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Research Article

Treatment of Domestic Wastewater by Phytodepuration: The Case of the Bangui University Restaurant in the Central African Republic

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Abstract

The aim of this work is to study the effectiveness of reed purification for wastewater treatment using a natural and ecological phytotreatment technique. Among the purification plant species identified, Phragmites australis was chosen for its high purification capacity. After six months of operation, the results show high purification efficiencies for parameters such as TSS, with an abatement rate of 99.16%, 94.01% for COD, 88.90% for BOD5, 99.24% for PO_4 3^- and 71.20% for SO_4^{2-}. We also observed values of 85.20% for NO_2^- and 85.40% for NO_3^-. With regard to microbiological parameters, we recorded an elimination rate of 80% for total coliforms and 97.75% for fecal streptococci after treatment, demonstrating the effectiveness of reeds in improving water quality. Overall, these results demonstrate the high purification performance of this technique and the powerful cleansing power of reeds.

Keywords

Phragmites Australis, Wastewater, Phytodepuration, COD

1. Introduction

As the human population has grown, aquatic environments have served as receptors for more and more domestic effluent, with increasingly visible consequences. The growing protection of watercourses has therefore led, for just over a century, to the creation of purification systems that are now well known. Domestic wastewater must be treated before being discharged directly into the natural environment, i.e. streams, rivers and lakes. This treatment is carried out in wastewater treatment plants, using bacteria to destroy polluted water before it is discharged back into nature. They then transform this pollution into a by- product called "sludge", which is then spread on agricultural land as fertilizer and organic matter [5, 15] Conventional urban wastewater treatment plants are highly technical, complex and costly, particularly in terms of electricity. In particular, regular sludge evacuation is a major constraint, because if it is not respected, it can lead to plant malfunction and, consequently, the discharge of poorly treated pollution.

Improved knowledge in this field has greatly contributed to the design of new water purification systems inspired by natural processes, known as "artificial marshes". Wastewater treatment plants designed according to the "lagoon" or "wetland" principle are now being used.

"Artificial marshes are therefore an important solution for the rural environment, and have been adopted by many local

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authorities for several decades [5, 6]. The purification potential of aquatic plants was first demonstrated by the biologist Seidel in the early 60 s, through experiments with filters planted with macrophytes. Based on rigorous observation of marsh and swamp plant life, she highlighted the intense biological activity of interface zones, such as water/land, land/air, etc. [33]. Since then, this extensive new technology has been successfully exploited by several authors [7, 8] for the treatment of several types of effluent.

The city of Bangui is experiencing problems with its wastewater collection and treatment systems, due to demographic expansion and the consequences of rural exodus. These factors are increasing water consumption and, consequently, the need to manage wastewater discharge.

Existing sewage canals flow into the river without prior treatment. The urban environment and natural receptors are becoming increasingly fragile and require greater protection against pollution. The quality of fish products consumed by the population, as well as that of bathing water, is being called into question. To avoid rapid and irreversible degradation of the natural environment, it has become necessary to assess needs and build wastewater treatment facilities. Various techniques can be used, with varying degrees of cost. The difficult economic conditions in the Central African Republic make it unlikely that a wastewater treatment system with expensive equipment can be set up quickly. As a result, phyto-purification, which is less costly and simpler to operate, represents a credible alternative for wastewater treatment in Bangui.

International standards: In this study, WHO standards were used to assess wastewater treatment performance (Table 1).

Table 1. *WHO standards.*

Features	Standards used (WHO)
pH	6,5 - 8,5
Temperature	< 30 ℃
EC	< 800 µS/cm
Dissolved Oxygen	50% < X< 120%
TSS	35 mg/L
NO2 -	< 1 mg/l
NO3 -	< 1 mg/l
BOD5	< 30 mg/l
COD	< 90 mg/l
PO_4	2 mg/L
Total coliforms	2000 UFC
Fecal Streptococci	UFC

2. Materials and Methods

In our work, we used a macrophyte renowned for its high purifying power: the common reed (Phragmites australis), one of the invasive plant species [4]. Reed is probably one of the most widespread vascular plants in the world. It is a hydrophilic species that grows naturally in wetlands or floodplains, such as freshwater or brackish marshes [29] and the banks of rivers and lakes. Reeds spread sexually or by vegetative propagation. A reed colony generally establishes itself in a new site through the germination of a seed spread by wind or water [1], or by the rooting of a stem or rhizome fragment [17, 19]. The plants tested at the University of Bangui's ecological pilot treatment plant are Phragmites australis. Water analyses are carried out after the plant has been irrigated at the treatment plant, followed by a series of analyses of the site's wastewater (Figure 1).

