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Research Article

Eichhornia crassipes Efficacy in Secondary Wastewater Treatment in the Western Highlands of Cameroon

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Wastewater treatment using lagoons technology is recognised to have potential to protect the environment and preserve water resources. The implementation requires mastery of ecological conditions of operation and management of the plants used. We aimed to contribute to the implementation of macrophyte-based lagoons for wastewater treatment in the Western Highlands of Cameroon. We used two sets of four lagoons in series; one was vegetated with *E. crassipes*, while the other served as the control. Each set constituted an anaerobic, two facultative, and maturation lagoons. Each lagoon system was supplied with primary-treated domestic wastewater from the wastewater treatment plant of the University of Dschang, Cameroon, at a hydraulic loading rate of 1.13 m^3/day. Monthly wastewater samples were collected from the inflow and outflow of each lagoon for physicochemical and bacteriological analyses, and plant growth was assessed biweekly for six months spanning the dry and rainy seasons. Macrophyte lagoons showed positive plant growth during both seasons. The highest plant height (10.67 and 25.21 cm), longer roots (11.3 and 37.41 cm), and the highest number of new buds (14 and 20 buds) were obtained during the dry and rainy seasons, respectively. Plants were significantly ($P < 0.0001$) taller in facultative lagoons in the rainy season than in the dry season. Vegetated lagoons significantly ($P < 0.05$) contributed to reducing TSS (−08.36% and 82.25%), true color (44.46% and 82.31%), orthophosphates (63.1% and 86.59%), and BOD_5 (−56.79% and 56.06%) during the dry and rainy seasons, respectively. 100% elimination of fecal streptococci (FS) and 74.89% and 43.80% of fecal coliforms (FC) were observed in the dry and rainy seasons, respectively. Significant ($P = 0.0019$) FS elimination was more in the dry season than in the rainy season. However, the average residual content of FC (190,000 UFC/100 ml) was still higher than WHO limits (≤1000 UFC/100 ml) for nonrestrictive reuse in agriculture. *E. crassipes* can be efficiently used in lagoon systems for domestic wastewater treatment in the Western Highlands of Cameroon.

1. Introduction

One of the major challenges in developing countries today is to ensure safe and sustainable access to water since it is the most exposed resource to contamination [1]. In Africa, water resources constitute an important part of the hydraulic heritage. In Cameroon, the quality of water has suffered great deterioration due to the intensification of agricultural activities, industrialization, and uncontrolled urbanization. As a consequence, an average of 93% of domestic wastewater and 75% of industrial wastes and wastewater are discharged into surface waters without any treatment [2]. These lead to eutrophication [3, 4]. The treatment of domestic wastewater aims to reduce the concentrations of pollutants to reach the standards for effluents discharged into the natural environment or for reuse [5]. However, despite this close relationship between the discharged water quality and that consumed by the population in developing countries, little importance is attached to the quality of water discharged into the environment [6]. In most cases, the lack of interest is justified by the high cost of conventional wastewater treatment with activated sludge, trickling filters, stabilization ponds, etc. In addition, these cost-effective conventional treatment technologies which have proven their efficiencies are less efficient in the removal of pathogens and heavy metals [7, 8]. Less expensive and ecofriendly technologies are recommended for wastewater treatment with most of them associating macrophytes as key components. The dense root system of these macrophytes coupled with substrates in constructed vegetated bed systems provides better efficiencies in the roots and substrate filtration of pathogens, as well as absorption and accumulation of heavy metals into their tissues and roots exudate, and medium pH can cause their precipitation [8–11]. The performances of several macrophytes in vegetated beds and lagoon systems as secondary treatment have been investigated and documented [4, 12–17].

Treated effluents have been proven for reuse in irrigation and aquaculture with the mobilization of additional water resources and the sustainable management of environmental pollution [18–21]. Macrophytic lagoon systems have been recognised as one of the most effective ecotechnologies in eliminating pathogens associated with the long retention time of wastewater in these systems [22, 23]. However, a major challenge for this treatment system is the elimination of nitrates and phosphates, which still causes a real problem given that the treated waters do not meet WHO standards for wastewater release into the environment [24, 25]. In the tropical and subtropical regions, free-floating macrophytes are dominant in wetlands. They are advantageous in wastewater treatment with high growth and productivity, good nutritional values, and ease of harvest and storage [26]. Among these plants is *E. crassipes* which was the first plant to be tested in wastewater treatment by NASA [27]. It is an invasive plant that can be used for wastewater treatment when the system is well controlled. It is a tropical floating plant whose nutrient absorption capacity has been documented. *E. crassipes* is found in the coastal region of Cameroon, especially in the Wouri estuary. It has a good root system that serves as a support for the adhesion and development of microorganisms. The microbial biodegradation of organic matter makes the necessary nutrients available for the plants which in turn provide the oxygen for the respiration of these heterotrophic microorganisms [28]. In Ivory Coast, the *E. crassipes* biomass produced in the tertiary treatment of wastewater has been used for biogas production in digesters [14]. In China, this macrophyte has been used for the elimination of unpleasant odors and the greenish color of water bodies [29]. Macrophytic lagoons combine the depollution performances of biodegrading bacteria and macrophytes, which play a role in the assimilation of nitrates and phosphates and as filtering agents [30].

Some studies on macrophytes diversity in the Western Highlands of Cameroon have noted the absence of floating plants [31]. But with the increasing urbanization, wastewater treatment systems with floating plants may be needed for small communities. The west region of Cameroon has been characterized by new agglomerations in the last decade which are rapidly growing into secondary cities without any sanitation system. The macrophytic lagoons system may be necessary as secondary treatment in fecal sludge or sewage treatment. The Western Highlands of Cameroon are also characterized by a four-month dry season (mid-November to mid-March) and an eight-month rainy season (mid-March to mid-November) [32]. The characteristics of these two seasons are very clear-cut, and the performances of such a lagoon system with floating plants may differ from one season to another. The aim of this paper is to contribute to the implementation of macrophyte-based lagoons as a sanitation system in the Western Highlands of Cameroon.

2. Materials and Methods

2.1. Study Area. The study was conducted in the experimentally constructed wetland facility of the University of Dschang, West Region of Cameroon. The Western Highlands of Cameroon lie between latitudes 4°54′ and 6°36′ north and longitudes 9°18′ and 11°24′ east with altitude variations from 1200 to 2700 m. Dschang is found in the Western Highlands of Cameroon and is located between latitudes 5°25′ and 5°30′ north and between longitudes 10°00′ and 10°5′ east (Figure 1). It is at an average altitude of 1400 m above the sea. The climate is equatorial with a four-month dry (mid-November to mid-March) and an eight-month rainy season (mid-March to mid-November) with a thermal amplitude of two (2).

2.2. Experimental Site Description. The work was conducted following the authorisation decision n°2021/07361/UDS/R/ED/D/DAAC/DSST/D/DA/CS/CSA/SP/SR/tc of the Vice-Chancellor of the University of Dschang. The experimentally constructed wetland station is located on the campus of the University of Dschang and receives domestic wastewater from the students' residential hostels. It was constructed with cement blocks filled with concrete and made waterproof with a mixture of concrete and Sikalite™. The wastewater inflow rate to the station is about 3 m^3/day [33]. The station has three compartments consisting of the pretreatment, primary, and secondary compartments (Figure 2). The third compartment is the secondary treatment consisting of a main distribution gutter for collecting the mineralized liquid fraction from the second decantation digester and their redistribution into two treatment systems: the vegetated beds and the lagoons system. The lagoons system consists of two sets of lagoons, each made up of one anaerobic, two facultative, and one maturation lagoons. These lagoons were fed with mineralized wastewater from the primary treatment which had been previously diluted to 80% with natural water from a nearby lake to allow the plants to grow. This dilution was carried out throughout the experiment using six interconnected plastic drums of 200 L each for a total volume of 1200 L before their inflow into the eight experimental lagoons, four of them with *E. crassipes* and four others serving as controls (Figure 3). The drums were refilled with diluted wastewater at three-day intervals to ensure continuity of flow. The inlet of each treatment system was equipped with a tap to regulate the inflow rate into the system with an average inflow rate of 1.13 m^3/day. The lagoons were separated from each other by compacted earth

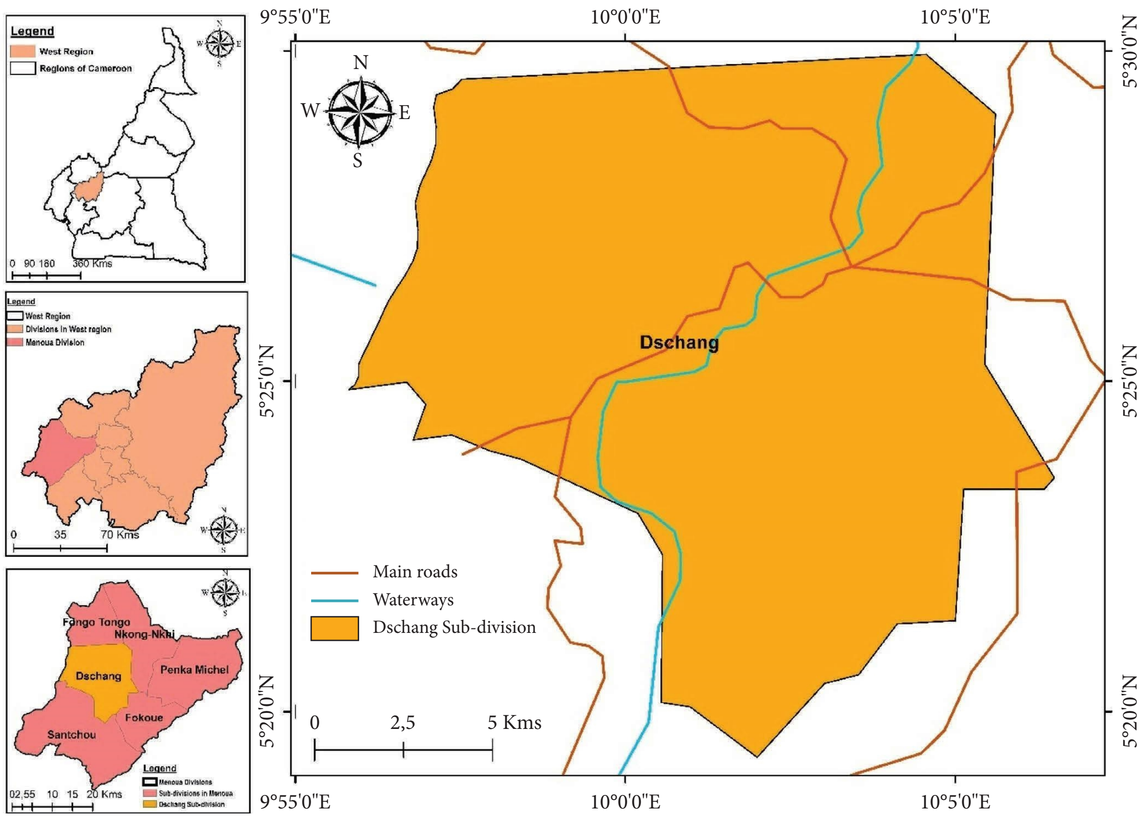

Figure 1: Location of Dschang in the West Region of Cameroon (Arc MAP.10.3.1 software).

dykes and communicated with each other by PVC pipes (polyvinyl chloride). The location of communication structures was designed to avoid areas of stagnant/dead water and preferential flows. The wastewater circulates by simple gravity from one lagoon to another and overflows into the other. Seedlings of *E. crassipes* were collected from a wetland in Douala, Cameroon. Once in Dschang, they were introduced into a basin containing diluted domestic wastewater to acclimatize them to Dschang for one month. After acclimatization, the lagoons of the experimental set were vegetated with ten seedlings of *E. crassipes.* Purification of wastewater in the system was ensured thanks to the long residence time (approximately four days) in the set of four lagoons arranged in series. The role of the anaerobic lagoon is to intensify the pretreatment and primary treatment phase upstream of the station; the two facultative lagoons help maximize the reduction of nitrogen and phosphorus in domestic wastewater which is loaded with mineralized organic matter for the maturation lagoon to receive a very lightly loaded effluent from facultative lagoon 2 just for polishing.

