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Wastewater Treatment Potentials of Vegetated Beds with *Brillantaisia cf. bauchiensis* Hutch & Dalz and *Polygonum salicifolium* Brouss ex Wild in the Western Highlands of Cameroon

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Abstract

The objective of this study was to evaluate the potentials of beds vegetated with medicinal species (*Brillantaisia bauchiensis* and *Polygonum salicifolium*) in a constructed wetland for domestic wastewater treatment in the Western Highlands of Cameroon. The study was carried out between March and September 2017 on plants collected from a natural wetland in Penka-Michel. The two plants species selected based on their ethnobotanical importance were transplanted and allowed to grow to maturity in a prepared natural wetland at Penka-Michel and a constructed wetland for domestic wastewater treatment on the campus of the University of Dschang. Growth parameters were followed for the two plants species in both wetlands. The physicochemical parameters and faecal bacteria concentrations were measured only for the vegetated and non-vegetated/control beds in the constructed wetland. Overall, the two plants species showed increased growth in height, diameter, leaf number and plants density. The change in diameter and density were very significantly influenced by species type in the constructed wetland than in the natural wetland. Generally, plant growth in height, diameter and density were higher with *B. bauchiensis* in the constructed wetland than with *P. salicifolium* in both wetlands. The mean faecal bacteria removal was higher in the vegetated beds for some bacteria than in the non-vegetated/control bed. There was a significant difference in the reduction efficiency of TSS, turbidity, BOD, Faecal streptococci and Total coliforms bacteria between the inflow and the outflow of some treatment beds especially the bed vegetated with *Brillan-*

taisia bauchiensis. There were correlations between the two plants species as concerns increased plants height, diameter, leave number, shoot number and nutrients uptake in the constructed wetland beds compared with the natural wetland.

Keywords

Wastewater, Vegetated Beds, Medicinal Macrophytes, *Brillantaisia bauchiensis* and *Polygonum salicifolium*

1. Introduction

The negative impact of the increase in world's population from 6 billion in 2013 to over 7.5 billion people in 2018 with Africa having about 1.3 billion and 24.054 million people in Cameroon directly affects the environment. It causes various adverse efffects on living organisms and an imbalance on the ecosystem affecting drinking water sources, biodiversity, health and reproduction of species [1] [2] [3].

Aquatic macrophytes are large water tolerant vascular plants visible to the naked eye and have at least their vegetative parts growing permanently or periodically in an aquatic habitat [4]. Wetlands are vital and most biologically diversed forms of ecosystems that are transitional between terrestrial and aquatic environments supporting predominantly hydrophytes [5] [6]. They serve as perennial sources of water, avenue for recreation, navigation, cattle grazing, resources for fuels, fodder, and habitat for wildlife. They harbour a huge number of medicinal plant species, and also are ecologically very important filters of pollutants in solving the pollution problem by using adapted macrophytes to improve the quality of the wastewater and run offs that they receive [7] [8] [9] [10]. Wetland macrophytes are naturally adapted to an anoxic and hypoxic stress conditions by making atmospheric oxygen available through aerenchyma tissues at the rhizosphere [11]. They are capable of stabilizing the substrate in constructed wetland (CW) by providing good condition for physical filtration and a huge surface bacteria growth and removal. Some wetland macrophytes like *Echinochloa pyramidalis*, *E. crus-pavonis*, *Fuirena umbellata* and *Leersia hexandra* amongst others have been tested for domestic wastewater treatment and these macrophytes under stress conditions of pollution produced high biomass in CW which can be valourised [12]-[17].

To avoid causing constant and perpetual disequilibrium in ecosystems, wastewater needs to be properly treated before discharge and CW technologies are used nowadays to mimic the natural wetlands for wastewater treatment purposes. They are designed as surface flow (SF) or sub-Surface flow (SSF) systems using emergent macrophytes and floating macrophytes as used in lagoons systems to remediate wastewater with several hydrological, biogeochemical and biological benefits. Hence, from a biogeochemical viewpoint, the main function of a CW is the temporary storage and/or removal of chemical substances such as total suspended solids (TSS), Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) as well as organic compounds (Phosphorus and Nitrogen) removal [18].