2.1. Description of the Ecological Pilot Wastewater Treatment Plant at Bangui University

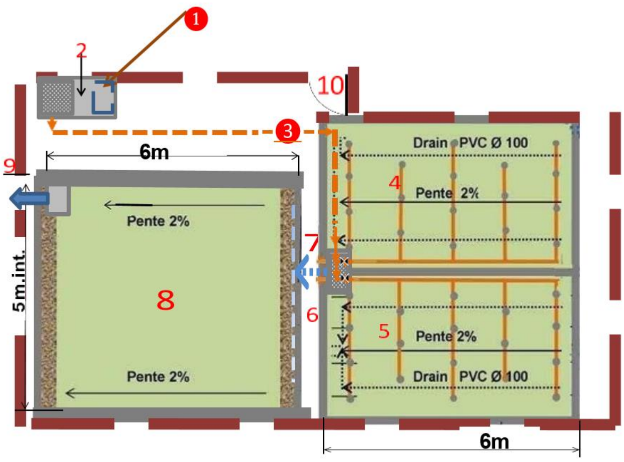

Figure 1. *Schematic diagram of the ecological pilot wastewater treatment plant at the University of Bangui.*

Figure 2. *Phragmites autralis (Source: STEP Université de Bangui).*

Table 2. Descriptive numbering of the ecological pilot wastewater treatment plant at the University of Bangui.

1	Water connection to wastewater treatment plant
2	Waste reception and screening tank with 2 lift pumps
3	Connection pipe for screened water to primary filters
4	Primary Filter N°1
5	Primary Filters N°2
6	Manhole for receiving treated water from primary filters 1 and 2
7	U. E. pipe to finish filter
8	Finishing filter (Secondary filter)
9	Treated wastewater outlet
10	Station entrance gate and wire mesh fence

2.2. Analysis Equipment

The instruments used in our analyses are listed in Table 3 below:

Table 3. Materials used.

Parameters	Units	Methods	Devices
pH	-		pH meter (HANNA model)
Temperature	℃		Multimeter 3320
Conductivity	µS/cm	Potentiometry	(WTW model)
02 dissolved	mg/l	Nephelometry	DR2800 (HACH model)
COD	mg/l		
Nitrites	mg/l		
Nitrates	mg/l	Spectrophotometry	Inductively Coupled Plasma Atomic Emission (ICP-AES). COD digester
Phosphates	mg/l		
Sulfates	mg/l		
BOD5	mg/l	Manometry	BOD meter
Total coliforms	UFC	Membrane filtration	TTC and PCA agar
Fecal Streptococci	UFC	Membrane filtration	Slanetz and Bartley agar

2.3. Methods

Taking a water sample is a very important operation, and one to which the utmost care must be taken. The sample must be homogeneous and representative, as the sampling conditions have a direct influence on the analysis results. Vials are rinsed with distilled water, labelled and sealed. All samples are transported to the laboratory the same day and stored at 4℃ for in vitro analysis (source of wastewater: Bangui university restaurant). In our study, samples were taken in 1 L polyethylene drums at the inlet and outlet of the plant, in order to gain a better understanding of the abatement rate. Samples were taken in October (rainy period, when the reeds were in full growth), in December (dry climate) and in May (off-season)..

3. Results and Discussion

Analyses of physico-chemical and bacteriological parameters of wastewater from the Bangui University restaurant focused on the following elements:

3.1. pH

Variations in water pH during our experiment are illustrated in Figure 3, showing a slight increase in pH after purification. This increase in pH at the outlet of the gravel pack could be explained by:

1) The accumulation of H+ ions as a result of the activity of nitrifying bacteria.
2) The accumulation of CO_2 due to plant metabolism or the

degradation of organic matter by heterotrophic bacteria.

