Scientific Research Publishing

Journal of Agricultural Chemistry and Environment, 2024, 13, 67-82
https://www.scirp.org/journal/jacen
ISSN Online: 2325-744X
ISSN Print: 2325-7458

A Comparative Analysis of Vetiver and *Typha* in Ecological Wastewater Treatment Using a Horizontal Flow Constructed Wetlands in Rural Setting

Falilou Coundoul[1], Abdou Khafor Ndiaye[2], Abdoulaye Deme[2], Antonina Torrens Armegnol[3]

[1]Polytechnic Institute of Saint-Louis (IPSL), Gaston Berger University, Saint-Louis, Senegal
[2]UFR of Applied Sciences and Technology, Gaston Berger University, Saint-Louis, Senegal
[3]Department of Biology, Healthcare and Environment, Faculty of Pharmacy and Food Sciences, University of Barcelona, Barcelona, Spain

Email: falilou.coundoul@ugb.edu.sn, ndiaye.abdou-khafor@ugb.edu.sn, antoninatorrens@ub.edu, abdoulaye.deme@ugb.edu.sn

How to cite this paper: Coundoul, F., Ndiaye, A.K., Deme, A. and Armegnol, A.T. (2024) A Comparative Analysis of Vetiver and *Typha* in Ecological Wastewater Treatment Using a Horizontal Flow Constructed Wetlands in Rural Setting. *Journal of Agricultural Chemistry and Environment*, **13**, 67-82.
https://doi.org/10.4236/jacen.2024.131005

Received: December 1, 2023
Accepted: January 28, 2024
Published: January 31, 2024

Abstract

This study presents an assessment of wastewater ecological treatment processes utilizing a horizontal flow bio-reactor at the Ndiebene Gandiol 1 school. It primarily aims to juxtapose the filtration efficacy of two distinct vegetative cells, Vetiver and *Typha*, in the pursuit of sustainable wastewater management strategies for rural scholastic institutions. A synergistic approach was employed, integrating on-site surveys for site-specific insights and laboratory analyses to quantify the pollutant loads pre- and post-treatment. Our findings indicate that both Vetiver and *Typha*-infused filter beds significantly reduce most contaminants, with particular success in diminishing chemical oxygen demand (COD) and biological oxygen demand (BOD_5). Vetiver was notable for its superior reduction of COD, achieving an average effluent concentration of 74 mg/L, in contrast to *Typha*'s 155 mg/L. Conversely, *Typha* excelled in suspended solids removal, registering 1 mg/L against Vetiver's 3 mg/L. While both systems notably surpassed the target metrics across several indicators, including fecal coliform reduction, our results pinpoint the need for refinement in phosphate remediation. Conclusively, the study underscores the efficacy of both Vetiver and *Typha* systems in rural wastewater treatment contexts, with their integrative application potentially paving the way for enhanced system robustness and efficiency. The outcomes herein highlight the imperative for continued research to further hone these ecological treatment modalities, especially concerning phosphate elimination.

Keywords

Hydraulics, Water Treatment, Agricultural Irrigation, Sanitation, Engineering, Environment

1. Introduction

The new Senegalese sectoral policy for the period 2016-2025 aims primarily to support the achievement of sustainable development goals, ensuring universal access to clean drinking water and adequate sanitation facilities by 2030, while also promoting integrated water resource management [1]. The policy emphasizes key elements of Sustainable Development Goals (SDG) 6, including: 1) household access to sustainable sanitation, 2) wastewater and stormwater management, and 3) eradication of open defecation. By confronting this desire with the reality on the ground, we find that there is a big gap. According to data available through 2021, approximately 56% of the Senegalese population had access to improved sanitation services, such as toilets connected to a wastewater disposal system. This means that a large part of the population still does not have access to adequate sanitation facilities. Sanitation networks, such as sewers, are still limited in many parts of the country, particularly in rural areas. Most sanitation systems are concentrated in urban areas, particularly in the capital, Dakar. Wastewater treatment is still insufficient in Senegal. Most existing wastewater treatment facilities are in large cities, while rural areas are largely devoid of them. This leads to pollution of waterways and groundwater by untreated wastewater. The Senegalese government has taken steps to improve sanitation and wastewater treatment. He launched the Millennium Sanitation Program (MAP) in 2009, which aims to expand access to sanitation across the country. In addition, the National Sanitation Plan (PNA) was put in place to improve wastewater management and develop sanitation infrastructure. Senegal also benefits from the support of international agencies, such as the World Bank, the African Development Bank and NGOs, which work in collaboration with the government to build capacity in the sanitation sector. Senegal is committed, like many countries, to achieving the Sustainable Development Goals (SDGs) defined by the United Nations General Assembly in 2015. These commitments cover various aspects related to water and to sanitation. Despite continued efforts and national and international initiatives, challenges remain in sanitation, particularly in rural areas [2] [3]. Alternative methods of wastewater treatment, such as reed filters, have been studied in various contexts, including developing countries [4] [5]. These methods have demonstrated their effectiveness, but their application requires specific local adaptation. Sustainable wastewater management is crucial, particularly in regions where water resources are limited. In this context, the experimentation of ecological systems for the treatment of this water is constantly evolving. Among these systems, the use of plants, such as Vetiver, is increasingly recognized for its effectiveness. Vetiver (*Chrysopogon zizanioides*) is a tropical grass whose deep root systems give it special properties for erosion control, phytoremediation and wastewater treatment [6] [7] [8]. This work proposes a case study focused on the Ndiebene Gandiol 1 school, equipped with a horizontal flow biological reactor. The latter includes two filter bed cells measuring 12 × 8.5 m each and is preceded by a septic tank. A reservoir is also planned to collect treated water. Although the two cells have identical dimensions, they differ in the plants used for the treatment: one uses Vetiver and the other *Typha*.