2.3. Dimensions and Characteristics of the Lagoons System. The experimental wastewater treatment plant of the University of Dschang treats wastewater from the student hostels located in Campus B. Wastewater from the hostels is channeled to the station through PVC pipes crossing the different treatment phases and ending with the lagoons system. This lagoon system is set up on a surface area of about 27.76 m^2 (Table 1).

2.4. Evaluation of the Purification Performances of Lagoons in Domestic Wastewater Treatment. The system evaluation was carried out through physicochemical and microbiological analyses of water samples and monitoring plant growth and productivity in the system during the dry and rainy seasons.

2.4.1. Collection and Analysis of Water Samples. Wastewater samples were collected in sterile 1000 ml bottles at the inflow and outflow of each lagoon for a total of nine samples at a time. The analyses were conducted monthly from January to June 2021 that is for six months for a total of 54 samples analyzed. The physicochemical analyses were carried out following Hach [34] for the pH using CyberScan 1500 pH meter from Eutech Instruments, electrical conductivity (EC) and total dissolved solids (TDS) using conductivity/TDS 44600™ meter from Hach Company, total suspended solids (TSS); color; orthophosphates (PO_4^{3-}); nitrates (NO_3^-); and chemical oxygen demand (COD digestion with DRB/200™ from Hach Company) were measured using a spectrophotometer DR/2500™ from Hach Company, biochemical oxygen demand (BOD5) was measured using the BOD Trak™ from Hach Company, while fecal coliforms (FC) and fecal streptococci (FS) concentrations were determined using the membrane filtration technique through the WHEATON TM funnel. The color was measured using the platinum-cobalt method, nitrates by the cadmium/reduction method with NitraVer5™ powder pillows, and phosphates by the ascorbic acid method with PhosVer3™

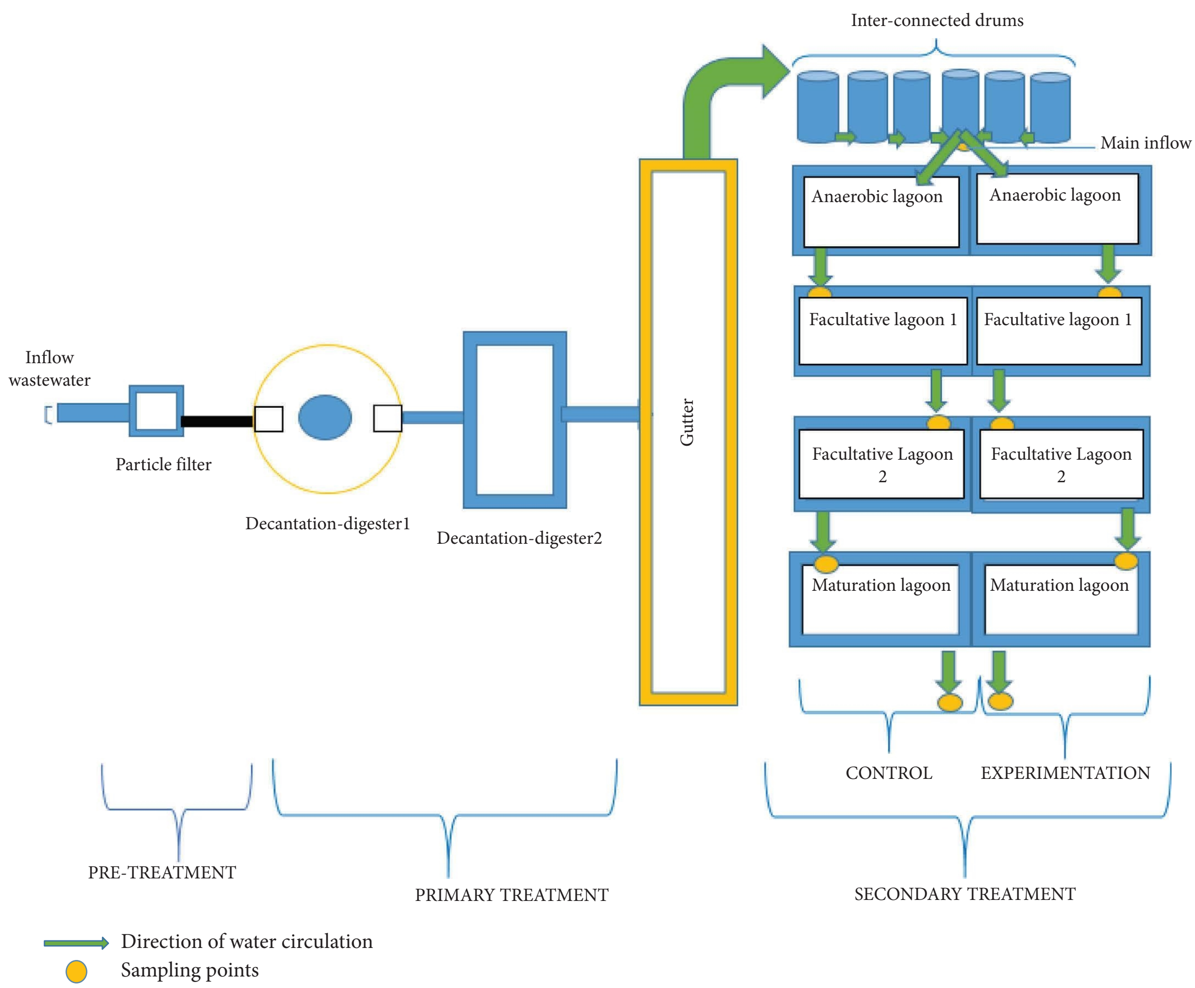

Figure 2: Layout of the experimental wastewater treatment station.

Figure 3: Presentation of the lagoons system comprising the experimental and the nonvegetated control: (a) start of experiment and (b) end of experiment.

powder pillows, and both reagents were from Hach Company. The BOD_5 values were measured by the respirometric method using the BOD Trak™ from Hach Company in an incubator at 20°C for five days. Fecal coliforms (FC) and fecal streptococci (FS) were determined by the membrane filtration following CEAE [35], using AC cellulose membrane filters with 0.45 μm pore size. After incubation, the colony-forming units (CFU) were counted using a colony counter 50971™ from Bioblock Scientific.

Table 1: Characteristics of the different lagoons.

Device	Length (m)	Width (m)	Depth (m)	Hydraulic retention time (days)
Anaerobic lagoon	1.65	1.3	0.99	1.80
Facultative lagoon 1	1.65	1.3	0.55	1.2
Facultative lagoon 2	1.65	1.3	0.55	0.88
Maturation lagoon	1.65	1.3	0.35	0.66

AL: anaerobic lagoon; FL: facultative lagoon; ML: maturation lagoon.

2.4.2. Measurement of Plant Growth Parameters. Forty seedlings of *E. crassipes* with three to five leaves and about 10 cm high were introduced into the four macrophytes lagoons for this purpose at a rate of 10 seedlings per lagoon. Plant growth parameters such as plant height, root length, number of new buds, and leaf number were measured at two-week intervals for six months.

2.4.3. Statistical Analysis of Data. Statistical analyses of physicochemical and microbiological parameters, as well as plant growth characteristics, were performed using the software XLSTAT 2014 version. One-way ANOVA was used to compare mean values of parameters in different experimental units, and Duncan's multiple range test was used for post hoc comparison and separation of means where necessary. All differences were tested at the probability threshold $P < 0.05$.

The purification performances were assessed based on the percentage reduction of parameters recorded at the outflow of each component: first by comparing the outflow to the inflow of the same lagoon and second by comparing the outflow of each lagoon to the main inflow into the system to get the overall reduction of the parameter through the system up to that level. The reduction efficiencies were calculated for each stage of the process, using the following formula [33]:

$$R = \frac{Ci - Co}{Ci} \times 100, \quad (1)$$

where R is the purification efficiency, Co is the concentration of the parameter at the lagoon outflow, and Ci is the concentration of the parameter at the lagoon inflow.

3. Results and Discussion

3.1. Growth Attributes of E. crassipes in the Different Lagoons. The variation of growth parameters during the study period is presented in Figure 4. Plant height in the dry season increased from the anaerobic to the maturation lagoons, as well as in the rainy season (Figure 4(a)). In the dry season, the shortest plant height was obtained in the maturation lagoon and the highest height in the facultative lagoon. There was no significant difference between facultative lagoons 1 and 2. The plant height in the facultative lagoon was significantly ($P < 0.0001$) higher than in the anaerobic and maturation lagoons, whereas plant height in facultative lagoon 2 was statistically similar to that in the anaerobic lagoon. This was significantly ($P < 0.0001$) higher than in the maturation lagoon. In the rainy season, the shortest plant height was obtained in the anaerobic lagoon and the highest in the maturation lagoon. In the rainy season, the plants were significantly ($P < 0.0001$) taller in the maturation lagoon than in the anaerobic and the two facultative lagoons. The height of plants in the rainy season was significantly ($P < 0.0001$) higher in facultative lagoon 2 than in the same lagoon in the dry season. There were no significant differences in the other lagoons between the seasons. The shorter plant height in the anaerobic lagoon during the rainy season may be because the excess nutrients in the environment may become a nuisance to the plants growing there. Gupta et al. [36] reported the reduced or stunted growth of *E. crassipes* and *Pistia stratiotes* under high concentrations of conductivity and TDS in polluted wastewater. The higher plant height obtained in facultative lagoon 1 during the dry season and maturation lagoon in the rainy season could be because the water entering these tanks had nutrient concentrations favorable for the growth and development of *E. crassipes*. These results were in agreement with those of Kengne et al. [37] and Fonkou et al. [4] who reported favorable growth of *E. pyramidalis* in favorable concentrations of polluted domestic wastewater.