The high production and indiscriminate discharge of domestic wastewater from homes and agro-industries into natural wetlands without any treatment has contaminated wetlands and greatly affected the biodiversity in these important ecosystems and is a source of many diseases affecting humans [19] [20]. This problem can be solved using the ecotechnology of constructed wetland systems vegetated with wetland plants [21] [18]. This ecotechnology is environmentally friendly and the species used are unfortunately not transferable. Therefore, wetland macrophytes should be identified locally for ecological wastewater management. Some wetland macrophytes tested for this purpose proved to produce high biomasses with high remediation potentials [16] [13] [14] [15] but these were not wetland species of medicinal importance like *Brillantaisia bauchiensis* or *B. fulva* (Acanthaceae) and *Polygonum salicifolum* (Polygonaceae) used as food for welfare and healthcare in the Western Highlands of Cameroon [22].

It was in this light that this study was undertaken using the above mentioned wetland medicinal plants species to investigate their phytoremediation potentials of domestic wastewater in constructed wetlands.

2. Material and Methods

2.1. Location of the Experimental Setup

The experimental setup was a Yard-Scale natural wetland in Penka—Michel located at latitude 5˚27'43.1"N and longitude 10˚14'09.3"E and the constructed wetland for domestic wastewater treatment located on the Dschang University campus on latitude 5˚26'39.9"N and longitude 10˚04'18.3"E. The climate in this region is of equatorial type with 4 months of dry season between mid-November and mid-March, and 8 months of rainy season between mid-March and mid-November. Annual precipitations are estimated to range between 1433 mm and 2137 mm, while annual mean temperature is estimated at 20.8˚C with thermal amplitude of 2˚C.

2.2. Design of the Experimental Wetlands

The prepared natural wetland had a surface area of (4×2 m^2) while the constructed wetland comprised of a 3 m^3 digester, a distribution gutter (3 m^3) and three wetland beds (WB_1, WB_2 and WB_3) of volume ($4 \times 2 \times 0.6$ m^3). All these, were constructed using cement blocks filled with concrete and the insides of the structures were plastered with a mixture of concrete, then smoothen with cement (CIMENCAM) mixed Sikalite® and ZUM Abdichten™ was applied for water tightness. A slope of about 1% was respected at the bottom of each wetland bed to ease the flow of water from the inflow to the outflow. The constructed wetland beds were then connected to the distribution gutter by polyvinylchloride (PVC) pipes, each having a tap to control the flow rate and to ensure the continuous flow of wastewater into the wetland beds. The entire system was then linked by a PVC pipe to the deteriorated and abandoned conventional wastewater treatment system pre-existing, which served as the primary treatment system (Figure 1).

2.3. Design of the Constructed Wetland Bed System

Gabions of 30 cm made up of stones of 5 - 8 cm in diameter were arranged at the inflow and outflow zones of the wetland beds. The outflow structures are fitted to enable the regulation of water level in the wetland. The main filter substrate is a 45 cm thick column of sand having particle size of about 2 mm in diameter (Figure 2).

2.4. Choice of Local Macrophytes for Domestic Wastewater Treatment

Macrophytes used in constructed wetland beds are preferably annual herbs with erect stem. Hence, the chioce of the two macrophytes species was based on two broad criteria: physiology (Plant life form, plant lifecycle, stem type and cuticle thickness) and fedelity index (the citation of plant as medicinal by traditional practitioners) [22]. The following scale of preference was constructed with assigned values to sum upto 20 points (Table 1) which enabled the selection of the plants with the highest value. Therefore, the two plants were annual herbs with

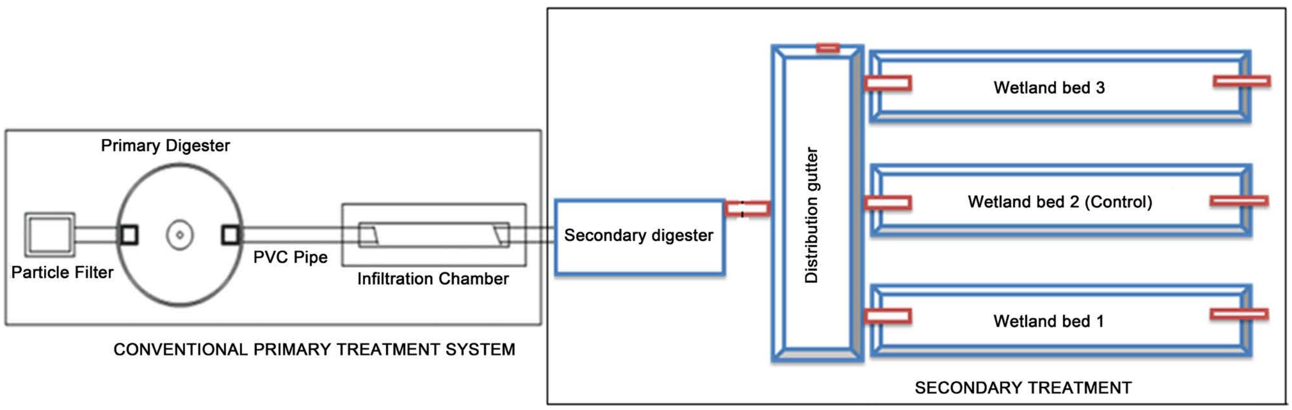


Figure 1. Layout of the experimental set up showing primary and secondary treatment systems.