3) The production of H+ ions by the plant to compensate for the removal of certain cations (mineral nutrition) [20, 22].

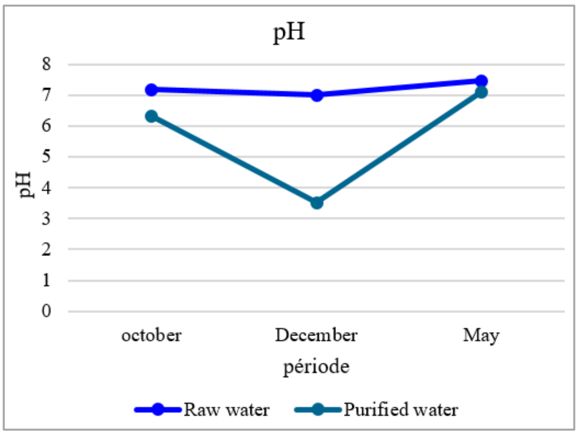

Figure 3. Changes in pH before and after wastewater treatment Phragmites australis plants.

3.2. Temperature

The temperature of wastewater is one of the parameters influencing its composition. It also favors the formation of a significant bacterial biomass [18, 26], Temperature values varied during our experiment. Outlet values are higher than those of the raw water (Figure 4). We know that the water temperature in the reed-covered pond is practically constant or changes little with variations in atmospheric temperature. This is due to the impact of the plant cover on the surface of the treatment filters, which acts as a screen limiting the penetration of solar radiation, a source of heat, into the depth of the basin.

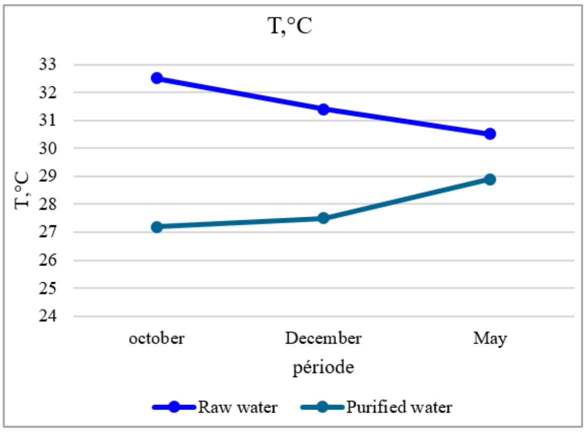

Figure 4. Temperature variations before and after wastewater soaking in Phragmites plants australis.

3.3. Dissolved Oxygen

Dissolved oxygen is essential for all aquatic life, as well as for the decomposition of organic matter produced by aquatic plants. Our results show a depletion of wastewater prior to treatment (Figure 5). At the inlet, the dissolved oxygen content of the raw water varies from 5.34 mg/l to 6.85 mg/l, depending on the period, and is lower than that of the water at the outlet. The increase in dissolved oxygen content after the water has passed through the planted purification systems could be explained by the high metabolic activity, probably due to the root biomass of Phragmites australis, since this oxygen is the result of metabolism and transfer due to air diffusion [2] In other words, the plant provides the oxygen required for aerobic degradation of organic matter.

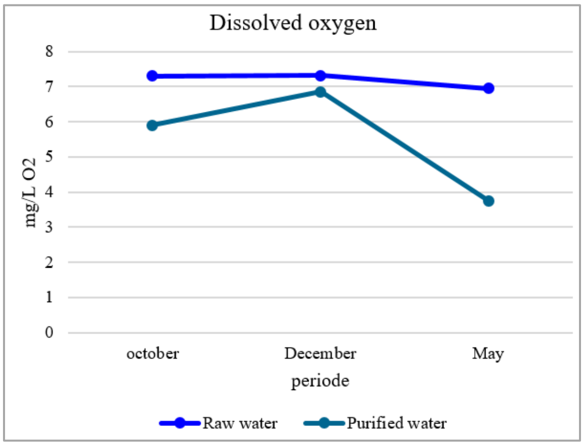

Figure 5. Variation dissolved oxygen before and after purification.