The root length of *E. crassipes* showed similar evolution in the dry season. In the rainy season, it evolved in pairs with the same trends between the anaerobic and the facultative lagoon 1 and between facultative lagoon 2 and the maturation lagoon (Figure 4(b)). The shortest root length was recorded in the anaerobic lagoon, while the longest root length was obtained in facultative lagoon 2. Root length was significantly ($P < 0.05$) longer in facultative lagoon 2 than in the anaerobic lagoon during the dry and rainy seasons. There was no significant difference between the two facultative lagoons in the dry season. In the rainy season, the root length in facultative lagoon 2 was significantly ($P < 0.0001$) longer than in facultative lagoon 1, whereas it was similar to that in the maturation lagoon. The root length in all the lagoons except for the anaerobic lagoon was significantly ($P = 0.0002$) longer in the rainy season than in the dry season. This could be due to the influx of rain water during this season leading to further dilution of the wastewater and causing the roots to go for longer distances in search of nutrients for the plant. The shorter roots obtained in the anaerobic lagoon may be because this compartment, located at the head end of the treatment system, receives high concentrations of nutrients such that the roots do not need to extend deeper down into the lagoon to obtain them. These results corroborate those of Koné in 2002 and Almoustapha and Millogo-Rasolodimby [38] who suggested that in nutrient-rich or polluted environments, the roots are shorter and then lengthen as nutrient levels reduce or when the purification level improves.

The number of new buds varied according to the seasons (Figure 4(c)). In the dry season, the lowest number was recorded in the maturation lagoon and the highest number

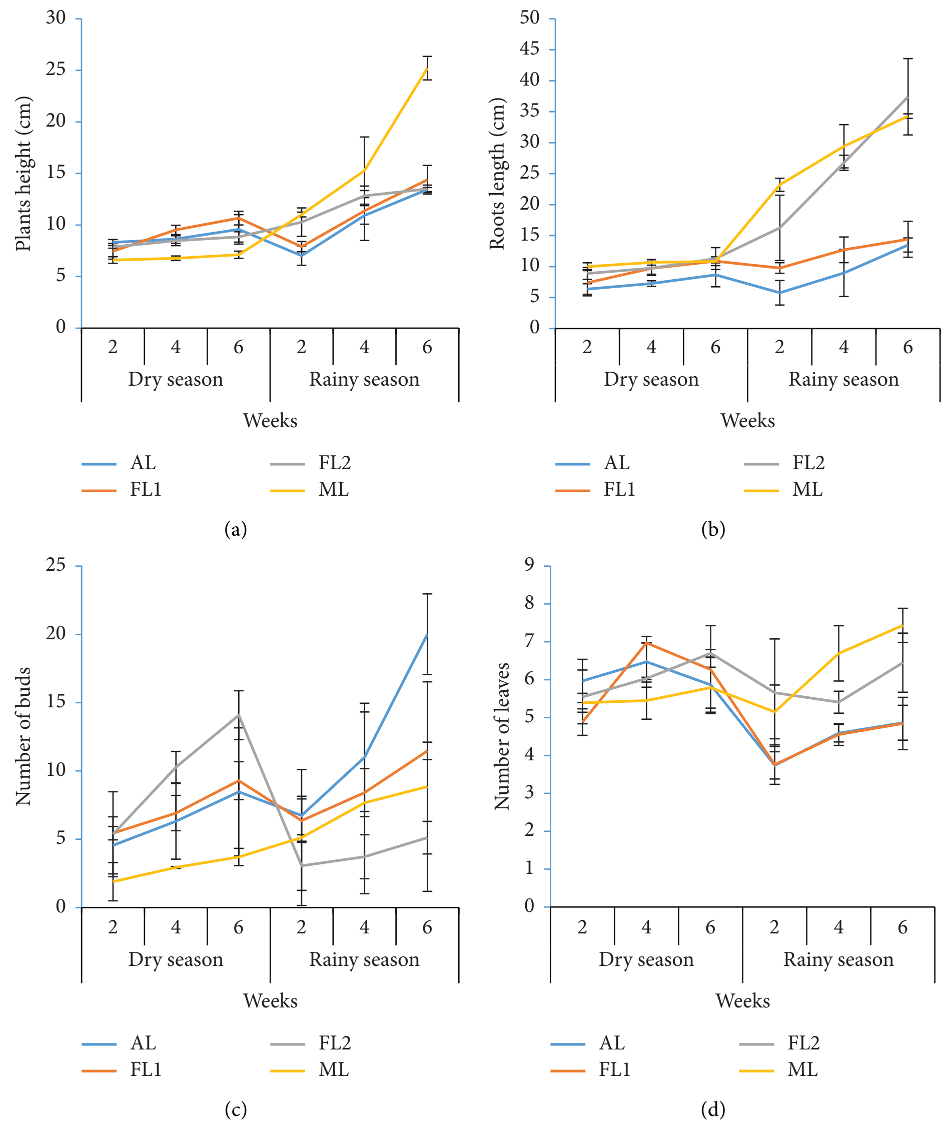

Figure 4: Variation of plant parameters (means ± S.D.) in each lagoon throughout the experimental period: (a) plant height, (b) root length, (c) number of new buds, and (d) number of leaves (AL: anaerobic lagoon; FL 1: facultative lagoon 1; FL 2: facultative lagoon 2; ML: maturation lagoon).

was recorded in facultative lagoon 2. There was a significant ($P < 0.0001$) difference between this lagoon and all the other lagoons. The number of new buds per plant in the facultative lagoon 1 was significantly ($P < 0.0001$) different from that in the maturation lagoon and similar to that in the anaerobic lagoon. In the rainy season, the lowest number was recorded in facultative lagoon 2 and the highest number was recorded in the anaerobic lagoon. This was significantly ($P = 0.001$) higher than the number of new buds in the rest of the lagoons. There was a significant ($P = 0.001$) difference between the two facultative lagoons and no significant difference between the facultative and the maturation lagoon. The number of new buds in all the lagoons except for the anaerobic lagoon was significantly ($P < 0.05$) higher in the rainy season than in the dry season. The higher number of new buds in the anaerobic lagoon could probably be because organisms in nutrient-rich environments will rapidly multiply to exhaust the abundant nutrients available in the environment [36]. This signifies the rapid use of nutrients such as nitrates and phosphates in the system as one goes from the anaerobic to the maturation lagoons [39, 40].

Regarding the number of leaves of *E. crassipes*, a zigzag pattern was observed in the different lagoons in the dry season. In the rainy season, the number increased regularly except in facultative lagoon 2 (Figure 4(d)). The two facultative lagoons were similar and significantly ($P < 0.0001$) higher than the maturation and anaerobic lagoons where the number of leaves was similar. On the other hand, a minimum number was observed in the anaerobic lagoon and facultative lagoon 1 and a maximum number in the maturation lagoon. The number of leaves was significantly ($P < 0.0001$) higher in the maturation than in the anaerobic lagoon and facultative lagoon 1. The number of leaves in the anaerobic lagoon and facultative lagoon 2 during the dry

TABLE 2: Percentage reduction in the physicochemical parameters of the wastewater in the various lagoons during the dry season and rainy season.

Season	Parameters (%)	Vegetated system					Control system				
		Anaerobic lagoon	Facultative lagoon 1	Facultative lagoon 2	Maturation lagoon	Overall reduction	Anaerobic lagoon	Facultative lagoon 1	Facultative lagoon 2	Maturation lagoon	Overall reduction
Dry season	EC	16.94	18.36	15.63	−2.26	41.43	29.39	22.35	−5.71	−2	40.88
	TDS	7.1	19.11	15.12	−2.9	34.38	22.73	22.43	−6.16	−4.46	33.52
	TSS	51.64	3.01	10.08	−109.86	−8.36	61.45	−5.66	−100.89	−10.22	9.82
	Color	59.04	4.97	8.76	−56.4	44.46	52.51	12.26	−48.64	1.07	38.73
	NO_{3-}	0	44.29	−243.59	87.31	0	0	29.41	−408.33	100	0
	PO_4^{3-}	22.86	19.37	−28.23	53.73	63.1	23.99	40.64	0.53	15.38	62.02
	BOD_5	−4.94	11.53	−67.55	−0.79	−56.79	14.81	38.12	23.89	−300	−60.49
	COD	−44.56	−48.21	27.39	14.49	−32.88	−26.22	3.55	24.11	−21.03	−11.82
	FS	85.48	61.11	100	0	100	87.9	33.33	100	0	100
	FC	73.57	28.33	23.26	−72.73	74.89	80.18	68.89	−721.43	−39.13	29.52
Rainy season	EC	51.22	14.16	20.44	−35.78	54.77	52.32	−73.08	6.67	−21.43	6.47
	TDS	51.04	14.81	19.42	−35.97	54.3	51.64	−72.5	5.8	−16.92	8.12
	TSS	62.13	65.63	40.91	−130.77	82.25	34.91	−180.91	−56.96	−25.15	−259.17
	Color	50.49	43.62	32.41	6.26	82.31	45.72	−50.38	−45.08	15.24	−36.47
	NO_{3-}	0	−146.51	−41.5	57.33	0	0	0	92.59	−1150	0
	PO_4^{3-}	10.02	65.17	32.25	36.85	86.59	33.62	29.22	27.67	−65.59	43.72
	BOD_5	−10.63	91.32	−315.53	−10.05	56.06	−25.93	67.26	39.37	−612.69	−78.17
	COD	−40.23	11.07	53.92	−27	27.01	−89.08	−182.37	39.4	−60.57	−419.54
	FS	97.39	66.67	100	0	100	100	0	54.1	−703.57	−95.65
	FC	78.1	71.7	−60	−466.67	43.80	48.76	−81.45	51.11	−7.27	51.24

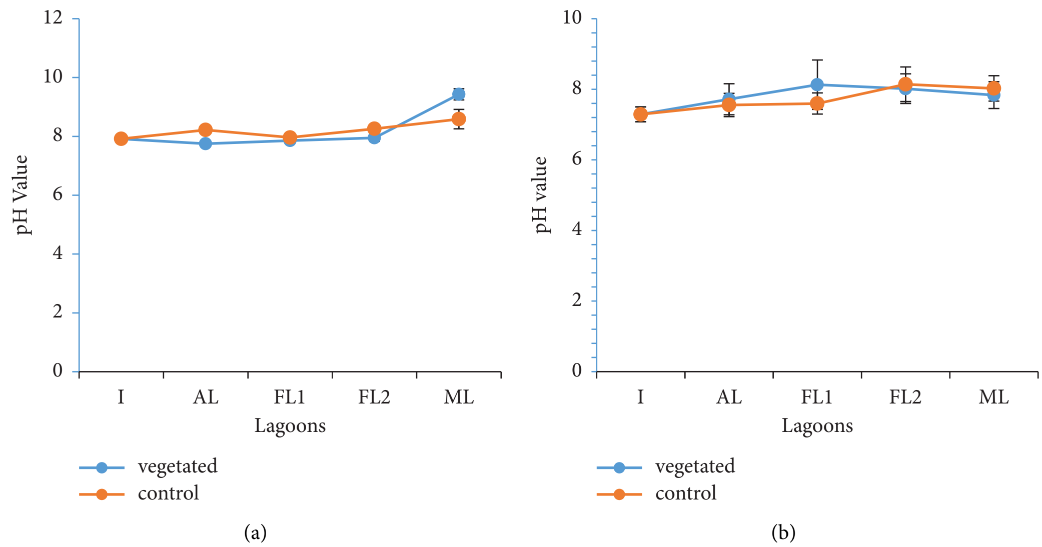

Figure 5: Average pH values (means ± S.D) in the vegetated and control lagoons systems during the dry season (a) and the rainy season (b) (I: inflow; AL: outflow of anaerobic lagoon; FL 1: outflow of facultative lagoon 1; FL 2: outflow of facultative lagoon 2; ML: outflow of maturation lagoon).

season was significantly ($P = 0.0075$) higher than in the rainy season. There were no significant differences between the seasons in the rest of the lagoons. This may be because the outer leaves die while new leaves form in the center. According to Kara [41] and Gupta et al. [36], the growth of *E. crassipes* is controlled by nitrogen sources in the wastewater. The high number of leaves in the first two lagoons could be attributed to the stress induced by the high concentration of pollutants in the inflowing wastewater.