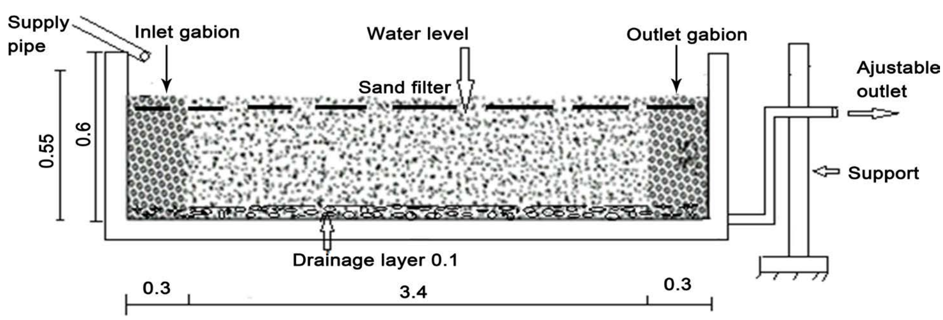


Figure 2. Longitudinal section of the wetland bed [13].

Table 1. Selection criteria of local macrophytes for phytoremediation in constructed wetlands.

Life form	Lifecycle	Type of stem	Stem and leaf thickness (Cuticle)	Fidelity level
				40% - 49% = 5
Herb = 4	Annual = 4	Erect stem = 4	Hard stem/leaf = 3	30% - 39% = 4
Shrub= 1	Biennal = 1	Criping stem = 2	Hard stem/soft leaf = 2	20% - 29% = 3
Tree = 0	Perennal = 0	Climbing stem = 0	Soft stem/soft leaf = 0	10% - 19% = 2
				0% - 9% = 1

erect stems, hard stem/leaf and high fidelity level (most cited as medicinal plants). Another criterion was very little material from Literature review about these plants.

From the above criteria, these two wetland macrophytes were selected with high values of 17/20 to be tested in the CW for domestic wastewater treatment.

1) *Brillantaisia cf. bauchiensis* Hutch. & Dalz. (Acanthaceae) 17/20

2) *Polygonum salicifolium* Brouss ex Wild. (Polygonaceae) 17/20

2.5. Source of the Wastewater Used in the Study

The domestic wastewater used in the study was a mixture of the grey and black type chennelled from the abandoned conventional treatment plant receiving domestic liquid wastes from the students' residence in campus of the University of Dschang at an inflow rate of about 3 m^3 per day.

2.6. Setting Up of the Experiment

Young shoots of the two plants species were obtained from a natural wetland in Penka-Michel sub-division (Menoua Division). These were transplanted in the natural wetland in Penka-Michel and in the constructed wetland station on campus A of the University of Dschang. In the constructed wetland station, the plantlets were transplanted in WB_1 and WB_3 at a density of 6 plants/m^2 as presented in Figure 3, using the "Rhizome Young shoot Method" (*i.e.* the young shoots may degenerate and the bud on the rhizome will give rise to a new shoots) in both wetlands. WB_2 was used as the non-vegetated/control bed throughout the experimental period.

The primarily treated effluent from the conventional plant was channelled into a secondary digester and then into a 10 m by 0.5 m by 0.6 m gutter from where a constant flow of the wastewater into the wetland beds was assured at a loading rate of about 35 Lm^{-2} day^{-1} with the help of a tap. This wastewater was allowed at this rate for one month to ensure the proliferation of microorganisms and the adaptation of macrophytes in the wetland beds. This step was the domestication phase after which the survival rate for each species was obtained as follows:

$$\text{Survival rate} = \frac{\text{Total number of shoots survived}}{\text{Total number of shoots planted}} \times 100$$

If any macrophyte species had less than 50% survival it was replanted. The surviving young plants (**Figure 4**) were allowed to grow and have standing vegetations considered to be having good biological activity. The effluent was then allowed to flow constantly into each wetland bed at a loading rate of about 85 Lm^{-2} day^{-1} in a horizontal subsurface flow (HSSF) design, for six consecutive months. The transplants in the natural environment received water from the surroundings throughout the experiment (**Figure 5**).