3.4. Conductivity

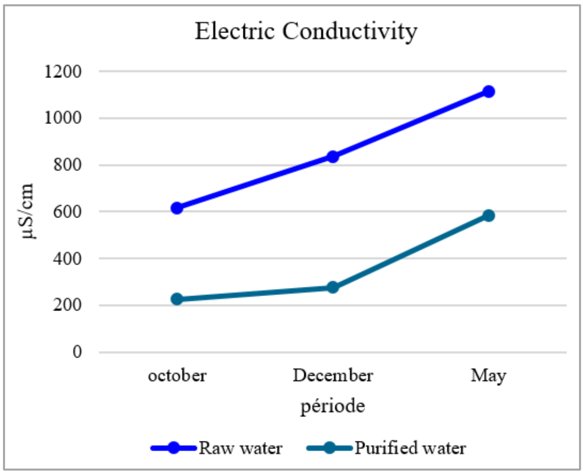

Figure 6. Variation of EC.

There is a clear reduction in the electrical conductivity of the water after passing through the devices. These results indicate that the conductivity of the raw water is higher than that of the output water (Figure 6). It varies from 617 µS/cm to 1,116 µS/cm, with an average value of 856.3 µS/cm at the inlet, compared with an average value of 362.6 µS/cm at the outlet (figure 5). This drop in values can be explained by the intensive absorption capacity of Phragmites australis with regard to mineral salts [17, 19, 35].

3.5. Suspended Solids (SS)

TSS is a significant factor in water treatment, as it is responsible for silting and reduced light penetration into the water, leading to reduced photosynthetic activity and a drop in phytoplankton productivity. TSS concentration values obtained for raw sewage are high, with a maximum concentration of 231 mg/l recorded in May (Figure 7). This shows a very significant reduction in suspended solids content after treatment. This underlines the purifying effect of macrophyte planted filters, with a purification efficiency of 99.16%.

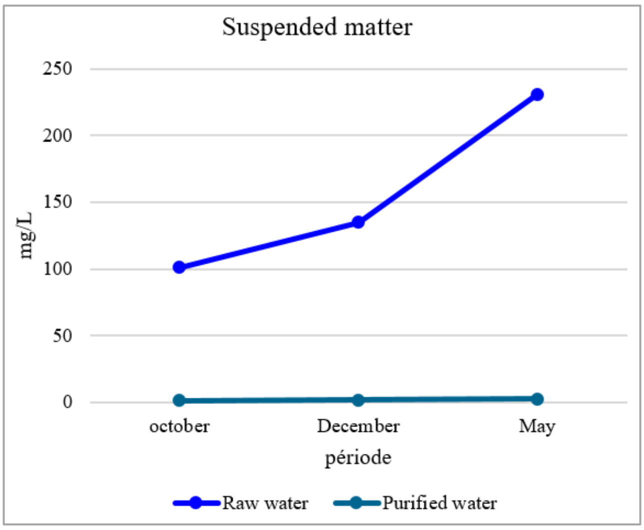

Figure 7. Variation in suspended solids.

3.6. Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is an estimate of the amount of oxygen required to oxidize organic and mineral matter in water. According to the results obtained, we observed a decrease in COD at the plant outlet. The maximum COD value was recorded in May at the plant inlet (629 mg/l), for an average of 506.6 mg/l. The average value at the outlet is 30.3 mg/l (Figure 8). This gives us a treatment efficiency of 94.01%. This shows that our treatment plant is efficient in terms of oxidizable matter degradation.

These results clearly indicate that the presence of the purification plant tested clearly improves organic load removal (BOD5 and COD) compared to the non-planted system. This may be linked to better oxygenation of the substrate in planted filters, enabling aerobic bacteria to proliferate and ensure better mineralization and oxidation of organic matter. According to Tiglyene [7, 37] Phragmites australis has the ability to transfer oxygen from the rhizome to the roots through an internal lacunar system, thus promoting the creation of an aerobic zone around the roots. This aerobic zone enables the proliferation of micro-organisms, which are the main decomposers of organic matter in the root zone.