3.2. Performances of Lagoons in Improving Physicochemical Parameters of Wastewater. The pollution reductions and overall percentage reductions in the different treatment lagoons are presented in Table 2. Both lagoons showed improvement in the physicochemical parameters of wastewater though negative reductions were observed for some parameters along the different lagoons. These negative reductions were even more pronounced at the outflow of the maturation lagoon of the control system during the rainy season where all the parameters recorded negative reduction rates. This was also true for the overall percentage reduction parameters along the control system during the rainy season.

3.2.1. Changes in pH in the Lagoon System. Figure 5 presents the average pH values recorded in the experimental lagoon system during the dry and rainy seasons. The pH values were slightly basic at the outflow of the maturation lagoon. There was a gradual increase in pH from the inflow of each system to the outflow with a high significant ($P < 0.0001$) difference obtained in the maturation lagoon during the dry season compared to the other lagoons and the control. Also, there were no significant differences between the rest of the lagoons and between the vegetated lagoons and the control. The high pH values obtained in the maturation ponds, particularly in the dry season, might have resulted from the higher sunshine intensity and the shallow depth of the pond leading to high evaporation in the system. The increase in pH across the lagoons could be explained by the fact that during the passage of wastewater in the lagoons, there is the development of organic matter degrading bacteria and microscopic algae which, through their photosynthesis, consume the dissolved CO_2 in the water, and this leads to the alkalinization of the environment [42, 43]; thus, the greater the phytoplankton development, the higher the pH value. Wastewater pH is an important factor that can affect lagoon performances, especially during the anaerobic digestion process [14, 44]. However, the pH values of the water obtained in the lagoons were within the range recommended by the World Health Organization ($4.0 < pH < 9.5$) for the proliferation of numerous bacteria which favors wastewater treatment [45].

3.2.2. Variation of Electrical Conductivity and TDS in the Lagoons. Overall, the electrical conductivity (EC) and TDS were higher at the inflow compared to the outflows (Figure 6). There was no significant difference between the entry of the system and outflow of the different vegetated lagoons during the dry season. This is similar between the vegetated lagoons and the control lagoons. On the contrary, during the rainy season, the EC was significantly P higher at the inflow than at the outflow of the lagoons but with no significant difference between the outflows of the different lagoons. The best reduction rates were obtained in the vegetated system (Table 2). The higher performance of the system vegetated with *E. crassipes* can be attributed to the absorptive capacity of the plants [46–48]. This corroborates the declaration of Chaurasia [30] that aquatic macrophytes have an enormous ability to absorb and accumulate excessive nutrients and toxic metals from water in their tissues. This decrease in conductivity at the outflow may be due to the degradation of organic matter by bacteria which contributes to the production of nutrient salts,

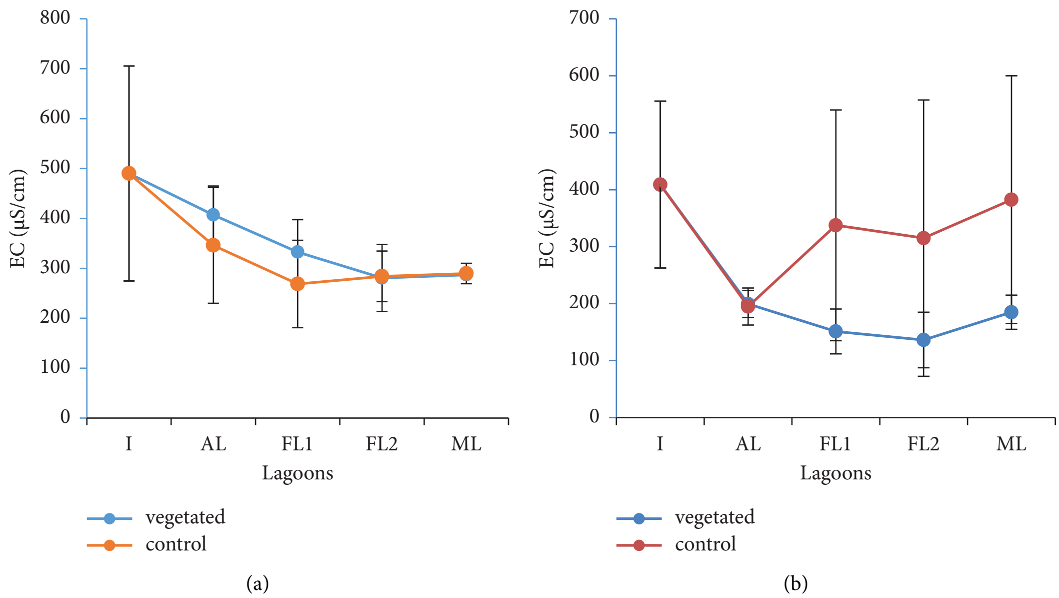

Figure 6: Variation of electrical conductivity (means ± S.D) in the vegetated and control lagoons systems from the inflow to the outflows during the dry season (a) and the rainy season (b) (I inflow; Al: outflow of anaerobic lagoon; FL 1: outflow of facultative lagoon 1; FL 2: outflow of facultative lagoon 2; ML: outflow of maturation lagoon).

which are assimilated by algae and plants [43]. Moreover, the low variation in conductivity values is normal since there is little or no reduction in soluble ionic compounds during the various treatment operations with a slight decrease observed along the system. This result is lower than that obtained by Boutayeb et al. [49] in Morocco and Benslimane et al. [50] in Algeria using different plant species in temperate climatic conditions. In this topical climatic context, the increase in electrical conductivity can be explained by the mineralization of organic matter.

3.2.3. Reduction of Total Suspended Solids (TSS). Figure 7 presents the average TSS profile for the vegetated and the control lagoon systems in the dry and rainy seasons. The TSS values were lower in the anaerobic lagoon and facultative lagoon 1 compared to those obtained at the outflows of the facultative lagoon 2 and maturation lagoons. This resulted in percentage reduction rates of 9.82% and −8.36%, respectively, for the control and vegetated systems (Table 2). The values of TSS at the inflow of the system and the outflow of the maturation lagoon are significantly ($P = 0.0021$) higher than those at the outflows of the rest of the lagoons. There was no significant difference between the outflow of the vegetated lagoons and the corresponding nonvegetated lagoons. On the other hand, during the rainy season, there was a gradual drop in total suspended solids along the vegetated system ($P < 0.0001$) but a rather drastic increase in the nonvegetated control system. This can be explained by the fact that during the dry season, water is concentrated due to evapotranspiration causing the rotting of plants and the proliferation of biodegrading microorganisms, hence the presence of suspended particles; while in the rainy season, the material sediment quickly. However, Akowanou et al. [51] reported that water hyacinth in lagoons depicted a high efficiency in the reduction of suspended solids of up to 92% in subtropical climates. The values at the inflow and the outflow of the vegetated and control systems resulted in reduction rates of 82.35% and −259.17% (Table 2). There was no significant difference between the vegetated anaerobic and control, whereas the TSS concentrations in the vegetated lagoons were significantly ($P < 0.0001$) lower in the corresponding control during this season. Total suspended solids (TSS) constitute a good part of the carbon pollution. Their reduction contributes to a better yield on BOD_5 and COD. The accepted theory on this subject is that which presents aquatic plants are physical barriers that slow down the transportation of total suspended solids towards the outflow of the lagoons and thus contribute to their settling and digestion in the sediments [52]. Also, the absence of plants in the control system led to a strong proliferation of algae which constitute the bulk of suspended matter, causing the high increase in TSS in the nonvegetated control and the maturation lagoons. A similar study carried out by Kim and Kim [53] on the elimination of TSS by *E. crassipes* showed that the submerged parts of the plants constitute supports for the fixing of algae and that their growth is prevented by the floating macrophytes because these retain approximately 90% of solar radiation. In addition, the new root shoots are also the site of particle agglomeration. The sludge storage capacity is therefore dependent on the size of the roots. When the size of the sludge (biofilms) around the roots becomes large, it settles, freeing up space for a new formation of sludge aggregate. Values of (50 mg/L) obtained at the outflow of the vegetated

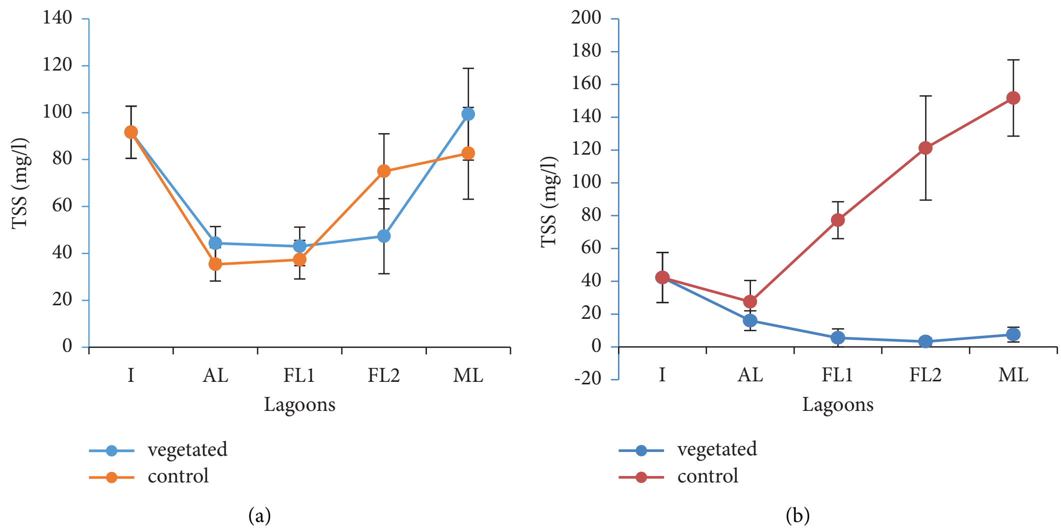

Figure 7: Variation of suspended solids (means ± S.D) from the inflow to the outflow of the vegetated and control lagoons systems during the dry season (a) and the rainy season (b) (I: inflow; Al: outflow of the anaerobic lagoon; FL 1: outflow of facultative lagoon 1; FL 2: outflow of facultative lagoon 2; ML: outflow of maturation lagoon).

system during the rainy season do not meet the standards for the discharge of wastewater into the environment in Cameroon, which is less than or equal to 30 mg/l [54].