The main objective of our study is to identify the strengths and weaknesses of the ecological wastewater treatment system in rural and school environments. We also aim to make recommendations, with particular emphasis on sustainable solutions adapted to local needs. This approach is more relevant as it focuses on the treatment of wastewater in a school context. Key steps in our investigation include:

- A field investigation to understand the specificities of the site.
- Laboratory analysis of wastewater samples to measure the pollutant load.
- Monitoring the quality of water treated by the biological reactor.
- A comparative study of the performance of cells using Vetiver and *Typha*.

The structure of this article is organized as follows: Section 2 presents our methodology, Section 3 presents the results obtained, Section 4 discusses the implications, and Section 5 concludes by formulating recommendations for future work.

2. Materials and Methods

2.1. Presentation of the Study Area

Ndiebene Gandiol is a commune in Senegal located 20 kilometers from the city of Saint-Louis, on the Grande-Côte, not far from the mouth of the Senegal River. It is part of the Rao district, the Saint-Louis department, and the eponymous region. Due to its geographical position, Ndiébène is in the heart of the historic region of Gandiol. Since 2014, with the adoption of Act 3 of decentralization, Ndiébène Gandiol has become the capital of the commune of Gandiol.

Our study focuses on the Ndiebene Gandiol 1 school, equipped with a horizontal flow biological reactor to treat wastewater. The latter includes two filter bed cells measuring 12 × 8.5 m each and is preceded by a septic tank. A reservoir is also planned to collect treated water. Although the two cells have identical dimensions, they differ in the plants used for the treatment: one uses Vetiver and the other *Typha*. The location and surface area of the establishment are illustrated in **Figure 1**. The establishment receives 505 students, whose ages vary between 7 and 14 years old, who are distributed in 12 classrooms. However, despite this large number of students, the school only has 4 latrines intended for students and one reserved for teachers. None of these latrines are operational. Furthermore, the school does not have any water point. Its sanitation system is

Figure 1. Location of the site studied: the Ndiebène Gandiol school.

considered non-compliant. Finally, the toilets are in poor condition, frequently clogged and, as a result, unusable for students and teachers most of the time.

Saint Louis experiences a Sahelian climate, noted for its hot, dry continental winds, with a yearly average temperature of around 24.5 degrees Celsius. Temperature variations span from a mild 18 degrees Celsius in January to a scorching 40 degrees Celsius in May. On average, the city basks in 250 hours of sunshine each month, which translates to about 8.5 hours of sunlight daily. The region is predominantly arid, receiving an annual average rainfall of just 265.0 mm. This climate is split into two distinct seasons: a warm and wet rainy season commencing towards the end of June and concluding in October, during which heavy showers can deliver up to 100 mm of rain in August; and a dry season that stretches from November through May, characterized by the harmattan winds from the desert that bring in hot, dusty days with virtually no rainfall [9].

2.2. Filter Description

The configuration of the horizontal flow planted filter is presented in 3D in **Figure 2**. The filter is made up of two filter bed cells measuring 12 × 8.5 m each, preceded by a septic tank. A tank collects the treated water. The two cells have the same depth, the difference lies in the choice of plants whose influence we want to determine in water treatment. Likewise, we have flint gravel everywhere but at different diameters. At the entrance and exit over a width of 0.5 m we have large gravel which covers the distribution and wastewater recovery pipes. In the middle, between the two layers of large gravel, we have gravel 5 - 15 of small dimensions. The general characteristics of the filter are presented in **Table 1**.

2.3. Experimental Protocol

2.3.1. Sample Collection

To determine the quality of the water at the inlet and outlet of the filter, a sampling program was established, detailed in **Table 2**. The parameters analyzed during each sampling campaign are presented in **Table 3**. The collected samples

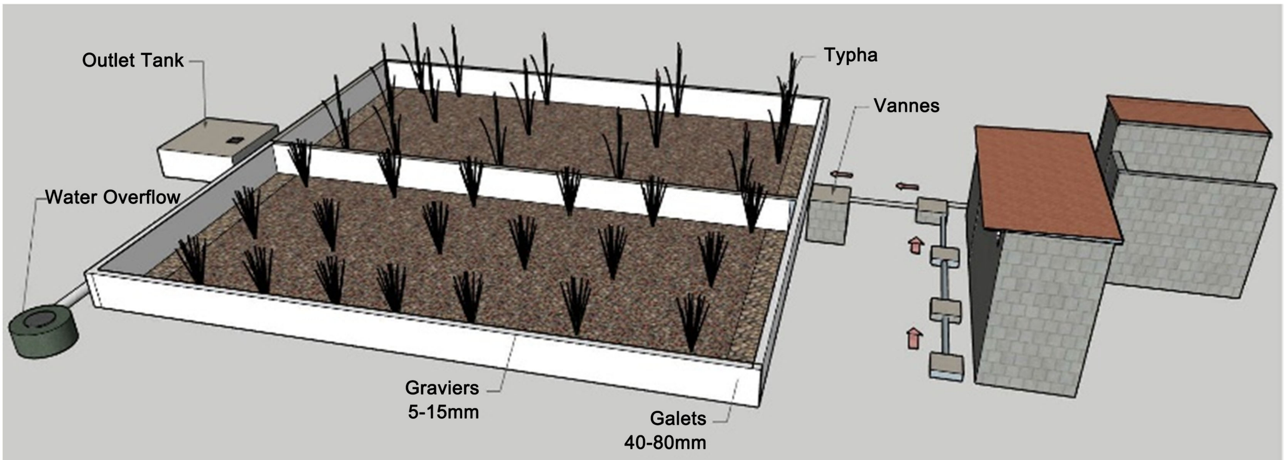

Figure 2. 3D plan of the filter.