Figure 3. Transplanted macrophytes in the wetlands beds: *Brillantaisia bauchiensis* (a) and *Polygonum salicifolium* (b).

Figure 4. Standing vegetation in the wetland beds after two months of growth: *Brillantaisia bauchiensis* (a) and *Polygonum salicifolium* (b).

Figure 5. Standing vegetation in the natural wetland after two months of growth: *Brillantaisia bauchiensis* (a) and *Polygonum salicifolium* (b).

2.7. Measurement of Physicochemical Parameters of the Wastewater

The efficiencies of the wetlands in the water quality improvement were evaluated by measuring the physicochemical characteristics of the wastewater at the inflow and from the outflow of the wetlands. 500 ml of water sample were collected from the inflow and from the outflow of each wetland. These were analysed at the Research Unit of Applied Botany at the University of Dschang for four consecutive months. The parameters measured included the true colour, turbidity, total suspended solids (TSS), nitrates (NO_3^-), phosphates (PO_4^{3-}), chemical oxygen demand (COD) and five days biochemical oxygen demand (BOD_5). However, parameters such as electrical conductivity (CND) and total dissolved solids (TDS) were measured directly in the field. All these parameters were measured following the standard methods for water and wastewater analyses described and published by [23].

2.8. Evaluation of the Efficiency of the Wetlands

The nutrient removal efficiency (%) of each wetland bed for each parameter was evaluated from the inflow concentration following the formula below:

$$\text{Efficiency} = \frac{C_i - C_0}{C_i} \times 100$$

where, C_i and C_0 respectively represent inflow and outflow concentration of each parameters.

The densities of plants growing in the natural wetland and those in the CW vegetated beds were evaluated following the formula below:

$$\text{Density of plants in the bed} = \frac{\text{Number of shoots}}{\text{Surface Area}}$$

2.9. Water Sample Collection and Faecal Bacteria Analyses

Wastewater samples were collected four times in four consercutive months from the inflow and outflow of WB_1 (vegetated with *B. bauchiensis*), WB_2 (non-vegetated control) and WB_3 (vegetated with *P. salicifolum*), from May 2017 to August 2017. Sterile laboratory glass bottles of 500 ml volume each were used to collect water samples that were immediately transported in a cooler to the Research Unit of Applied Botany for analyses. In the laboratory, manipulations were carried out in strict conditions of sterility. In antiseptic conditions, 1 ml of homogenous raw sample was measured and added into 9 ml of sterile distilled water to have 1:10 dilution. This same operation was repeated from the first dilution until the desired dilution was obtained (1:10, 1:100, 1:1000, 1:10,000, etc.). The pipette was always rinsed between dilutions and a sterile new pipette was used for each sample to avoid contamination. Distilled water was sterilized by autoclaving in sealed sterile glass bottles for 15 minutes at 121˚C. Total coliforms, *Faecal coliforms* and Faecal streptococci were detected by membrane filtration following standard methods [24] [25]. AC Cellulose Membranes Filters™ with pore-size 0.45 µm were used on a WHEATON filtering Funnel™ attached to a CM 1500^{TM} vacuum pump.

Appropriate sample volumes, in three different dilutions (10^{-2}, 10^{-3} and 10^{-4}) for effluent or (10^{-3}, 10^{-4} and 10^{-5}) for influent were filtered and incubated for each parameter. This was to ensure having at least a plate with colony counts ranging between 20 to 100 CFU. Samples for *Faecal coliforms* were incubated on Difco^{TM} m FC prepared Agar in Petri dishes at 44.5˚C for 24 hrs [26] [27]. Thereafter, all characteristically blue and central white hollowed blue colonies were counted as *Faecal coliforms*.

Samples for Faecal streptococci and Total coliforms were respectively incubated on BBL^{TM} Bile Esculin and Tergitol$^{®}$ 7 Agars at 35˚C for 48 hrs [26]. Thereafter all characteristically black and yellow colonies were respectively counted for Faecal streptococci and Total coliforms. Each result was expressed as number of Colony Forming Units per 100 ml (CFU/100 ml) of sample.