3.2.4. Color Reduction. Overall, there was a significant ($P < 0.05$) drop in color for the vegetated systems in the dry and rainy seasons with reduction rates of 44.46% at the outflow of the vegetated system and 38.73% at the outlet of the control system (Table 2). There was no significant difference between the vegetated and the control and no significant difference between lagoons in the vegetated system. However, during the rainy season, there was an increase in the mean color value at the outflow of the control lagoons compared with the inflow. A reduction rate of 36.7% was obtained in the control system and a significant ($P = 0.0037$) drop of 82.31% in the vegetated system during this season (Table 2). There was a significant ($P = 0.0037$) difference between the vegetated and the control lagoons globally during this season. Also, there were no significant differences between the different lagoons from the inflow to the final outflow of the vegetated systems. The high color values recorded at the outflow of the control system during the rainy season are probably due to the high concentration of colloidal pollution such as degraded organic matter, clay, algae, and metal oxides which are high contributors of color in wastewater [16]. The color concentrations in the vegetated facultative and maturation lagoons were significantly lower than in the corresponding lagoons in the control during the rainy season (Figure 8). This could be attributed to the fact that macrophyte roots provide a large surface area for the adhesion of biodegrading bacteria which removes the dissolved pollution in water and causes their sedimentation in the lagoons [39, 51].

3.2.5. Nutrient Removal. Independent of the seasons, a considerable decrease in the concentrations of orthophosphates was observed at the maturation outflows of the two systems compared with the inflow. On the other hand, the nitrate concentration increased in a zigzag manner along the lagoons before decreasing at the outflow of the maturation lagoon. The facultative lagoon 2 of both the non-vegetated control and vegetated systems reached their peak of concentration during the dry season which considerably dropped to zero at the outflow of the maturation lagoon (Figure 9). It should be noted that the concentration of nitrates at the inflow throughout the experiment in both systems, whether in the dry or rainy season, was always 0 mg/L. However, its concentrations at the facultative lagoon 2 were significantly higher than in the facultative lagoon 1 and the maturation lagoons. There were no significant differences between the different lagoons in the rainy season. The overall nitrate reduction rate during the dry season in both systems was 0.0%. During the rainy season, a similar tendency was observed with reduction rates of 57.33% and 92.59%, respectively, obtained in the vegetated maturation and second facultative lagoons of the control (Table 2). These results corroborate those of Seghairi et al. [55] who obtained reduction rates of −209% in vegetated bed systems. Indeed, nitrates constitute the final stage of the oxidation of nitrogen and represent the absorbable form of nitrogen present in water and wastewater. Their concentration in natural waters is between 1 and 10 mg/l [56]. However, their levels in untreated wastewater are low. The averages obtained for the nitrates followed a relatively increasing gradient in the lagoons of the two systems. This could be due to the influx of photosynthetic oxygen through the rhizosphere of the macrophytes that enhanced the proliferation of aerobic degradation bacteria in the system [57, 58]. But at the outflow of the control maturation lagoons in the dry season, there were no nitrates. This may be because nitrates produced by aerobic degrading bacteria in the control were again all absorbed by algae upstream for the proliferation in the system [59]. The zero value obtained at the inflow of the

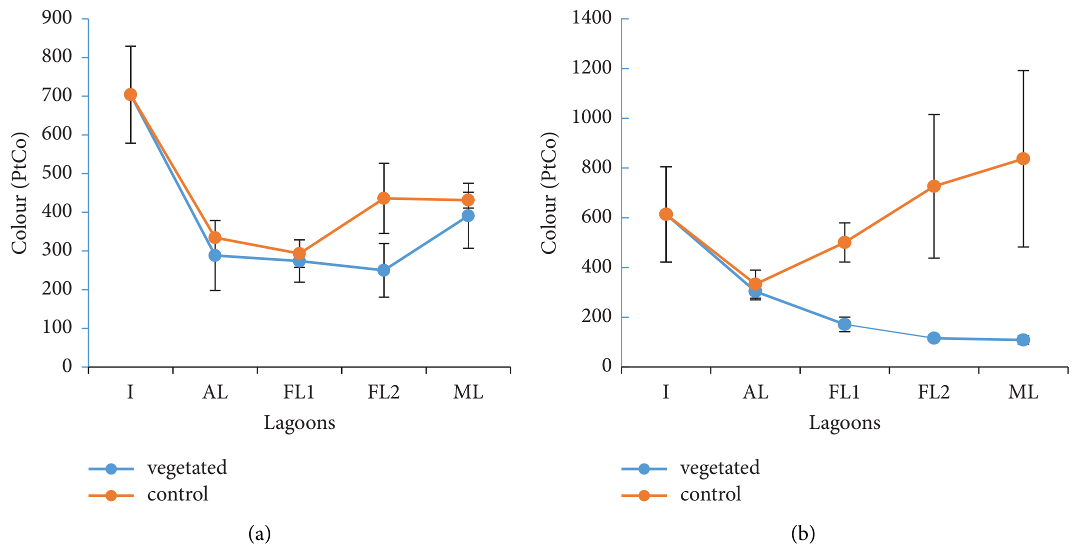

Figure 8: Variation of color (means ± S.D) from the inflow to the outflows of the vegetated and control lagoons systems during the dry (a) and rainy (b) seasons (I inflow; Al: outflow of the anaerobic lagoon; FL 1: outflow of facultative lagoon 1; FL 2: outflow of facultative lagoon 2; ML: outflow of maturation lagoon).

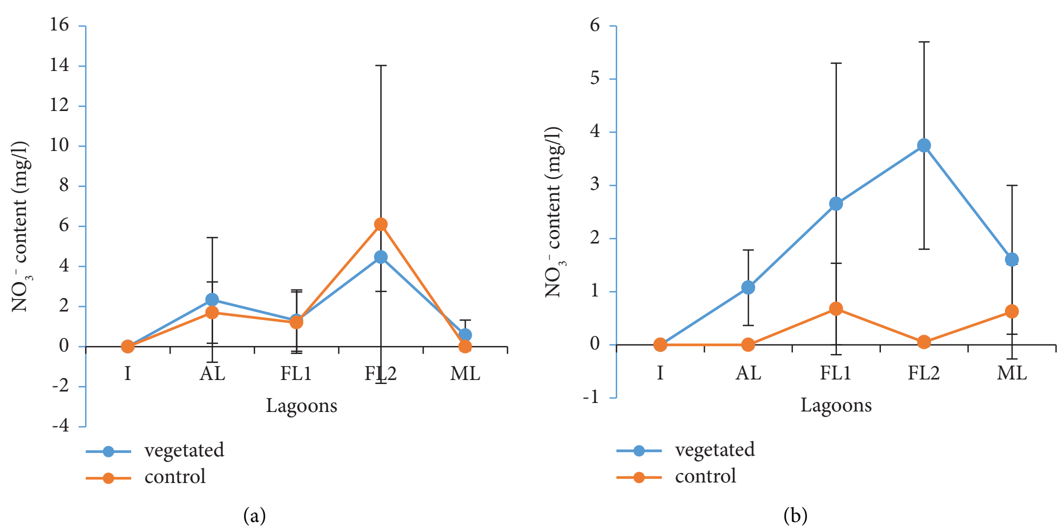

Figure 9: Variation in nitrate content (means ± S.D) from the inflow to the outflows of the vegetated and control lagoons systems during the dry season (a) and the rainy season (b) (I: inflow; Al: outflow of anaerobic lagoon; FL 1: outflow of facultative lagoon 1; FL 2: outflow of facultative lagoon 2; ML: outflow of maturation lagoon).

two systems throughout the experiment could be because inorganic nitrogen is present in the form of ammonium and nitrite and it is only under the action of nitrifying bacteria that the ammonium is transformed into nitrates [60–62]. According to Koné [6], nitrification is dependent on the oxidation state of the medium and the availability of dissolved oxygen. Thus, the significant sunshine that the lagoons received would have favored the proliferation of microscopic algae which, through photosynthesis, produce oxygen used by the biofilms on the roots of macrophytes [63, 64]. This would have favored nitrification. These results corroborate those obtained by Mounjid et al. [59]. However, they are contrary to those of Seghairi et al. [55] who obtained (−209%) at the outflow of treatment beds vegetated with *Cyperus papyrus* in Algeria under temperate climatic conditions.

The average phosphate concentrations decreased at the outflow of the vegetated lagoons system compared with the inflow (Figure 10). The concentrations of this parameter were significantly ($P < 0.05$) lower at the outflows of both systems compared to the entry. There were no significant differences between the different lagoons, as well as between the vegetated and the control systems (Table 2). The concentration of PO_4^{-3} was significantly ($P < 0.05$) reduced at the maturation outflow of the vegetated system. The decrease in phosphate concentrations in these systems may be due to

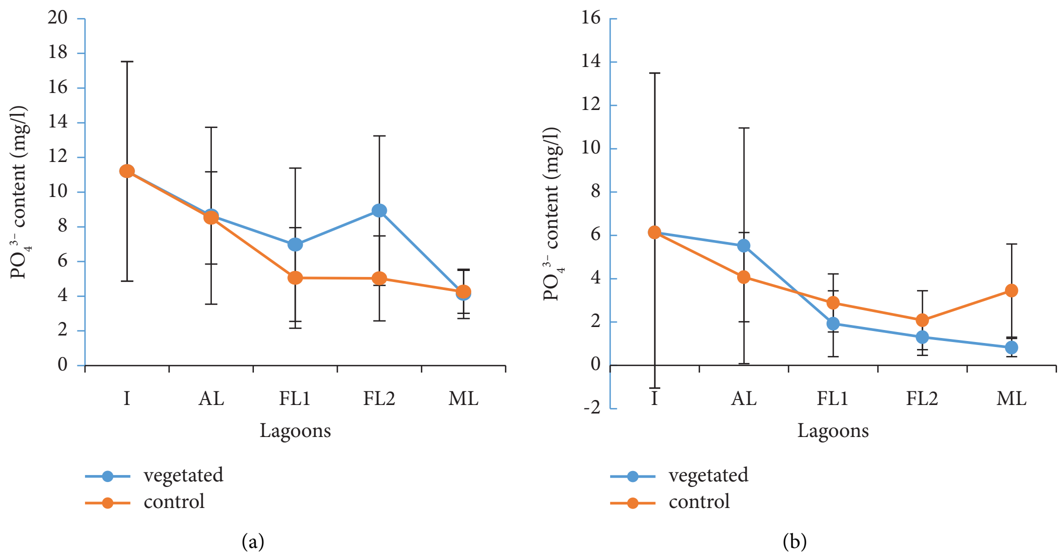

FIGURE 10: Variation in phosphate content (means ± S.D) from the inflow to the outflows of the vegetated and control lagoons systems during the dry season (a) and the rainy season (b) (I: inflow; Al: outflow of anaerobic lagoon; FL 1: outflow of facultative lagoon 1; FL 2: outflow of facultative lagoon 2; ML: outflow of maturation lagoon).

the direct use of phosphates by plants and algae [65], but the reduction could be highly influenced by hydraulic retention time [51, 66] which favors sedimentation and adsorption to the root system. The microbial population residing in the control system and on the roots of the macrophytes could also assimilate the phosphates present in the wastewater [67]. In addition, orthophosphates precipitate when the pH increases and/or are absorbed by the phytoplankton. The results obtained are similar to those reported by Fonkou et al. [4] in tropical climates and Merghem et al. [68] and Benyoucef [5] in semiarid climates.