Table 1. General filter characteristics.

Filter	Dimension	Height	Material	Input and Output Granulometry over 0.5 m	Middle Granulometry	plant
THF	12 × 8.5 m	70	Flint	40 - 80 mm	5 - 15 mm	*Typha*
VHF	12 × 8.5 m	70	Flint	40 - 80 mm	5 - 15 mm	Vetiver

Table 2. Sampling periods.

No.	**Date**	**Sampling points**	**Location points**
1	mid-February	3	inlet, septic tank outlet, THF outlet, VHF outlet,
2	end of February	3	septic tank inlet, septic tank outlet, THF outlet, VHF outlet
3	mid-March	2	septic tank outlet, THF outlet, VHF outlet
4	mid-April	2	septic tank outlet, THF outlet, VHF outlet
5	mid-May	2	septic tank outlet, THF outlet, VHF outlet
6	mid-June	3	septic tank inlet, septic tank outlet, THF outlet, VHF outlet

VHF: Vetiver horizontal filter; THF: *Typha* horizontal filter.

Table 3. Sampling campaign.

No.	**SS**	**COD**	**BOD$_5$**	**NH_4^+**	**NO_3^-**	**PO_4^{3-}**	**FC**	**HE**	**pH**	**EC**
1	x	x	x	x	x	x	x	x	x	x
2	x		*x*	*x*	*x*	*x*	*x*		*x*	*x*
3	x	x	x	x			x			
4	x	x	x				x			
5	x	x	x	x			x	x		
6	x	x	x	x		x	x		x	x

were subjected to detailed analysis to estimate the concentration of the following parameters. The biological oxygen demand over a period of 5 days (BOD_5) is used to quantify the oxygen required for the biological degradation of organic materials in the sample [10] [11]. The chemical oxygen demand (COD) is used to determine the total amount of oxygen that would be needed to chemically oxidize the organic and inorganic compounds present in the water [10] [11]. Suspended solids (SS) refer to solid particles that are not dissolved in water [12]. Nitrates ($N\text{-}NO_3^-$) indicate a form of nitrogen available in water, usually stemming from the degradation of organic substances or agricultural runoff [13]. Phosphates ($P\text{-}PO_4^{3-}$) often derived from detergents, fertilizers, and natural decomposition processes, are a primary source of nutrients [14]. FC (CFU/100ml) counts serve as an indicator of fecal contamination and inform about the microbiological quality of water. It provides crucial information about water safety and microbiological quality [15].

2.3.2. Sample Analysis

In accordance with the schedule in **Table 2**, a monitoring program was established, as detailed in **Table 3**. This program involved the collection of samples, followed by their preservation and storage according to standard methods of [16]. In situ measurements of pH, electrical conductivity (EC) and temperature (T) were also carried out using portable instruments. Analysis of water quality parameters, including chemical oxygen demand (COD), biological oxygen demand (BOD_5), suspended solids (SS), ammonia ($N\text{-}NH_4^+$), nitrates ($N\text{-}NO_3^-$), and phosphates ($P\text{-}PO_4^{3-}$) and Total Phosphorous (TP) was carried out according to standard methods [16]. These analyzes were carried out at the Wastewater Treatment and Water Pollution Laboratory, affiliated with Cheikh Anta Diop University in Dakar, Senegal [17]. For the evaluation of fecal coliforms (FC), the standard method using violet red bile lactose (VRBL) agar was implemented, and the results were expressed in log10 colony-forming units (FCU) per volume unit. The quantification of helminth eggs (HE) was carried out in accordance with the standard methods [16].

2.3.3. Data Processing

Statistical analyzes were performed on the raw data using Excel 2016 and IBM-SPSS Statistics for Windows statistical software [18]. Excel 2016 was used for descriptive statistics (means, maximum, minimum, and standard deviation). IBM-SPSS was used for analysis of variance (ANOVA). An analysis of variance was conducted to assess the influence of various design and operational variables on pollutant removal. The statistical significance level was set at $p < 0.05$.

3. Results

3.1. Wastewater Quality

Table 4 presents the water quality results at different stages of the treatment process: at the septic tank inlet, at the septic tank outlet, at the *Typha* horizontal

Table 4. Water quality results.