2.10. Statistical Analysis

Data were managed using Microsoft Excel and the software R, version 3.0.1 (R Core Team, 2013). Results at 95% probability level were considered significant. The plants height and diameter were examined for normality using the Shapiro-Wilk normality test. When they were found to be normally distributed, Analysis of variance (ANOVA) with the "summary.lm" function and two classificatory factors (species and wetland) were used to test whether there were significant differences between the means of parameters in the same site or between parameters in the same species in different sites. The distribution of counts of plant leaves (OR plant density) in relation to species (*P. salicifolium* and *B. bauchiensis*), wetland (constructed and natural) and the interaction between the two factors was modelled using log-linear Poisson, with time (every two weeks) serving as covariates.

A one-way ANOVA with the "summary.lm" function was used to verify the existence of significant differences in the means of physico-chemical parameters (electrical conductivity, TDS, TSS, turbidity, colour, BOD, COD, NO_3^- and PO_4^{3-}) and bacteriological parameters (*Faecal coliforms*, Faecal streptococci, Total coliforms and *E. coli*) between the inflow and the outflow wetland beds and between the outflows of the wetland beds.

$$\text{Model 1: Leaf number} \sim \text{Species} * \text{Site} + \text{Time}$$

$$\text{Model 2 : Bactria counts}\left(\text{log units}\right) \sim \text{treatment bed} * \text{Time}$$

3. Results and Discussion

After one month of adaptation in the natural wetland, all the 45 plantlets of both plants species survived in the natural wetland while all 45 survived for *Polygonum salicifolium* and 43 for *Brillantaisia bauchiensis* survived after one month of domestication in the constructed wetland for wastewater treatment.

3.1. Variation in the Plants Height

In the natural wetland, both plants gradually adapted in their new site and steadily grew from an average height of 30.58 cm to 99.49 cm at the end of the experiment with a relative growth rate of 0.055 cm/cm/day for *Polygonum salicifolium*. The tallest plant here was 140 cm. *Brillantaisia bauchiensis* also grew from an average height of 15.07 cm to 60.03 cm with a relative growth rate of 0.034 cm/cm/day, the tallest plant here measuring 79 cm. In the CW, both plants gradually acclimatized in their new environment and *Polygonum salicifolium* steadily grew from an average height of 28.55 cm to 99.53 cm with a relative growth rate of 0.055 cm/cm/day and the tallest plant being 203 cm. *Brillantaisia bauchiensis* as well grew from an average height of 11.6 cm to 114.53 cm with a relative growth rate of 0.064 cm/cm/day and the tallest plants here being 165 cm. These results show that the two plants species grew taller in the constructed wetland than in the natural wetland. These are comparable to those of [16] who showed that plants grew taller in the CW. The analysis of variance with two classification factors showed significant height change with time index of two weeks for the two plant species in the wastewater treatment station ($P < 0.05$). **Table 2** shows the height change with time index of two weeks for the two plant species in relation to wetland type.

The growth in height of *P. salicifolium* in the natural wetland was significantly different from that of *Brillantaisia bauchiensis* as indicated by the intercept effect in **Table 2** while that of *Brillantaisia bauchiensis* in the CW was significantly different from of *P. salicifolium* in the constructed wetland (**Table 2** and **Figure 6**). The effect of the two factors (wetland and species type), was significant for *B. bauchiensis* as concerns the mean increase in height of the plant $\left(\hat{\beta} = 6.121 \pm 2.583, P = 0.023\right)$. For both plants, the growth in height was greatest for *B. bauchiensis* in the constructed wetland (10.26 ± 2.583) as shown on the lattice plot (**Figure 6**) and confirmed in the model output (**Table 2**).

3.2. Variation in Plants Diameter

The diameter of *Polygonum salicifolium* in the natural wetland increased from an average of 3.063 to 7.1 mm giving a relative increase of 0.004 mm/mm/day with the largest plant having a diameter of 15.78 mm. *Brillantaisia bauchiensis* increased from 3.82 to 11.51 mm with a relative increase of 0.0064 mm/mm/day and the thickest plant having a diameter of 17.76 mm. The diameter of *Polygonum*

Table 2. Increase in the mean height of *Polygonum salicifolium* and *Brillantaisia bauchiensis* (ANOVA).

Model effects	Estimates	Standard errors	t-values
Intercept	7.286	1.292	5.641***
Natural wetland	−2.790	1.827	−0.195
Constructed wetland	−0.356	1.827	−0.195
B. bauchiensis vs Treatment site	6.121	2.583	2.369*

* shows the level of significance at probability level of 5%. The intercept is the effect of *P. salicifolium* and natural wetland combined.

salicifolium in the CW increased from 4.22 to 9.1 mm with a relative increase of 0.0051 mm/mm/day and the thickest plant having a diameter of 12.01 mm. *Brillantaisia bauchiensis* averagely increased from 3.34 to 20.15 mm with a relative increase of 0.011 mm/mm/day and the thickest plant having a diameter of 29.61 mm. These results equally show that the two plants species grew thicker in the constructed wetland than in the natural wetland. The changes in the diameter of a plant in the different habitats are summarised in **Table 3**.