3.2.6. Removal of Organic Matter. Figure 11 presents the variations of BOD_5 concentrations in the different lagoons. There was an increase in the concentrations of BOD_5 at the outflows of the experimental lagoons and the control. The BOD_5 contents at the outflows of the vegetated and control systems in the dry season were significantly higher compared with the main inflow, with no significant differences between the two systems. The increase in the BOD_5 content at the outflow of the maturation lagoon compared to the main inflow could be due to the proliferation and death of algae. Indeed, the elimination of the BOD_5 was ensured by a good elimination of suspended solids since these constitute the major part of carbon pollution. These suspended solids were mainly algae in the control lagoons, as well as the algae and decomposing macrophytes in the vegetated lagoons. These results were contrary to those obtained by Benyoucef [5] who worked in a temperate zone and reported a decrease in BOD_5 concentration in the system.

As for the COD, no significant differences were found between the two systems and between the seasons (Table 2). The average concentrations were much higher in the control lagoon than in the macrophytic lagoons during the rainy season (Figure 12). This difference may be due to the presence of macrophytes. According to Seghairi et al. [55], macrophytes can transfer oxygen from the rhizome to the roots through aerenchyma which promotes the creation of an aerobic zone around the roots. This aerobic zone allows the proliferation of aerobic microorganisms; thus, increasing the density of the biodecomposer of organic matter in the vegetated system concerning the control whose photosynthetic activity is comparatively less with the microalgae.

3.3. Performances of Lagoons in Improving Microbiological Parameters of Domestic Wastewater. Table 3 depicts the concentrations of fecal streptococci (FS) in the different lagoons during the study period. This concentration gradually decreased along the two systems until it reached a value of 0 CFU/100 ml in the maturation lagoon. With regard to the rainy season, the concentrations recorded, respectively, at the inflows and the outflows varied in the vegetated system. In the control system, they evolved in a zigzag manner, but the highest value was obtained at the outflow of the maturation lagoon. However, there were significant ($P = 0.0019$) differences between the vegetated and control systems for the removal of fecal streptococci during the dry season. In the vegetated system, no negative yield was recorded compared with the control (Table 3). The fecal contamination parameters are more abundant at the inflow of the lagoons than at the outflow. This may be due to the shallow depth of the maturation lagoon which would favor the penetration of sun radiations (UV radiations) and consequently lead to the natural death of microbes. In addition, the increase in pH and high algal activity through photosynthesis would allow the elimination of fecal pollution indicators in the maturation lagoon [69]. Furthermore, aerobic conditions would improve the rate of reduction of fecal contamination indicators [70]. These results are higher than those obtained by Nya et al. [71] who equally worked on

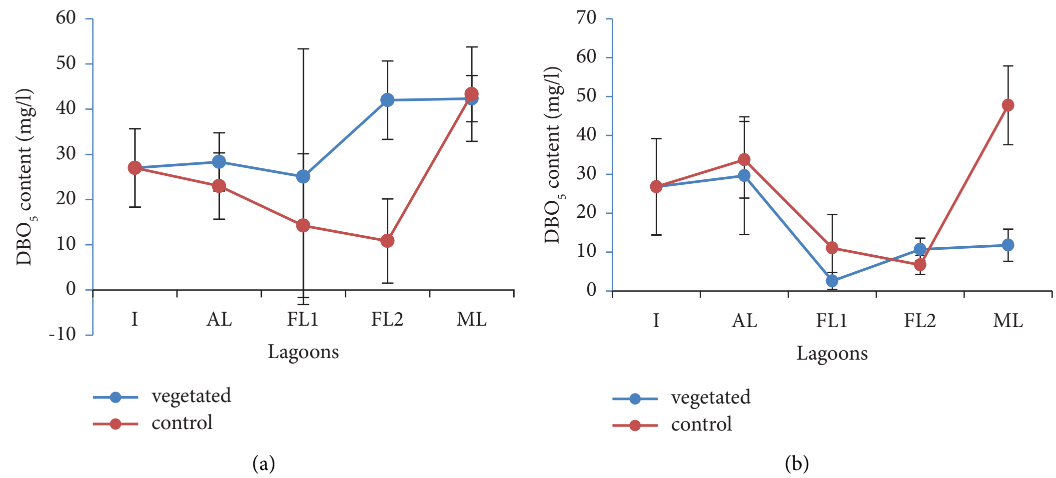

Figure 11: Variation in BOD_5 content (means ± S.D) from the inflow to the outflows of the vegetated and control lagoons systems during the dry season (a) and the rainy season (b) (I: inflow; Al: outflow of anaerobic lagoon; FL 1: outflow of facultative lagoon 1; FL 2: outflow of facultative lagoon 2; ML: outflow of maturation lagoon).

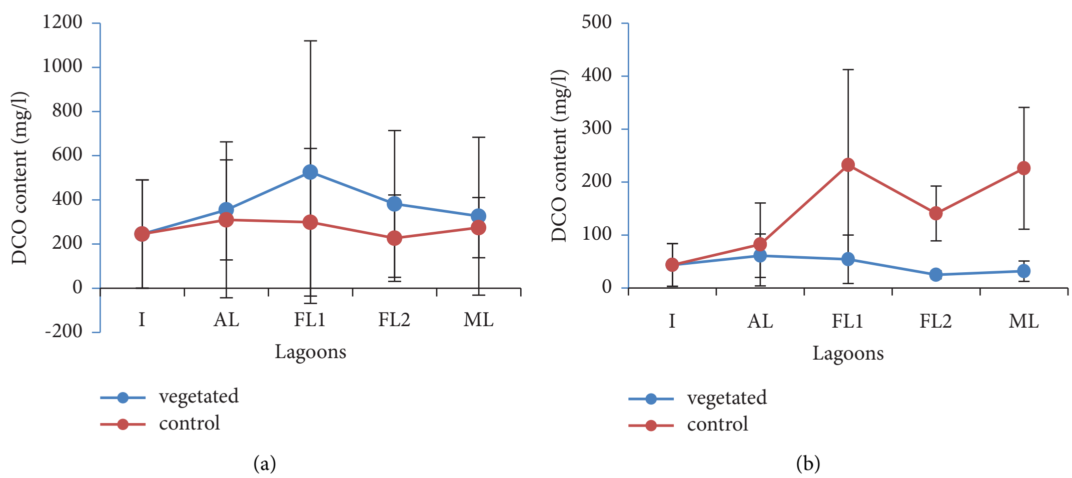

Figure 12: Variation in COD content (means ± S.D) from the inflow to the outflows of the vegetated and control lagoons systems during the dry season (a) and the rainy season (b) (I: inflow; Al: outflow of anaerobic lagoon; FL 1: outflow of facultative lagoon 1; FL 2: outflow of facultative lagoon 2; ML: outflow of maturation lagoon).

the treatment of domestic wastewater by the lagoons system in Cameroon. This difference would be due to the short water retention time in the lagoons which does not favor the elimination of these microorganisms. But at the outflow of the treatment system, a reduction of 100% was recorded which testifies to the effectiveness of the polishing lagoons.

The fecal coliform (FC) concentrations in the different lagoons during the study period are presented in Table 3. The averages obtained show a high concentration of FC at the inflows during the two seasons. These concentrations gradually decrease in the vegetated lagoon system toward the maturation lagoon. The vegetated system was significantly ($P < 0.05$) more efficient than the control during both seasons. The best purification efficiencies were 73.57 and 78.1% obtained in the anaerobic lagoon in the dry and rainy seasons, respectively (Table 3). The control system presented concentrations that decreased compared to the outflow, but these remained higher than those of the vegetated system. There were no significant differences between the lagoons concerning the two seasons (Table 3). The low concentrations recorded in the vegetated system compared to the control system might have been due to the presence of macrophytes which trap these bacteria at the level of their roots. Studies by [12, 13, 72] reported in this light. But this elimination could also be due to the presence of reactive oxygen species ($O_2^{-\bullet}$) liberated into the system by the macrophytes. Furthermore, the oxygen transferred by the aerial parts of the macrophytes to the submerged roots for respiration in the anoxic water might also have excesses released into the water. These create a microaerobic zone at the rhizosphere for the proliferation of aerobic microbes whose activities or presence might be bactericidal. The mean

Table 3: Fecal coliforms and streptococci contents in the vegetated and control lagoons system during the dry and rainy seasons at the inflow and outflow of each lagoon.

Lagoon system	Parameters	Dry season					Rainy season				
		Inlet	Anaerobic lagoon	Facultative 1 lagoon	Facultative 2 lagoon	Maturation lagoon	Inlet	Anaerobic lagoon	Facultative 1 lagoon	Facultative 2 lagoon	Maturation lagoon
Vegetated	SF $* 10^4$ (UFC/100 ml)	41.33 ± 21.56^{b}	6 ± 3.33^{a}	2.33 ± 3.11^{a}	0 ± 0^{a}	0 ± 0^{a}	28.75 ± 34.12^{ab}	0.75 ± 11.25^{a}	0.25 ± 0.37^{a}	0 ± 0^{a}	0 ± 0^{a}
	CF $* 10^4$ (UFC/100 ml)	75.67 ± 49.56^{c}	20 ± 16^{abc}	14.33 ± 42.22^{ab}	11 ± 9.33^{ab}	19 ± 11.33^{abc}	60.5 ± 28.25^{bc}	13.25 ± 7.25^{ab}	3.75 ± 1.75^{a}	6 ± 7^{a}	34 ± 38.5^{abc}
Control	SF $* 10^4$ (UFC/100 ml)	41.33 ± 21.56^{ab}	5 ± 3.33^{ab}	3.33 ± 4.44^{ab}	0 ± 0^{a}	0 ± 0^{a}	28.75 ± 34.12^{ab}	0 ± 0^{a}	15.25 ± 19.87^{ab}	7 ± 9^{ab}	56.25 ± 54.25^{b}
	CF $* 10^4$ (UFC/100 ml)	75.67 ± 49.56^{a}	15 ± 16^{a}	4.67 ± 3.56^{a}	38.33 ± 41.11^{a}	53.33 ± 57.78^{a}	60.5 ± 28.25^{a}	$31 \pm 11.5a$	56.25 ± 39.25^{a}	27.5 ± 15^{a}	29.5 ± 22.5^{a}

The letters a, b, and c signify that the values are significantly different.

concentrations of fecal coliforms obtained are similar to those obtained by Maiga et al. [73] in a Sahelian climate who found that these loads would correspond to the typical bacteriological compositions of raw effluent load of low-to-medium categories, as reported by Laabassi [74]. According to the WHO standards, treated water can only be reused in nonrestrictive irrigation for fecal coliform loads of less than 1000 CFU/100 ml. Also, the results from this study conducted in a tropical climate remain unsatisfactory for the elimination of fecal coliform bacteria according to this standard. These results are lower than those reported by Nya et al. [71] in a tropical climate. This author obtained a purification efficiency of 99.98% in the macrophyte lagoon which is quite higher than the 74.89 and 43.80% obtained in this study, respectively, in the dry and rainy seasons.