Setting	Septic tank entrance	Septic tank outlet			*Typha* filter output			Vetiver filter outlet		
	Avg	Avg	*Max*	*Min*	Avg	*Max*	*Min*	Avg	*Max*	*Min*
COD (mg/L)	1347	291	*500*	*186*	155	*358*	*48*	74	*149*	*35*
BOD5 (mg/L)	259	78	*101*	*59*	8	*11*	*6*	11	*20*	*7*
SS (mg/L)	76	35	*40*	*33*	1	*3*	*1*	3	*6*	*0*
$N\text{-}NH_4^+$ (mg/L)	248	53	*146*	*15*	8	*2*	*0*	7	*20*	*0*
$N\text{-}NO_3^-$ (mg/L)	30	30			15			27		
$P\text{-}PO_4^{3-}$ (mg /L)	48	47			8.6			4.5		
pH	8.2	8.5			7.9			7.9		
EC	2950	3400			1710			1870		
FC (FCU/100mL)	8.30E+05	3.80E+04	*5.40E+04*	*2.30E+04*	170	*300*	*0*	180	*330*	*0*
FC (Log10)	5.9	4.6	*4.7*	*4.4*	2.2	*2.5*	*0*	2.2	*2.5*	*0*
HE (Eel. larvae)		0			0			0		

filter (THF) outlet and at the Vetiver horizontal filter (VHF) outlet. The parameters studied include COD, BOD_5, SS, ammonium concentrations ($N\text{-}NH_4^+$), nitrate concentrations ($N\text{-}NO_3^-$), phosphate concentrations ($P\text{-}PO_4^{3-}$), pH, electrical conductivity (EC), the number of FC (FCU) and their logarithm (FC Log10), as well as the presence of HE. For each parameter and each processing step, Table 4 indicates the average value (Avg), as well as the maximum (Max) and minimum (Min) values recorded, where applicable.

3.1.1. Quality of Wastewater Treated by the Vetiver Filter

Table 4 shows a notable improvement in water quality after passing through the VHF. Initially, the COD and BOD_5 at the entrance to the septic tank are respectively 1347 mg/L and 259 mg/L. After pit treatment, these values decreased drastically to 291 mg/L and 78 mg/L, respectively. However, after passing through the VHF, an even more marked drop is observed, with average values of 74 mg/L for COD and 11 mg/L for BOD_5. Regarding SS, there is a significant decrease from 76 mg/L to 35 mg/L after the septic tank, and a significant reduction to only 3 mg/L after the VHF ammonium concentrations ($N\text{-}NH_4^+$) and nitrate ($N\text{-}NO_3^-$) also show a decreasing trend after each processing step. In particular, the ammonium concentration decreases from 248 mg/L to 53 mg/L after the septic tank and reaches 7 mg/L after the vetiver filter. The phosphate concentration ($P\text{-}PO_4^{3-}$) shows a marked decrease from 48 mg/L to 47 mg/L after the septic tank, but it is after passing through the VHF that its concentration drops drastically to 4.5 mg/L. Microbiologically, the concentration of FC decreases considerably from 5.9 log10 FCU/100mL to 4.6 log10 at the outlet of the septic tank, and reaches a value as low as 2.2 log10 after treatment with the VHF. It should also be noted that helminth eggs, especially eel larvae, are not detected at the filter outlet.

3.1.2. Quality of Wastewater Treated by the *Typha* Filter

Table 4 further details the changes in water quality after passing through the THF. At the entrance, the average COD concentration is 1347 mg/L. Following passage through the THF, it drops to 155 mg/L, varying between 48 mg/L and 358 mg/L. For BOD_5, it goes from 259 mg/L initially to 8 mg/L after filtration by THF, lying between 6 mg/L and 11 mg/L. SS are reduced from 76 mg/L on average to 1 mg/L, with a range of 1 to 3 mg/L. Ammonium drops from an average of 248 mg/L to 8 mg/L, fluctuating from 0 to 2 mg/L. Nitrates ($N\text{-}NO_3^-$) maintain a stable average of 30 mg/L after the pit and filter. Phosphates ($P\text{-}PO_4^{3-}$) drop from 48 mg/L to 8.6 mg/L after filtration. Concerning the pH, it starts at 8.2, increases slightly to 8.5, then falls to 7.9 after passing through the THF. The conductivity, noted CE, starts at 2950, rises to 3400 then drops to 1710. Finally, the FC are at 8.30E+05 FCU (100 mL) at the entrance, rising to 3.80E+04 FCU (100 mL) and stand at 170 FCU (100 mL) after the filter, with a variation from 0 to 300 FCU. The Log10 of these coliforms decreases from 5.9 to 2.2 passing by 4.6. Helminth eggs are not observed at the outlet of the THF.

3.2. Filter Performance

Table 5 illustrates the removal percentages of various essential pollutants, obtained by the treatment plant as a whole, as well as THF and VHF, thus providing a precise overview of the effectiveness of the planted filters based on *Typha* and of Vetiver, highlighting the specific performance of each system in terms of pollutant elimination.

3.2.1. THF Performance

Table 5 shows that the COD shows a reduction of 46.74%. The BOD_5 was eliminated up to 89.70%. SS experienced an elimination of 96.30%. Ammonium ($N\text{-}NH_4^+$) was reduced by 85.20%. For FC, the reported logarithmic reduction is 2.4 units.

3.2.2. VHF Performance

Table 5 shows that after treatment by the Vetiver filter after treatment in the

Table 5. Percentages of removal of greater pollutants by filters calculated on average values.

Parameter	% Removal total station (Septic + Filter) (Average)	% Removal *Typha* filter	% Removal Vetiver filter
COD (mg/L)	91.50%	46.74%	74.57%
BOD_5 (mg/L)	96.30%	89.70%	85.90%
SS (mg/L)	97.20%	96.30%	91.40%
$N\text{-}NH_4^+$ (mg /L)	97.00%	85.20%	86.70%
FC (ULog reduction)	3.7	2.4	2.3

septic tank, the COD shows a reduction of 74.57%. There BOD_5 shows a reduction of 85.90%, SS are eliminated 91.40% and ammonium ($N\text{-}NH_4^+$) eliminated at 86.70%. Finally, in terms of FC, the filter achieved a reduction of 2.3 log units.

