treatment of Storm Water from Agricultural Catchment in Pilot Scale Constructed Wetland. *Environmental and Climate Technologies*, 25(1), 640–649. <https://doi.org/10.2478/rtulect-2021-0048>
 36. Wang, J., Chen, Z., Liu, M., Chen, M., Wang, Y., Wu, G., ... Deng, Y. (2024). A Review of Enhanced Nitrogen Removal Measures and Mechanisms in Constructed Wetlands. *Polish Journal of Environmental Studies*, 1–22.
<https://doi.org/10.15244/pjoes/192561>
 37. Adame, M. F., Waltham, N. J., Iram, N., Farahani, B. S., Salinas, C., Burford, M., & Ronan, M. (2021). Denitrification within the sediments and epiphyton of tropical macrophyte stands. *Inland Waters*, 11(3), 257–266.
<https://doi.org/10.1080/20442041.2021.1902214>
 38. Vymazal, J. (2007). Removal of nutrients in various types of constructed wetlands. *Science of the Total Environment*, 380(1–3), 48–65.
<https://doi.org/10.1016/j.scitotenv.2006.09.014>
 39. Chen, G., Mo, Y., Gu, X., Jeppesen, E., Xie, T., Ning, Z., ... Wu, H. (2024). Sustainability of global small-scale constructed wetlands for multiple pollutant control. *npj Clean Water*, 7(1), 1–13.
<https://doi.org/10.1038/s41545-024-00336-3>
 40. Shirdashtzadeh, M., Chua, L. H. C., & Brau, L. (2022). Microbial Communities and Nitrogen Transformation in Constructed Wetlands Treating Stormwater Runoff. *Frontiers in Water*, 3, 1–20.
<https://doi.org/10.3389/frwa.2021.751830>
 41. Li, J., Zheng, B., Chen, X., Li, Z., Xia, Q., Wang, H., ... Yang, H. (2021). The use of constructed wetland for mitigating nitrogen and phosphorus from agricultural runoff: A review. *Water (Switzerland)*, 13(4), 1–16.
<https://doi.org/10.3390/w13040476>
 42. Johnston, J., LaPara, T., & Behrens, S. (2019). Composition and Dynamics of the Activated Sludge Microbiome during Seasonal Nitrification Failure. *Scientific Reports*, 9(1), 1–15.
<https://doi.org/10.1038/s41598-019-40872-4>
 43. Feizizadeh, B., Yariyan, P., Yakar, M., Blaschke, T., & Almuraqab, N. A. S. (2025). An integrated hybrid deep learning data driven approaches for spatiotemporal mapping of land susceptibility to salt/dust emissions. *Advances in Space Research*.
 44. Körbahti, B. K., & Erdem, M. C. (2017). pH Change in Electrochemical Oxidation of Imidacloprid Pesticide Using Boron-Doped Diamond Electrodes. *Turkish Journal of Engineering*, 1(1), 32–36. <https://doi.org/10.31127/tuje.316683>



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