4. Conclusion

The water hyacinth proliferated rapidly in the lagoons system with increasing trends of the growth characteristics with significantly higher values observed in the rainy season for plant height, root length, and number of leaves. Effluent from the system showed a significant drop in physicochemical and microbiological parameters compared to the influent. Average reduction rates greater than 80% for TSS, color, and orthophosphates and greater than 50% for BOD_5 were observed in the rainy season. The season had a significant effect on the treatment efficiencies of the lagoons as the best results were recorded in the vegetated system during the rainy season. The vegetated system with *E. crassipes* significantly reduced the TSS (82.25%), color, phosphates, and BOD_5 compared to the control with TSS, color, PO_4^{-3}, and BOD_5 in the rainy season. No significant differences were observed in the reduction of EC, TDS, phosphates, and COD between the vegetated and the control systems in the dry season. The vegetated system also presented high efficiencies in the removal of bioindicators of fecal contamination in both seasons with 100% elimination observed for fecal streptococci and for fecal coliforms, 74.89 and 43.80, respectively, in the dry and rainy seasons. This study confirms that *E. crassipes* can be domesticated and used in the improvement of domestic wastewater in the lagoon system in the Western Highlands of Cameroon.

Data Availability

The data are available on request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Amandine Elodie MANEKEU TANETSA is the main researcher and writer of the manuscript; Martin LEKEUFACK is the field supervisor and the proof reader of the manuscript; Marcelle Léonce EDZIGUI TSIMI, Gabriel Nicodème TSETAGHO, and Raoul Camen LONGNIANG were involved in the laboratory and data analyses, while Théophile FONKOU is the main supervisor and head of the laboratory.

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References

[1] L. Bouchaala, N. Charchar, and A. Gherib, "Ressources Hydriques traitement et Reutilisation des Eaux Usees en Algerie Water Resources Treatment and Reuse of Wastewater in Algeria," *Algerian journal of arid environment*, vol. 7, no. 1, pp. 84–95, 2017.

[2] R. du Cameroun, "Cinquieme Rapport National du Cameroun à la Convention de la Diversite Biodiversité MINEPDED," 2014, https://www.cbd.int/doc/world/cm/cm-nr-05-fr.pdf.

[3] S. Kantawanichkul, S. Kladprasert, and H. Brix, "Treatment of high-strength wastewater in tropical vertical flow constructed wetlands planted with Typha angustifolia and Cyperus involucratus," *Ecological Engineering*, vol. 35, no. 2, pp. 238–247, 2009.

[4] T. Fonkou, M. F. Fonteh, D. M. Kanouo, and A. Akoa, "Performances des filtres plantes de Echinochloa pyramidalis dans l'épuration des eaux usées de distillerie en Afrique subsaharienne," *Tropicultura*, vol. 28, no. 2, pp. 69–76, 2010.

[5] A. Benyoucef, *Traitement des eaux usées par phytoépuration*, Université Larbi Ben M'hidi Oum El Bouaghi, Oum El Bouaghi, Algeria, Thèse de doctorat PhD, 2021.

[6] D. Koné, "Epuration des eaux usées par lagunage à microphytes et à macrophytes en Afrique de l'Ouest et du Centre: Etat des lieux, performances épuratoires et critères de dimensionnement," Ecole polytechnique fédérale de Lausanne, Lausanne, Switzerland, Thèse de doctorat N° 2653, 2002.

[7] Q. Mahmood, A. Pervez, B. S. Zeb et al., "Natural treatment systems as sustainable ecotechnologies for the developing countries," *BioMed Research International*, vol. 2013, Article ID 796373, 19 pages, 2013.

[8] C. A. Odinga, A. Kumar, M. S. Mthembu, F. Bux, and F. M. Swalaha, "Rhizofiltration system consisting of Phragmites australis and Kyllinga nemoralis: evaluation of efficient removal of metals and pathogenic microorganisms," *Desalination and Water Treatment*, vol. 169, pp. 120–132, 2019.

[9] A. A. Ansari, M. Naeem, S. S. Gill, and F. M. Alzuaibr, "Phytoremediation of contaminated waters: an eco-friendly technology based on aquatic macrophytes application," *The Egyptian Journal of Aquatic Research*, vol. 46, no. 4, pp. 371–376, 2020.

[10] H. M. Mustafa and G. Hayder, "Recent studies on applications of aquatic weed plants in phytoremediation of wastewater: a review article," *Ain Shams Engineering Journal*, vol. 12, no. 1, pp. 355–365, 2021.

[11] A. U. Khan, A. N. Khan, A. Waris, M. Ilyas, and D. Zamel, "Phytoremediation of pollutants from wastewater: a concise review," *Open Life Sciences*, vol. 17, no. 1, pp. 488–496, 2022.

[12] T. Fonkou, M. Lekeufack, and F. Teguimdje, "Performances of a yard-scale surface flow wetland vegetated with echinochloa crus-pavonis in the removal of nutrients and faecal bacteria from domestic wastewater," *Journal of Biology and Life Science*, vol. 4, no. 2, pp. 2157–6076, 2013.

[13] M. Lekeufack, T. Fonkou, and E. P. Tedonkeng, "Growth characteristics of *Fuirena umbellata* in a surface flow constructed wetland and its influence in nutrients and faecal bacteria removal from domestic wastewater in Cameroon," *Journal of Environmental Protection*, vol. 8, no. 2, pp. 171–193, 2017.

[14] P. Ntakiyiruta, G. Nsavyimana, B. G. H. Briton, K. Adouby, D. Nahimana, and G. Ntakimazi, "Actions combinées de Eichhornia crassipes et Pistia stratiotes pour traitement tertiaire de l'effluent des bassins facultatifs de la station d'épuration de Buterere, Burundi," *International Journal of Brain and Cognitive Sciences*, vol. 14, no. 7, pp. 2463–2475, 2020.

[15] K. Samal, S. Kar, S. Trivedi, and S. Upadhyay, "Assessing the impact of vegetation coverage ratio in a floating water treatment bed of Pistia stratiotes," *SN Applied Sciences*, vol. 3, no. 1, pp. 120–9, 2021.

[16] E. B. Visiy, B. M. K. Djousse, L. Martin et al., "Effectiveness of biochar filters vegetated with Echinochloa pyramidalis in domestic wastewater treatment," *Water Science and Technology*, vol. 85, no. 9, pp. 2613–2624, 2022.

[17] T. L. Randrianantoandro, "La phytoépuration: une solution écologique pour le traitement des eaux usées urbaines: etude des marais dans la commune urbaine d'Antananarivo," *International Multilingual Journal of Science and Technology*, vol. 7, pp. 2528–9810, 2022.

[18] B. Bourbon, G. Lapalus, V. Le Daheron, C. Louvet, J. Marais, and M. Pages, "Les traitements tertiaires: pour quoi faire? 14e séminaire eau/Université Montpellier II," 2015, https://reseau-eau.educagri.fr/files/fichierRessource1_Rapport_bibliographique__traitements_tertiaires.pdf.

[19] V. Kumar, K. K. Jaiswal, M. Verma et al., "Algae-based sustainable approach for simultaneous removal of micropollutants, and bacteria from urban wastewater and its real-time reuse for aquaculture," *The Science of the Total Environment*, vol. 774, Article ID 145556, 2021.

[20] G. Fedorova, R. Grabic, K. Grabicova et al., "Water reuse for aquaculture; Comparative removal efficacy and aquatic hazard reductionof pharmaceuticals by a pond treatment system during a one year study," *Journal of Hazardous Materials*, vol. 421, Article ID 126712, 2022.

[21] H. Hosney, M. H. Tawfik, A. Duker, and P. Van Der Steen, "Prospects for treated wastewater reuse in agriculture in low- and middle-income countries; Systematic analysis and decision-making trees for diverse management approaches," *Environmental Development*, vol. 46, Article ID 100849, 2023.

[22] A. Fagrouch, S. Amyay, A. Berrahou, H. El Halouani, and H. Abdelmoumen, "Performances d'abattement des germes pathogènes en lagunage naturel sous climat aride: cas de la filière de traitement des eaux usées de la ville de Taourirt," *Afrique science*, vol. 6, no. 3, pp. 87–102, 2010.

[23] M. Wang, J. Zhu, and X. Mao, "Removal of pathogens in onsite wastewater treatment systems: a review of design considerations and influencing factors," *Water*, vol. 13, no. 9, p. 1190, 2021.

[24] C. Y. Wang and D. J. Sample, "Assessment of the nutrient removal effectiveness of floating treatment wetlands applied to urban retention ponds," *Journal of Environmental Management*, vol. 137, pp. 23–35, 2014.

[25] A. J. Gboko, A. C. Akobe, A. M. Aka et al., "Etat d'eutrophisation de la lagune continentale Ono (Bonoua sud-est de la Côte d'Ivoire) dans un environnement agro-industriel durant la crue du fleuve Comoé," *International Journal of Brain and Cognitive Sciences*, vol. 13, no. 6, pp. 2942–2958, 2020.

[26] I. Beniah Obinna and E. C. Ebere, "A review: water pollution by heavy metal and organic pollutants: brief review of sources, effects and progress on remediation with aquatic plants," *Analytical Methods in Environmental Chemistry Journal*, vol. 2, no. 3, pp. 5–38, 2019.

[27] B. C. Wolverton and R. C. McDonald, "Bioaccumulation and detection of trace levels of cadmium in aquatic systems by Eichhornia crassipes," *Environmental Health Perspectives*, vol. 27, pp. 161–164, 1978.

[28] F. Su, Z. A. Li, Y. W. Li et al., "Removal of total nitrogen and phosphorus using single or combinations of aquatic plants," *International. Journal of. Environmental. Research and Public Health*, vol. 16, no. 23, p. 4663, 2019.

[29] P. Saunders, "La jacinthe d'eau à racine pourpre est une solution naturelle en cas de pollution," *Rapport de l" ISIS en date du*, vol. 9, 2013.

[30] S. Chaurasia, "Role of macrophytes: a review," *Advances in Zoology and Botany*, vol. 10, no. 4, pp. 75–81, 2022.

[31] T. Fonkou, V. F. Nguetsop, J. Y. Pinta, V. M. A. Dekoum, M. Lekeufack, and A. Amougou, "Macrophyte diversity in polluted and non polluted wetlands in Cameroon," *Cameroon Journal of Experimental Biology*, vol. 1, no. 1, pp. 26–33, 2006.

[32] Climate Data, "Diagramme climatique, Courbe de temperature, Table climatique," 2020, https://fr.climate-data.org/europe/france/midi-pyrenees/cours-342801/.

[33] J. Boyah, T. Fonkou, T. Nguelefack, V. Nguetsop, and M. Lekeufack, "Wastewater Treatment Potentials of Vegetated Beds with *Brillantaisia cf. bauchiensis* Hutch & Dalz and *Polygonum salicifolium* Brouss ex Wild in the Western Highlands of Cameroon," *Journal of Environmental Protection*, vol. 10, no. 03, pp. 389–412, 2019.