4. Discussion

4.1. Performance of the Filter Planted with Vetiver

The analysis of the quality of the water treated by the VHF based on the information in **Table 4** and **Table 5**, clearly demonstrates that the filter planted with vetiver offers a significant improvement in water quality, particularly with regard to the elimination of pollutants. Comparison of these results with existing data can provide insight into the effectiveness of the Vetiver filter in regional and similar contexts including the work of [9] studied a wetland wastewater treatment system constructed for treatment and the reuse of municipal wastewater for agricultural purposes in Senegal. Although their study does not focus specifically on Vetiver, it provides a solid basis for comparing the efficacies of different treatment methods. Regarding COD, which is an indicator of the amount of oxygen needed to oxidize organic matter, our study revealed a drastic reduction from 1347 mg/L to 74 mg/L thanks to the filter planted with vetiver. This performance appears to be more efficient than those reported by [9] although exact values are necessary for a precise comparison. The reduction of the BOD_5 from 259 mg/L to 11 mg/L is also notable, showing that the amount of oxygen required for biochemical degradation over 5 days is significantly reduced. These results seem to be in line with those in the literature, or even surpass them, highlighting the effectiveness of the filter for wastewater treatment. The significant reduction in SS from 76 mg/L to just 3 mg/L shows the effectiveness of the filter in capturing and retaining solid particles. Compared to existing data for the region, this performance is significant and could even outperform other wetland treatment systems. Reductions in ammonium ($N\text{-}NH_4^+$) and phosphate ($P\text{-}PO_4^{3-}$) concentrations also indicate effective nutrient removal, which is essential to prevent eutrophication when releasing treated water into the environment. The values obtained in this study appear to be comparable, if not better, than those reported by [9] for the same geographical area. Finally, from a microbiological point of view, the drastic reduction in FC from 5.9 log10 to 2.2 log10 demonstrates the effectiveness of the filter in eliminating pathogens. This performance is essential to ensure that the treated water is safe for possible reuse, particularly for agricultural purposes. Based on the target values for effective treatment or acceptable rejection established by [19] we can evaluate the performance of the Vetiver filter. Concerning the BOD_5, the post-treatment results show a concentration of 11 mg/l, well below the standard set at 25 mg/l. This demonstrates the effectiveness of the filter in removing biologically degradable organic matter. For COD, the concentrations after treatment are at 74 mg/l, lower than the target value of 125 mg/l, thus highlighting the effective elimination of most of the organic matter. Post-treatment SS showed a concentration of 3 mg/l, well below the standard of 35 mg/l, attesting to the effective removal of particles. The nitrate concentrations after treatment are 27 mg/l, respecting the limit of 50 mg/l. As for total Kjeldahl nitrogen (TKN), although it does not appear explicitly in our data, the concentration of ammoniacal nitrogen after treatment is 7 mg/l, thus respecting the standard set at less than 30 mg/l. However, for phosphates, the post-treatment concentration of 4.5 mg/l exceeds the standard of 2 mg/l, which may require special attention. Regarding FC, they display a concentration of 180 FCU/100ml after treatment, significantly lower than the standard of 1000 FCU/ 100ml. In short, the Vetiver filter demonstrates excellent performance for most of the parameters analyzed, respecting, or even surpassing established standards. However, the treatment of phosphates could require optimization or addition to fully meet the standards but its elimination rate of 90.43% is still satisfactory according to [19].

The strengths and weaknesses of the water quality results and pollutant removal percentages by the Vetiver filter, which uses flint gravel as the filter bed, are evident. The Vetiver filter shows a great capacity to reduce BOD_5 and COD, demonstrating effective elimination of biologically degradable organic matter. These conclusions correspond well with the standards established by [19], highlighting the optimal performance of the Vetiver filter in this situation. Additionally, post-treatment concentrations of SS are remarkably low, indicating that flint gravel plays a critical role in the physical filtration of suspended particles, as noted by [20]. The efficiency of the filter in nitrogen treatment is also commendable, with significantly reduced ammoniacal nitrogen levels post-treatment, suggesting effective prevention of eutrophication risks. Additionally, low concentrations of FC after treatment are a positive indicator of improved microbiological water quality, making its use for applications such as irrigation much safer. However, despite these strong points, the Vetiver filter has limitations, particularly in the elimination of phosphates. Flint gravel, as a filter bed, may not have ideal surface chemistry for phosphate adsorption. Over time, flint could potentially reach a saturation point, further reducing its effectiveness in removing phosphates [21] [22]. Other factors, such as the nature of the phosphates, adsorption capacity, the presence of other ions, a high initial concentration, and issues related to hydraulic residence time or excessive flow, can also contribute to this limitation [5] [23] [24] [25]. In particular, the specific adsorption capacity of flint or its particle size can influence this efficiency [20] [22]. In summary, although the Vetiver filter with flint gravel has notable benefits for water treatment, particularly for the removal of organic matter, suspended solids, and nitrogen, there remain areas, such as the removal of phosphates, which require additional attention and optimization.