The increase in diameter of *Brillantaisia bauchiensis* in the Constructed wetland was significantly different from that *P. salicifolium* in the constructed wetland as indicated by the intercept effect in **Table 3**. *Brillantaisia bauchiensis* in the natural was significantly different from *P. salicifolium* in the natural wetland (**Table 3** and **Figure 7**). The change in plant diameter was highly influenced by species type and wetland $\left(\hat{\beta} = 0.894 \pm 0.269, P = 0.002\right)$. In particular, the change

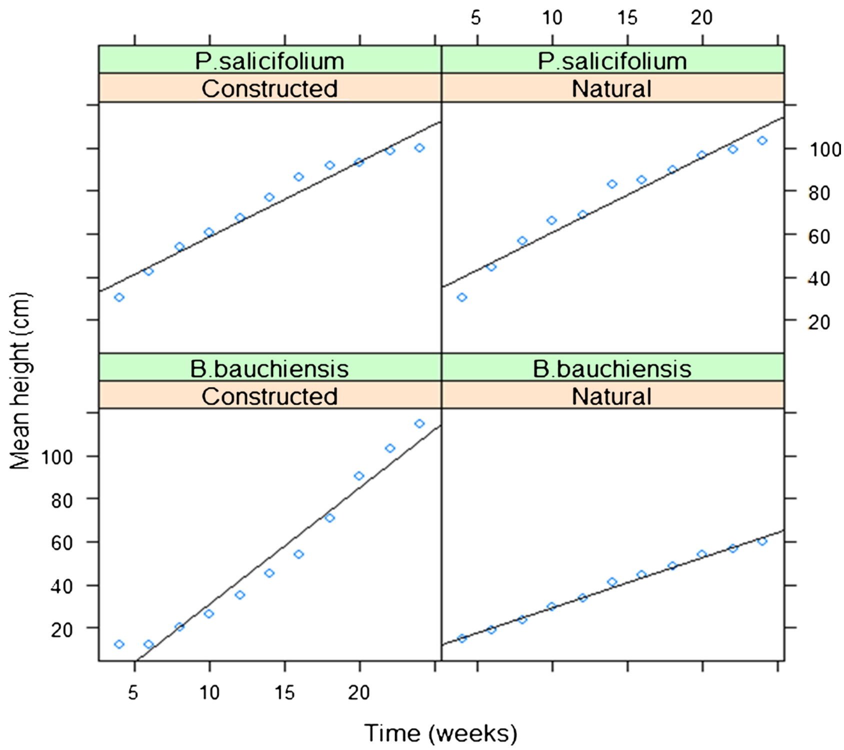


Figure 6. Variation in plant height with time in relation to the plants species and wetland.

Table 3. Changes in the mean diameter of *Polygonum salicifolium* and *Brillantaisia bauchiensis* in the different habitats (ANOVA).

Model effects	Estimates	Standard errors	t-values
Intercept	0.469	0.135	3.484**
Natural Wetland	0.295	0.190	1.550
Constructed Wetland	0.019	0.190	0.100
B. bauchiensis vs Constructed Wetland	0.894	0.269	3.321**

** shows significance at probability level of 1%. The intercept is the effect of *P. salicifolium* and natural wetland combined.

in plant diameter was highest with *B. bauchiensis* in the constructed wetland $(1.677 \pm 0.269, \mathrm{N} = 45)$ compared to other species-habitat interactions, as evidenced in Figure 7.

3.3. Leaves Production

Table 4 shows the difference in leave production between the two plant species from the natural and constructed wetlands.

There was no interaction between species and wetland type in predicting leaf production. *P. salicifolium* in the CW showed a constant trend in leaf production, the natural wetland witnessed rather a fall in leaf production. Overall, *B. bauchiensis* had the minimum leaf production irrespective of the wetland where it was grown $\left(\hat{\beta} = -0.669 \pm 0.120, P < 0.001\right)$ as shown in Table 4 and Figure 8 though with fewer number of leaves, its leaf length and width was by far longer and larger in the CW than in the natural wetland.