[34] Hach, *The Handbook. DR/2500 Laboratory Spectrophotometer: Procedure Manuel*, HACH be right, Loveland, Colorado, 4th Edition, 2004.

[35] Centre d'Expertise en Analyse Environnementale du Québec (Ceae), "Recherches et dénombrement des coliformes totaux, entérocoques, coliformes fécaux (thermo-tolérants) et confirmations à l'espèce Escherichia coli," *méthode par filtration sur membrane*, vol. 15, no. 2, 2005.

[36] P. Gupta, P. S. Niveditha, and S. Sharada, "Treatment of contaminated ground Water using phytoremediation technique at anantapur, India," *World Environment*, vol. 9, no. 2, pp. 46–55, 2019.

[37] I. M. Kengne, P. H. Dodane, A. Akoa, and D. Koné, "Vertical-flow constructed wetlands as sustainable sanitation approach for faecal sludge dewatering in developing countries," *Desalination*, vol. 248, no. 1-3, pp. 291–297, 2009.

[38] O. Almoustapha and J. Millogo-Rasolodimby, "Production de biogaz et de compost à partir de Eichhornia crassipes, (Mart) Solmslaub (pontederiaceae) pour un Développement durable en Afrique sahélienne," *Vertigo La revue électronique en sciences de l'environnement.*, vol. 7, no. 2, 2006.

[39] A. Y. Ugya, S. M. Tahir, and T. S. Imam, "The efficiency of Pistia stratiotes in the phytoremediation of romi stream a case study of kaduma refinery and petrochemical company polluted stream," *International Journal of Health Sciences & Research*, vol. 5, no. 2, pp. 2249–9571, 2015.

[40] K. M. Namwanja, S. M. Siachoono, A. M. Yambayamba, and L. Chama, "The impact of mine effluents on the water quality and macrophyte plant communities in the kifubwa stream, solwezi, Zambia," *Natural Resources*, vol. 9, no. 5, pp. 198–211, 2018.

[41] Y. Kara, "Bioaccumulation of copper from contaminated wastewater by using lemna minor," *Bulletin of Environmental Contamination and Toxicology*, vol. 72, no. 3, pp. 467–471, 2004.

[42] L. Bouarab, "Dynamique et rôle des algues phytoplanctoniques dans le traitement des eaux usées (station pilote de lagunage naturel de Ouarzazate-Maroc)," Faculté des sciences Semlalia-Marrakech, Marrakesh, Morocco, Thèse Doctorat d'état es-sciences, 2000.

[43] O. El Hachemi, *Traitement des eaux usées par lagunage naturel en milieu désertique (oasis de Figuig): performances épuratoires et aspect phytoplanctonique*, Université Mohammed Premier, Oujda, Morocco, Thèse de Doctorat PhD, 2012.

[44] M. Djaafri, S. Kaloum, M. Khelafi et al., "Méthanisation des déchets organiques issus de la résidence universitaire de l'université Africaine de la ville d'Adrar Sud-Ouest de l'Algérie," *Journal of Materials and Environmental Science*, vol. 5, no. 52, pp. 2484–2488, 2014.

[45] R. M. Carr, U. J. Blumenthal, and D. Duncan Mara, "Guidelines for the safe use of wastewater in agriculture revisiting WHO guidelines," *Water Science and Technology*, vol. 50, no. 2, pp. 31–38, 2004.

[46] M. Ebel, M. W. H. Evangelou, and A. Schaeffer, "Cyanide phytoremediation by water hyacinths (Eichhornia crassipes)," *Chemosphere*, vol. 66, no. 5, pp. 816–823, 2007.

[47] Y. Y. Fang, X. E. Yang, H. Q. Chang, P. M. Pu, X. F. Ding, and Z. Rengel, "Phytoremediation of nitrogen polluted water using water hyacinth," *Journal of Plant Nutrition*, vol. 30, no. 11, pp. 1753–1765, 2007.

[48] M. A. Rahman and H. Hasegawa, "Aquatic Arsenic phytoremediation using floating macrophytes," *Chemosphere*, vol. 83, no. 5, pp. 633–646, 2011.

[49] M. Boutayeb, A. Bouzidia, and M. Fekhaoui, "Etude de la qualité physicochimique des eaux usées brutes de cinq villes de la région de la Chaouia – ouardigha (Maroc)," *Bulletin de l'Institut Scientifique. Rabat, section Sciences de la Vie*, vol. 34, no. 2, pp. 145–150, 2012.

[50] M. Benslimane, T. Mostephaoui, A. Hamimed, and Z. T. Cherif, "Performances épuratoires et intéret du procédé de phyto traitement des eaux usées par des végétaux macrophytes," *courier du savoir*, vol. 17, pp. 47–51, 2013.

[51] A. V. O. Akowanou, H. E. J. Deguenon, K. C. Balogoun, M. M. A. Daouda, and M. P. Aina, "The combined effect of three floating macrophytes in domestic wastewater treatment," *Scientific African*, vol. 20, pp. e01630–e02276, 2023.

[52] Y. Kim, W. J. Kim, P. G. Chung, and W. O. Pipes, "Control and separation of algae particles from WSP effluent by using floating aquatic plant root mats," *Water Science and Technology*, vol. 43, no. 11, pp. 315–322, 2001.

[53] Y. Kim and W. J. Kim, "Roles of water hyacinths and their roots for reducing algal concentration in the effluent from waste stabilization ponds," *Water Research*, vol. 34, no. 13, pp. 3285–3294, 2000.

[54] Minepded, "Normes Environnementales et Procédure d'Inspection des Installations Industrielles et Commerciales au Cameroun," 2005, https://docplayer.fr/922963-Normes-environnementales-et-procedure-d-inspection-des-installations-industrielles-et-commerciales-au-cameroun.html.

[55] N. Seghairi, L. Mimeche, M. Debabeche, and S. Khider, "Possibilités d'élimination des phosphates et de l'azote à partir des eaux usées domestiques en utilisant un filtre planté de papyrus," in *Proceedings of the The 4th International Congress Water, Waste & Environment (EDE4)*, pp. 46–50, Agadir, Morobco, December 2013.

[56] UNDL, "Guidelines on Environmental Inspection Systems for Mediterranean Region," *MAP technical reports series N°*, vol. 149, 2004.

[57] J. Jin, M. Wang, W. Lu et al., "Effect of plants and their root exudate on bacterial activities during rhizobacterium-plant remediation of phenol from water," *Environment International*, vol. 127, pp. 114–124, 2019.

[58] X. Li, Y. Li, and J. Wu, "Different in root exudates and rhizosphere microorganisms effect on nitrogen removal between three emergent aquatic plants in surface flow constructed wetlands," *Chemosphere*, vol. 337, Article ID 139422, 2023.

[59] J. Mounjid, N. Cohen, S. Fadlaoui, A. Belhouari, and S. Oubraim, "Contribution à l'évaluation de la qualité physicochimique du cours d'eau merzeg (périurbain de Casablanca, Maroc)," *Larhyss Journal*, vol. 18, pp. 31–51, 2014.

[60] J. Hürlimann and P. Niederhauser, *Méthodes d'analyse et d'appréciation des cours d'eau. Diatomées Niveau R (région). État de l'environnement n° 0740*, Office fédéral de l'environnement, Berne, Switzerland, 2007.

[61] M. P. Zhang, J. C. Huang, S. S. Sun, M. M. Ur Rehman, S. B. He, and W. L. Zhou, "Dissimilatory nitrate reduction processes and corresponding nitrogen loss in tidal flow constructed wetlands," *Journal of Cleaner Production*, vol. 295, Article ID 126429, 2021.

[62] J. Wang, Y. Long, G. Yu et al., "A review on microorganisms in constructed wetlands for typical pollutant removal: species, function, and diversity," *Frontiers in Microbiology*, vol. 13, Article ID 845725, 2022.

[63] G. S. Colares, N. Dell'Osbel, P. G. Wiesel et al., "Floating treatment wetlands: a review and bibliometric analysis," *The Science of the Total Environment*, vol. 714, no. 1, Article ID 136776, 2020.

[64] S. Karstens, M. Langer, H. Nyunoya et al., "Constructed floating wetlands made of natural materials as habitats in eutrophicated coastal lagoons in the Southern Baltic Sea," *Journal of Coastal Conservation*, vol. 25, no. 4, p. 44, 2021.

[65] O. Urbanc-Berćić and A. Gaberśćik, "The relationship of the processes in the rhizosphere of common reed Phragmites australis, (Cav.) Trin. Ex Steudel to water fluctuation," *International Review of Hydrobiology*, vol. 89, no. 5-6, pp. 500–507, 2004.

[66] M. F. Imron, A. A. F. Firdaus, Z. O. Flowerainsyah et al., "Phytotechnology for domestic wastewater treatment: performance of Pistia stratiotes in eradicating pollutants and future prospects," *Journal of Water Process Engineering*, vol. 51, pp. 103429–429, 2023.

[67] Q. Wang, J. W. Ding, H. J. Xie et al., "Phosphorus removal performance of microbial-enhanced constructed wetlands that treat saline wastewater," *Journal of Cleaner Production*, vol. 288, Article ID 125119, 2021.

[68] K. A. Merghem, H. El Halouani, A. A. Alnedhary et al., "Etude de l'impact des rejets d'eaux usées brutes et épurées sur la qualité de l'Oued Bani Houat (Bassin de Sanaa): etude spatio-temporelle," *Journal of Materials and Environmental Science*, vol. 7, no. 5, pp. 1516–1530, 2016.

[69] Y. Maiga, "Processus d'élimination d'Escherichia coli et des entérocoques des bassins de lagunage sous climat sahélien:

influence de la radiation solaire [Rapport]," Office fédéral de l'environnement OFEV, Ouagadougou, West Africa, Thèse de doctorat, 2010.

[70] O. Decamp and A. Warren, "Investigation of Escherichia coli removal in various designs of subsurface flow wetlands used for wastewater treatment," *Ecological Engineering*, vol. 14, no. 3, pp. 293–299, 2000.

[71] J. Nya, F. Brissaud, I. M. Kengne et al., "Traitement des eaux usées domestiques au Cameroun: performances épuratoires comparées du lagunage à macrophytes et du lagunage à microphytes," *Proceedings of International Symposium on Environmental Pollution Control and Waste Management*, vol. 15, pp. 726–736, 2002.

[72] L. Martin, T. Fonkou, T. E. Pamo, and A. Akoa, "Removal of faecal bacteria and nutrients from domestic wastewater in a horizontal surface flow wetland vegetated with echinochloa pyramidalis," *African Journal of Environmental Science and Technology*, vol. 6, no. 9, pp. 337–345, 2012.

[73] A. H. Maiga, Y. Konate, J. Wethe, K. Denyigba, D. Zoungrana, and L. Togola, "Performances épuratoires d'une filière de trois bassins en série de lagunage à microphytes sous climat sahélien cas de la station de traitement des eaux usées de 21E (groupe EIER- ETSHER)," *Revue des Sciences de l'Eau*, vol. 21, no. 4, pp. 399–411, 2008.

[74] A. Laabassi, *L'épuration des eaux usées par le système de lagunage à macrophyte*, Universite ferhat abbas setif, Sétif, Algeria, These de doctorat PhD, 2016.