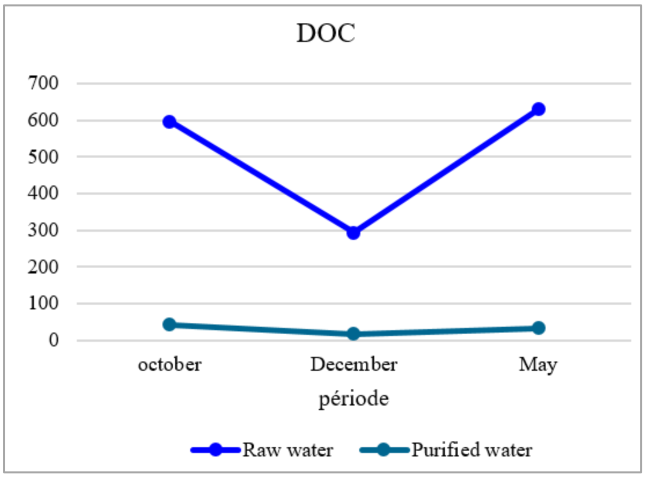

Figure 8. Variation in COD.

3.7. Biochemical Oxygen Demand After 5-day Incubation (BOD5)

The evolution of biochemical oxygen demand is shown in (Figure 9). Throughout the station's monitoring period, BOD5 values at the outlet are lower than those at the inlet, at 24 mg/l, 11.5 mg/l and 20 mg/l respectively. In the presence of Phragmites australis plants, BOD5 tends to decrease, with an abatement of around 88.9%.

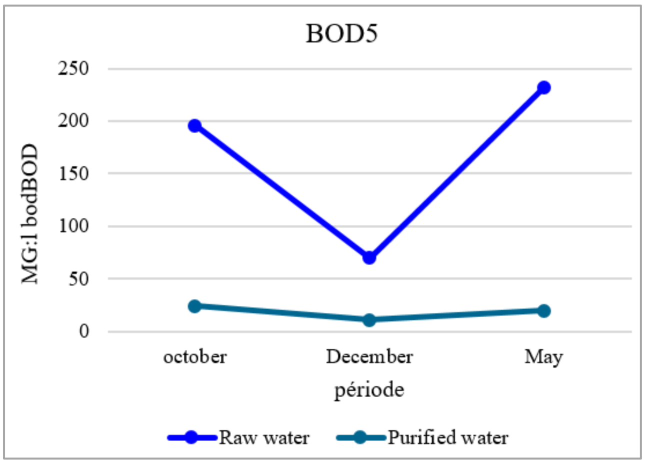

Figure 9. Variation in BOD5 COD/BOD5 ratio.

The COD/BOD5 ratio is an important indicator of an effluent's biodegradability and the origin of organic pollution. It can be used to determine the origin and nature of the pollution. As a general rule, the higher the ratio, the more difficult it is to biodegrade the pollution. For domestic wastewater, this ratio is generally between 2 and 2.5. A ratio greater than 3 indicates pollution of industrial origin or the presence of toxic substances inhibiting biological activity. In our study, the average value of the COD/BOD5 ratio was 2.075 (Figure 10). This is consistent and means that the raw effluent from Bangui University's restaurant is moderately biodegradable, as the ratio is between 1.5 and 2.5.5 < COD/BOD5 < 2.5, [28].

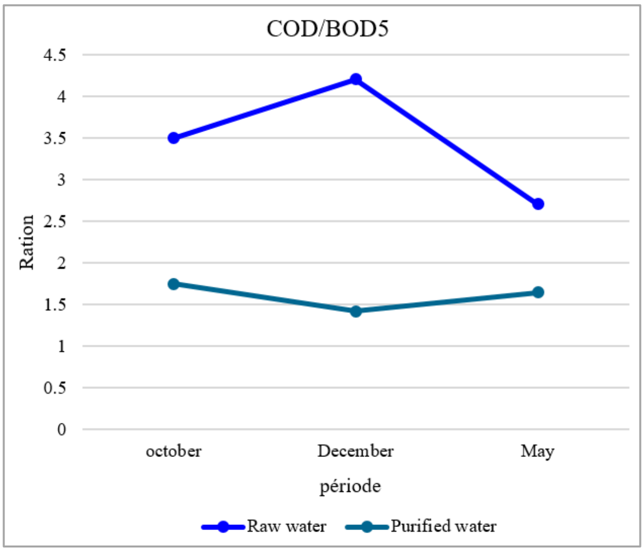

Figure 10. *Ratio COD/BOD5.*

3.8. Nitrates and Nitrites

The Figure 11 below shows the evolution of the nitrite content in the wastewater at the inlet and outlet of the treatment plant. According to our results, nitrite ions have decreased considerably at the outlet of the tanks. This represents a treatment efficiency of 85.20%.