4.2. *Typha* Planted Filter Performance

The analysis of the water quality treated by the *Typha* planted filter, based on the information in **Table 4** and **Table 5**, provides a relevant overview of the effectiveness of the treatment system in question. According to the percentages of removal of the most important pollutants by the filter, presented in **Table 5**, the latter excels in the elimination of BOD_5, SS and FC, with respective elimination rates of 89.70%, 96.30% and a logarithmic reduction of 2.4 for coliforms. This highlights the effectiveness of *Typha* as a treatment agent, in accordance with the work of [9] on its purification capabilities. The results concerning *Typha* in **Table 4** show that, at the filter outlet, the average value of BOD_5 is 8 mg/L. By comparing it to the target value according to [19] which is less than 25 mg/l, we observe that the value obtained is well below, which indicates an effective treatment. Regarding COD, the average concentration at the filter outlet is 155 mg/L, while the target value is less than 125 mg/l. This means that the concentration obtained slightly exceeds the target value, indicating the need for improvements to achieve the acceptable release. For SS, the value obtained after filtration is 1 mg/L, significantly lower than the target value which is 35 mg/l, suggesting a very effective treatment. Regarding nitrates, they remain stable with an average value of 30 mg/L at the filter outlet, which is below the target value of 50 mg/l, thus illustrating satisfactory treatment. As for phosphates, at the filter outlet, their average value is 8.6 mg/L, significantly higher than the target value of 2 mg/l, highlighting a clear need to improve the treatment for these elements. Finally, for FC, the value obtained at the filter outlet is 170 FCU (100 mL), well below the target value of 1000 FCU/100ml, indicating effective elimination. In summary, the majority of parameters in **Table 4** meet or exceed the target values for effective treatment or acceptable rejection. However, some elements, particularly COD and phosphates, require special attention to achieve the desired standards. Examination of the results in **Table 4** reveals several essential elements regarding the quality of the treated water. By juxtaposing these results with existing data for the region [9], we can better understand the context. Water in the region generally shows high concentrations of organic matter such as COD and BOD_5, post-*Typha* filtration values show notable treatment effectiveness. On the other hand, comparable or lower initial concentrations compared to other similar regions indicate that the upstream septic tank already plays an important role in water treatment. The strengths of the *Typha* planted filter lie in the reduction of organic matter. The notable decrease in COD values and BOD_5 demonstrates the effectiveness of the filter in removing organic matter. Microbiological effectiveness is also highlighted, particularly with the significant reduction in FC. This demonstrates the potential of the filter to eradicate microbiological contaminants and thus improve the health quality of the water. Additionally, the reduction in SS indicates that the post-treatment water contains fewer solid particles. On the weak side, nitrates do not seem to vary significantly after passing through the septic tank and the filter. This could suggest that the current system is not sufficiently optimized for their elimination. In some areas, a high concentration of nitrates in water can cause public health risks. In addition, the variability of results is an aspect to consider. Standard deviations, if available, could provide insight into this variability. Large deviations could indicate fluctuating performance of the treatment system. The ineffectiveness of the treatment on nitrates in the *Typha* planted filter with flint gravel as filter bed can be explained in several ways. First, regarding *Typha*, it is known for its ability to absorb nutrients, including nitrates, from wastewater [25]. However, the absorption and transformation of nitrates by *Typha* depends on factors such as the age of the plant, seasonality, and environmental conditions, in particular the oxygenation of the substrate. Under conditions where substrate oxygenation is high, the denitrification process, which transforms nitrates into nitrogen gas, may be limited [26]. Regarding the filter bed, flint gravel is a granular material with a low nitrate adsorption capacity. Additionally, it tends to promote rapid water infiltration, which could limit contact time and, consequently, denitrification [27]. Flint gravel is generally more aerated, which may favor aerobic rather than anaerobic conditions necessary for denitrification [28]. To improve the efficiency of denitrification, some modifications could be considered. One option would be to mix the flint gravel with an organic material to increase its nitrate adsorption capacity and promote anaerobic conditions [27]. Additionally, specific anaerobic zones could be created to promote denitrification. Finally, research could be conducted to determine whether specific variations in *Typha* cultivation, for example, planting density or management of humidity levels, could optimize nitrate uptake [20]. It is important to note that the combination of *Typha* and river sand, although potentially improvable, could already offer good removal rates for other contaminants. Therefore, each system must be evaluated according to its strengths and weaknesses and adapted according to the specific needs of the site.

4.3. Comparative Performance of Vetiver and *Typha* Filters in Ecological Wastewater Treatment: An In-Depth Analysis

4.3.1. Comparative Analysis in Absolute Values

Examining **Table 4** allows us to draw several interesting conclusions on the comparative performance of *Typha* and Vetiver filters in the ecological treatment of wastewater. In terms of effectiveness in reducing COD, the Vetiver filter proved to be more efficient with an average output concentration of 74 mg/L, compared to 155 mg/L for the *Typha* filter. This distinction highlights the effectiveness of Vetiver in the treatment of organic contaminants, an essential quality for any wastewater treatment plant. For BOD_5, both filters show similar performance, with Vetiver showing a slight increase with an average concentration of 11 mg/L compared to *Typha*'s 8 mg/L. When it comes to the elimination of SS, *Typha* appears to be superior with an average of 1 mg/L, while Vetiver records an average of 3 mg/L, suggesting a better capability of *Typha* to filter solid particles. In terms of nutrient and pathogen reduction, both filters were effective, with *Typha* reducing the ammonium concentration to 8 mg/L versus 7 mg/L for Vetiver. However, *Typha* is slightly superior in reducing FC, reducing the concentration to 170 CFU/100 mL compared to 180 CFU/100 mL for Vetiver. It is important to note the minimum and maximum variations recorded for each filter, which could raise concerns about stability in large-scale applications, as shown by the fluctuating values of Vetiver for COD between 149 mg/L and 35 mg/L. In conclusion, although Vetiver and *Typha* each have their advantages and disadvantages, the choice between them will depend on the specific needs of the wastewater treatment. Vetiver seems to excel in the reduction of COD, while *Typha* is more effective for SS and FC. Further studies could help optimize these filtration systems, or even consider hybrid systems that combine the strengths of both.