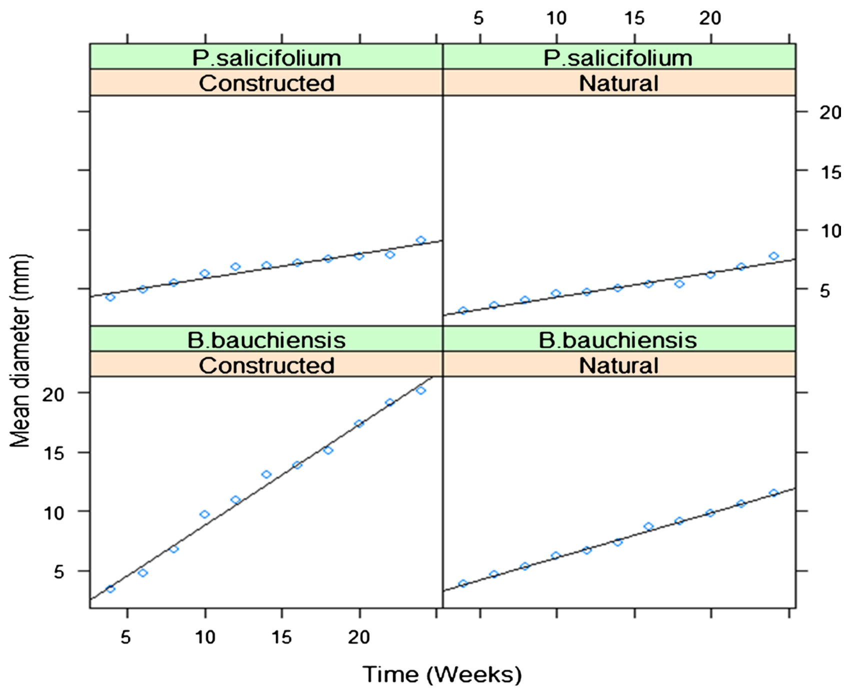


Figure 7. Changes in diameter of the two plant species in the constructed and in the natural wetland.

Table 4. Log-linear Poisson model for the number leaves produced

Model effects	Estimates	Standard errors	Z-values
Intercept	2.943	0.113	26.491***
Natural wetland	−0.669	0.120	−5.575***
Constructed wetland	−0.000	0.988	0.000
Time	−0.005	0.006	−0.705
B. bauchiensis vs Treatment site	−0.112	0.173	−0.640

*** shows significance at probability level of 0.1%. The intercept is the effect of *P. salicifolium* and natural wetland combined.

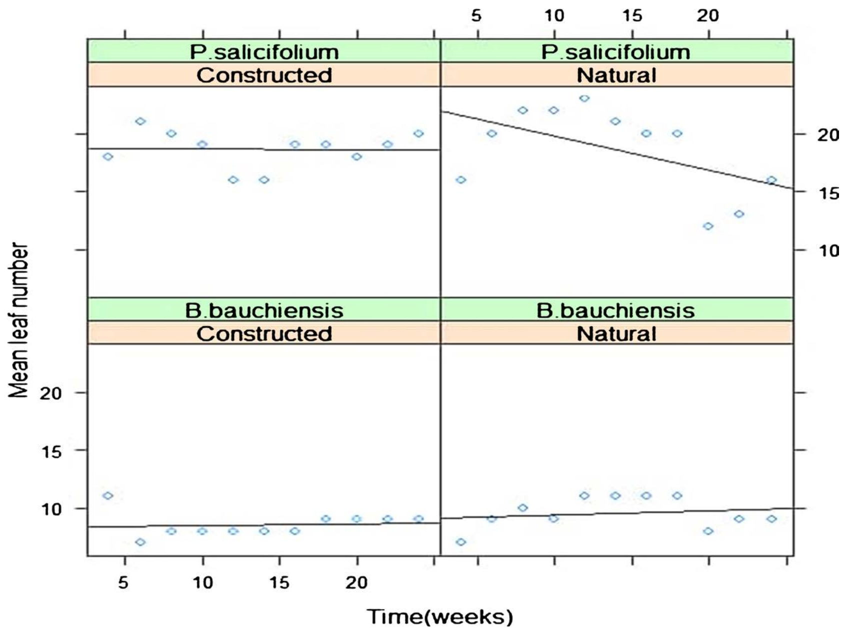


Figure 8. Mean number of leaves produced by *P. salicifolium* and *B. bauchiensis* in the constructed and natural wetlands.