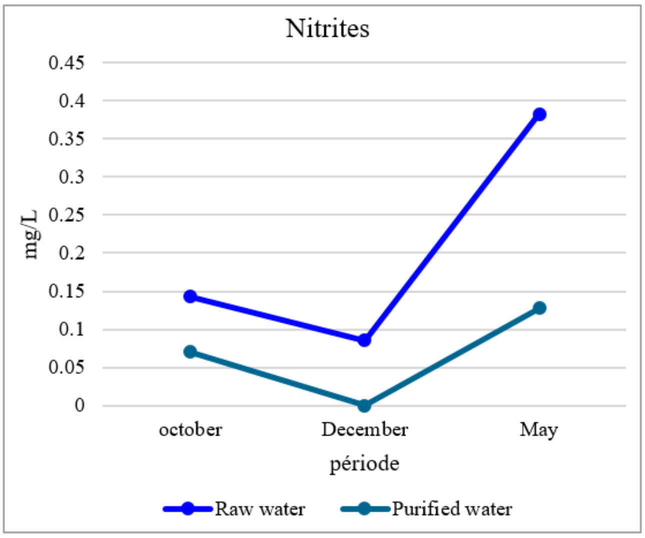

Figure 11. *Variation in nitrite content Nitrates.*

Nitrate levels in the water before and after passing through the two reed basins are shown in Figure 12. These levels reveal a low level of nitrogen pollution. The highest nitrate value was recorded in May 2023 at the inlet, with a maximum value of 1.74 mg/l and an average value of around 1 mg/l. At the outlet, on the other hand, the nitrate ion content was reduced, with an average value of 0.146 mg/l and a maximum value of 0.31 mg/l in October 2022. This represents a treatment efficiency of 85.4%.

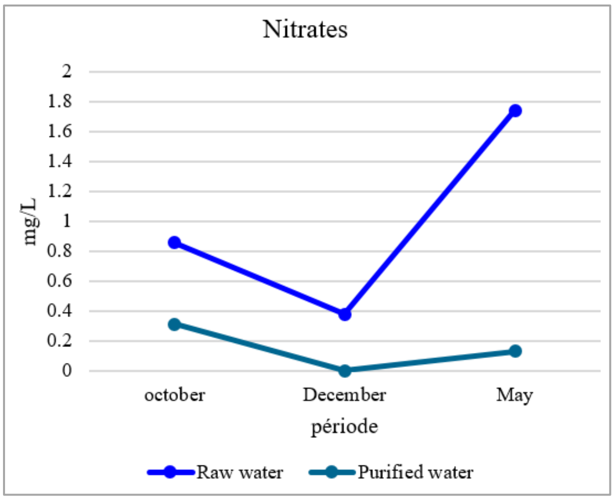

Figure 12. *Variation in nitrate content.*

3.9. Orthophosphates

Phosphate is one of the elements required for plant growth. Total dissolved phosphorus includes organic and inorganic phosphorus, the latter consisting of orthophosphates and polyphosphates. In our analyses, the highest phosphate value was recorded in October 2022, with a maximum value of 76.3 mg/l and an average value of 62.63 mg/l at the inlet. This value is significantly higher than that obtained at the outlet, with a maximum value of 1.25 mg/l and an average value of 0.47 mg/l. This gives a treatment efficiency of 99.24% (Figure 13).