4.3.2. Comparative Analysis against Target Values

Examination of **Table 4**, associated with the target values established in the work of [19], highlights the performance of *Typha* and Vetiver filters in the treatment of wastewater. For BOD_5, both filters manage to achieve average output values of 8 mg/L and 11 mg/L, respectively, well below the target value of 25 mg/L. Regarding COD, the Vetiver filter is more efficient, achieving an average output concentration of 74 mg/L, which is below the target value of 125 mg/L, while the *Typha* remains above with 155 mg/L. For SS, both systems exceed the target value of 35 mg/L, with average values of 1 mg/L and 3 mg/L for *Typha* and Vetiver, respectively. Regarding nitrates, both filters also manage to stay well below the target value of 50 mg/L, with concentrations of 15 mg/L for *Typha* and 27 mg/L for Vetiver. Regarding phosphates, none of the filters reach the target value of 2 mg/L, Vetiver coming closer with 4.5 mg/L compared to 8.6 mg/L for *Typha*. In terms of FC, both systems perform very well, well exceeding the target value of 1000 FCU/100 mL with concentrations of 170 and 180 FCU/100 mL for *Typha* and Vetiver, respectively. In conclusion, both filters are generally very effective, although Vetiver has a slight advantage for COD. However, optimization is necessary for phosphates. The data collected offers important avenues for the development and optimization of future wastewater treatment systems, particularly in rural areas. **Table 6** summarizes the performance of the different filters compared to the target values established in the work of [19]. According to these same heights, even if none of the filters reach the target value for the elimination of Phosphates, their overall elimination rates of 81.70% and 90.43%, respectively for *Typha* and Vetiver, are quite equally satisfactory.

Table 6. Filter performance comparison.

Setting	Target value	THF performance	VHF performance	Conclusions
BOD5 (mg/L)	<25	8	11	Both filters are effective
COD (mg/L)	<125	155	74	More effective vetiver
SS (mg/L)	<35	1	3	Both filters are very effective
N-NO_3^- (mg/L)	<50	15	27	Both filters are effective
P-PO_4^{3-} (mg/L)	<2	8.6	4.5	No filter reaches the target value
FC (FCU/100mL)	<1000	170	180	Both filters exceed the target value

5. Conclusion

Our research meticulously analyzed the ecological treatment of wastewater at the Ndiebene Gandiol 1 school, equipped with a horizontal flow biological reactor. By studying two filter bed cells, one with Vetiver and the other with *Typha*, we gained a valuable comparative perspective on their respective performance. The methodology deployed, combining field surveys and laboratory analyses, was crucial for assessing the pollutant load before and after treatment. The data collected confirmed the effectiveness of Vetiver in the elimination of COD, an essential parameter for the decomposition of organic contaminants. On the other hand, *Typha* stood out for its ability to filter suspended matter. Although both filters have demonstrated their effectiveness for several parameters, optimizing phosphate treatment remains a priority. These results highlight the relevance and usefulness of such ecological solutions, particularly in resource-limited contexts such as rural areas. Wastewater treatment using plants such as Vetiver and *Typha* is not only an environmentally friendly solution, but also an economically viable one. The notable effectiveness of both plants, despite their variations in performance, indicates the need for comparative approaches for the development of more robust treatment systems. It is essential to recognize that, to maximize the effectiveness of Vetiver and *Typha* based systems, continuous optimization and further studies are necessary. Our work, through its recommendations and conclusions, aspires to guide and inspire future initiatives, aimed at promoting suitable ecological sanitation solutions, especially in rural educational establishments. Ultimately, our research contributes significantly to the advancement of knowledge in the field of ecological wastewater treatment, placing sustainability and adaptability at the heart of the approach.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] United Nations General Assembly (2015) Transforming Our World: The 2030 Agenda for Sustainable Development.

[2] Ouédraogo, S.K.L., Kébré, M.B. and Zougmoré, F. (2020) Water Dynamics under Drip Irrigation to Proper Manage Water Use in Arid Zone. *Journal of Agricultural Chemistry and Environment*, **10**, 57-68. https://doi.org/10.4236/jacen.2021.101004

[3] Prüss-Ustün, A., Wolf, J., Corvalán, C., Neville, T., Bos, R. and Neira, M. (2017) Diseases Due to Unhealthy Environments: An Updated Estimate of the Global Burden of Disease Attributable to Environmental Determinants of Health. *Journal of Public Health*, **39**, 464-475. https://doi.org/10.1093/pubmed/fdw085

[4] Kylstra, S., Watkinson, A.D., Fausak, L. and Lavkulich, L.M. (2021) Irrigation Water Demand Model as a Comparative Tool for Assessing Effects of Land Use Changes for Agricultural Crops in Fraser Valley, Canada. *Agricultural Sciences*, **12**, 888-906. https://doi.org/10.4236/as.2021.128057

[5] Vymazal, J. (2011) Constructed Wetlands for Wastewater Treatment: Five Decades

of Experience. *Environmental Science & Technology*, **45**, 61-69. https://doi.org/10.1021/es101403q

[6] Abaga, N.O.Z., Dousset, S. and Munier-Lamy, C. (2021) Phytoremediation Potential of Vetiver Grass (Vetiveria Zizanioides) in Two Mixed Heavy Metal Contaminated Soils from the Zoundweogo and Boulkiemde Regions of Burkina Faso (West Africa). *Journal of Geoscience and Environment Protection*, **9**, 73-88. https://doi.org/10.4236/gep.2021.911006

[7] Roongtanakiat, N. (2009) Vetiver Phytoremediation for Heavy Metal Decontamination. Technical Bulletin No. 2009.