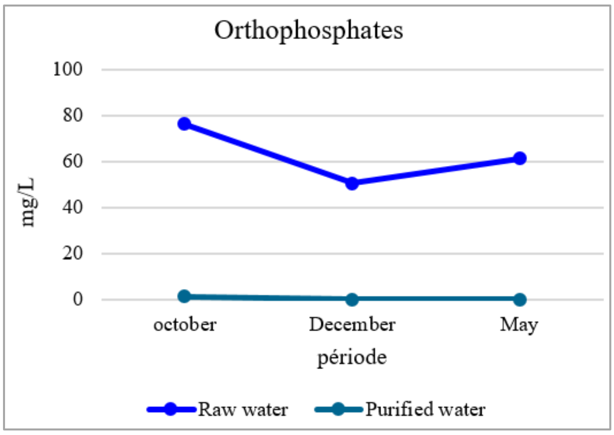

Figure 13. *Variation in orthophosphate content.*

The removal efficiency obtained in the presence of Phragmites australis is very high, reaching 100% at the outlet of reed filters. According to Brix [8], some plants consume a significant amount of phosphorus during their growth. They can store it in roots, rhizomes, stems and leaves. For his part, [24] has pointed out that phosphorus is an essential constituent for plant development, which is assimilated in the form of orthophosphate at root level. Orthophosphate elimination can involve two different phenomena: uptake by the substrate, including litter, or consumption by plants.

3.10. Sulfates

Sulfates are among the anions that are easily fixed by the soil; their presence is linked to the decomposition of organic matter. Sulfate ion concentration was quite variable during our study, with an average value of 32.3 mg/l at the inlet. The highest value at the inlet was recorded in May 2023, with a maximum value of 42 mg/l, compared with 12 mg/l at the outlet (Figure 14). The average outlet value is 9.3 mg/l. In particular, the concentration of sulfate ions at the outlet has fallen, indicating that they have been consumed by the phytodepuration plants. This represents a treatment efficiency of 71.2%.

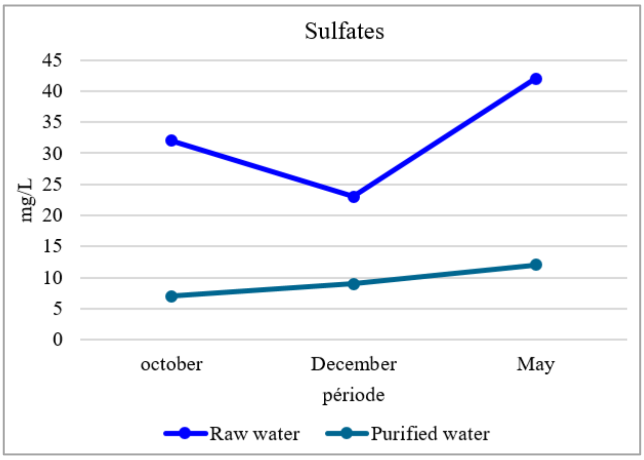

Figure 14. *Variation in sulfate content.*

4. Results of Analyses of Biological and Microbiological Parameters

Figures 15 and 16 below show the evolution of total coliform and fecal streptococcus counts at the inlet and outlet of the wastewater treatment plant at the Bangui University Restaurant. Considerable abatement of the order of 80% for total coliforms and 97.75% for fecal streptococci can be seen.

For the month of October:

At the plant inlet, we observed 15,000 CFU, compared with 100 CFU for total coliforms, giving a yield of 99.3%.

For December:

At the plant inlet, we observed 4,000 CFU for total coliforms versus 1,100 CFU at the outlet; i.e. a 72.5% yield.

For May:

At the station inlet, we observed 1000 CFU for total coliforms, compared with a value of 200 CFU at the outlet, i.e. a yield of 80%.

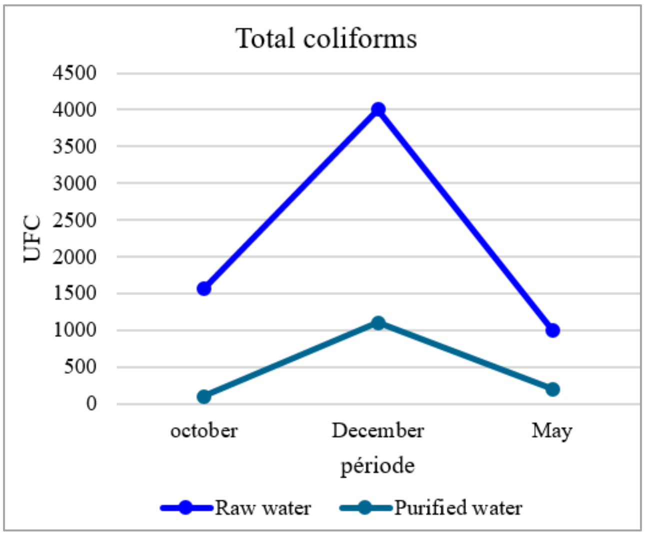

Figure 15. *Total coliform.*

For the month of October:

On entry, we observed 100 CFU for streptococci, compared with 0 CFU on exit. The elimination of these germs is therefore considerable. This represents a yield of 100%.

For December:

200 CFU for streptococci were observed at the station inlet, compared with 0 CFU at the outlet, giving a yield of 100%.

For the month of May

At the station inlet, we obtained 1300 CFU for fecal streptococci versus a value of 300 CFU; i.e. a yield of 76.92%.

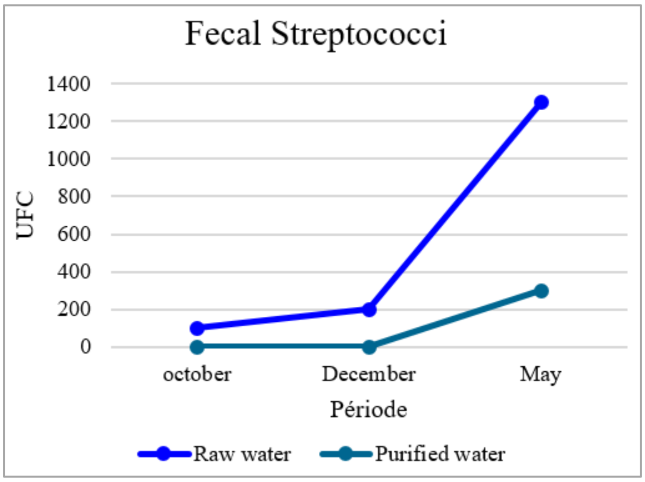

Figure 16. *Fecal streptococci.*

5. Conclusion

Today, wastewater treatment has become a priority, not only to protect human health and the environment, but also to produce water that can be reused for other social activities. Numerous purification processes have been developed, including phytodepuration. It stands out for its simplicity, reliability and low investment and operating costs. The aim of this work is to demonstrate the phytodepuration performance of Phragmites australis reeds in the ecological pilot wastewater treatment plant at the University of Bangui, in the decontamination and purification of domestic wastewater from the University's restaurant. By monitoring the physico-chemical and microbiological indicators of this water, we were able to obtain a range of information on its inlet and outlet quality. The various parameters measured in the raw water (pH, temperature, EC, COD, BOD5, TSS, total coliforms, faecal streptococci, etc.) clearly indicate a high level of pollution. Our results show that this system (plants, microorganisms, substrate) has a strong purifying power, with a reduction in most of the physico-chemical and microbiological parameters studied. Suspended solids were eliminated with an efficiency of 99.16%, and ortho-phosphates with a purification efficiency of 99.25%. Nitrate removal efficiency was 85.24%, while nitrite removal efficiency was 73%. For BOD5 and COD, we achieved treatment efficiencies of 88, 90% and 96% respectively. As far as microbiological parameters are concerned, the results showed that the reeds can ensure significant, if not total, elimination of the bacterial load. The values obtained at the outlet meet WHO standards for practically all the parameters studied. This demonstrates the efficiency of the plant.

Abbreviations

BOD5	Biochemical Oxygen Demand After 5-day Incubation
COD	Chemical Oxygen Demand
FCU	Fotma Colny Unite
TSS	Total Suspended Solids
WHO	World Health Organization

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Author Contributions

Olga Biteman: Formal Analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing

Nicole Poumaye: Data curation, Formal Analysis, Methodology, Validation, Visualization, Writing – review & editing

Oscar Allahdin: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing

Eric Foto: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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