[8] Golabi, M.H. and Duguies, M. (2012) Application of the Vetiver System for Wastewater Treatment: An Innovative Nutrient Removal Technology for Sewage Water Treatment in Southern Guam. *PRVN Tech. Bull. No.* 2012/1, ORDPB, Bangkok. https://www.rdpb.go.th/UploadNew/Documents/05f0f2e9-9d30-4a82-a3cb-7dfb3f08eed6_2013_1_Wastewater%20Treatment.pdf

[9] Torrens, A., de la Varga, D., Ndiaye, A.K., Folch, M. and Coly, A. (2020) Innovative Multistage Constructed Wetland for Municipal Wastewater Treatment and Reuse for Agriculture in Senegal. *Water*, **12**, Article 3139. https://doi.org/10.3390/w12113139

[10] Prambudy, H.S. (2019) Les tests de la demande chimique en oxygène (DCO) et de la demande biologique en oxygène (DBO) de l'eau de la rivière à Cipager Cirebon. *Journal of Physics: Conference Series*, **1360**, Article ID: 012010.

[11] Asteris, P.G. (2020) Machine Learning Approach for Rapid Estimation of Five-Day Biochemical Oxygen Demand in Wastewater. *Water*, **15**, Article 103. https://doi.org/10.3390/w15010103

[12] Bertrand, E.N. (2008) Etude de l'influence des matières en suspension sur les sols irrigués par les eaux usées traitées. Institut International d'Ingénierie de l'Eau et de l'Environnement.

[13] Banas, D. (2006) Nitrates. *The White Paper Pollutants Habitat*.

[14] Jiao, G.M. (2021) Avancées et défis récents en matière d'élimination et de recyclage du phosphate des eaux usées à l'aide d'adsorbants dérivés de la biomasse. *Chemosphère*, **278**, Article ID: 130377.

[15] Makuwa, S., Tlou, M., Fosso-Kankeu, E. and Green, E. (2020) Evaluation of Fecal Coliform Prevalence and Physicochemical Indicators in the Effluent from a Wastewater Treatment Plant in the North-West Province, South Africa. *International Journal of Environmental Research and Public Health*, **17**, Article 6381. https://doi.org/10.3390/ijerph17176381

[16] Bridgewater, L.L., *et al.* (2017) Standard Methods for the Examination of Water and Wastewater. 23rd Edition, American Public Health Association, Washington DC.

[17] LATEU (2023) Présentation. Laboratoire de Traitement des Eaux Usées. https://lateu.ucad.sn/article/pr%C3%A9sentation

[18] (2023) IBM SPSS Statistics. https://www.ibm.com/products/spss-statistics

[19] Bourrier, R., Satin, M. and Selmi, B. (2010) Guide technique de l'assainissement. Le Moniteur. https://books.google.sn/books?id=LzLDYgEACAAJ

[20] Arias, C.A., Del Bubba, M. and Brix, H. (2001) Phosphorus Removal by Sands for Use as Media in Subsurface Flow Constructed Reed Beds. *Water Research*, **35**, 1159-1168. https://doi.org/10.1016/S0043-1354(00)00368-7

[21] Johansson, L. and Gustafsson, J.P. (2000) Phosphate Removal Using Blast Furnace Slags and Opoka-Mechanisms. *Water Research*, **34**, 259-265.

https://doi.org/10.1016/S0043-1354(99)00135-9

[22] Drizo, A., Forget, C., Chapuis, R.P. and Comeau, Y. (2006) Phosphorus Removal by Electric Arc Furnace Steel Slag and Serpentinite. *Water Research*, **40**, 1547-1554. https://doi.org/10.1016/j.watres.2006.02.001

[23] Kadlec, R.H. and Wallace, S. (2008) Treatment Wetlands. CRC Press, Boca Raton. https://doi.org/10.1201/9781420012514

[24] Vymazal, J. (2007) Removal of Nutrients in Various Types of Constructed Wetlands. *Science of the Total Environment*, **380**, 48-65. https://doi.org/10.1016/j.scitotenv.2006.09.014

[25] Reddy, K.R. and DeLaune, R.D. (2008) Biogeochemistry of Wetlands: Science and Applications. CRC Press, Boca Raton. https://doi.org/10.1201/9780203491454

[26] Brix, H. (1997) Do Macrophytes Play a Role in Constructed Treatment Wetlands? *Water Science & Technology*, **35**, 11-17. https://doi.org/10.2166/wst.1997.0154

[27] Robertson, W.D. and Cherry, J.A. (1995) *In Situ* Denitrification of Septic-System Nitrate Using Reactive Porous Media Barriers: Field Trials. *Groundwater*, **33**, 99-111. https://doi.org/10.1111/j.1745-6584.1995.tb00266.x

[28] Tiedje, J.M. (1988) Ecology of Denitrification and Dissimilatory Nitrate Reduction to Ammonium. John Wiley & Sons, New York, 179-244.