3.4. Shoot Production and Plants Density

In the natural wetland, the density of *Polygonum salicifolium* increased from 6 plants/m^2 at the start of the experiment in March to 7 plants/m^2 during the domestication phase, to 21 plants/m^2 at the end of the experiment while that of *Brillantaisia bauchiensis* increased from 6 plants/m^2 to 9 plants/m^2 during the domestication phase, to 62 plants/m^2 at the end of the experiment. The plant density of *Polygonum salicifolium* in the CW increased from 6 plants/m^2 at the start of the experiment to 15 plants/m^2 during the domestication phase, to 49 plants/m^2 at the end of the experiment. As for *Brillantaisia bauchiensis*, its density increased from 6 plants/m^2 to 20 plants/m^2 during the domestication phase, and finally to 214 plants/m^2 at the end of the experiment in the month of September. The young shoots which arose from both plants species in the wastewater treatment beds grew rapidly without any inconveniency and covered the entire respective beds with time.

Shoot production by the two plants species in response to natural and artificial habitats is summarised in **Table 5**.

Figure 9 shows an overall high density of the two plants in the constructed wetland than in the natural wetland $\left(\hat{\beta} = 0.875 \pm 0.119, P < 0.001\right)$. In association with wetland type, the density of *B. bauchiensis* was highest in the constructed wetland $\left(\hat{\beta} = 0.678 \pm 0.136, P < 0.001\right)$ compared to the effect of the intercept (**Figure 9**). Moreover, there was a general increase in the density with time $\left(\hat{\beta} = 0.083 \pm 0.004, P < 0.001\right)$ but this was more perceptible for *B. bauchiensis* in the constructed wetland (**Figure 9**).

The growth parameters increased very slowly during the domestication phase as the plants were still struggling to adapt in their new but more polluted environment

Table 5. Log-linear Poisson model for the density of plants

Model effects	Estimates	Standard errors	Z-values
Intercept	0.916	0.119	7.652***
Natural wetland	1.061	0.116	9.147***
Constructed wetland	0.875	0.119	7.355***
B. bauchiensis vs Constructed	0.678	0.136	5.000***
Time (Weeks)	0.083	0.004	21.583***

*** shows significance at probability level of 1%. The intercept is the effect of *P. salicifolium* and natural wetland combined.

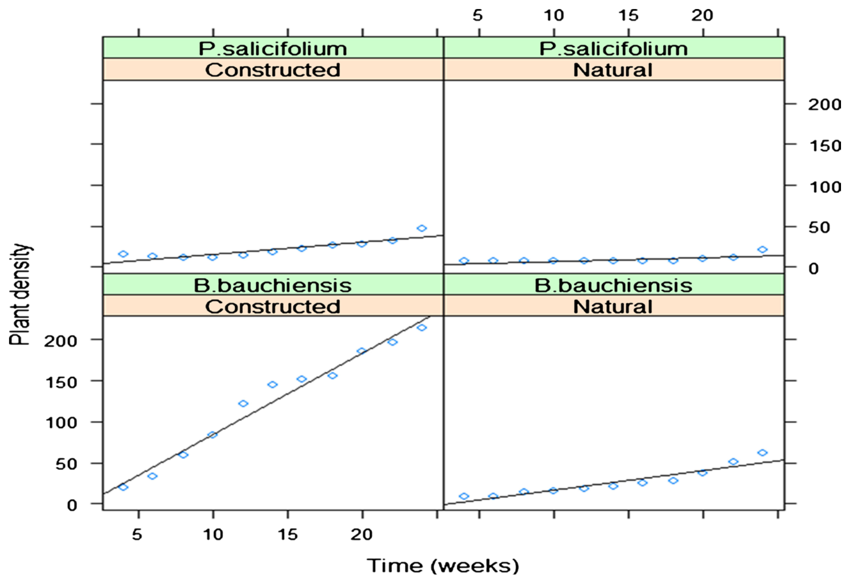


Figure 9. Plants density in the constructed and natural wetlands during the experimental period.

at the start of the experiments in March (during the dry.season). This slow growth might have been due to the fact that the experiment was started in the dry season with the plants receiving more concentrated wastewater with mineralized pollution. The plants grew rapidly with the coming of the rainy season with the highest growth registered within the last weeks of the study when the wastewater was more diluted with constant rain fall [14] [15] [16] [28] [29]. However, some plants especially those closer to the gabions at the inlet showed a stunted growth probably due to the high concentration of wastewater at the inlet during the dry season. This linear growth in growth parameters was also observed by [14] [15] using *Echinochloa crus-pavonis* and *Fuirena umbellata* respectively.

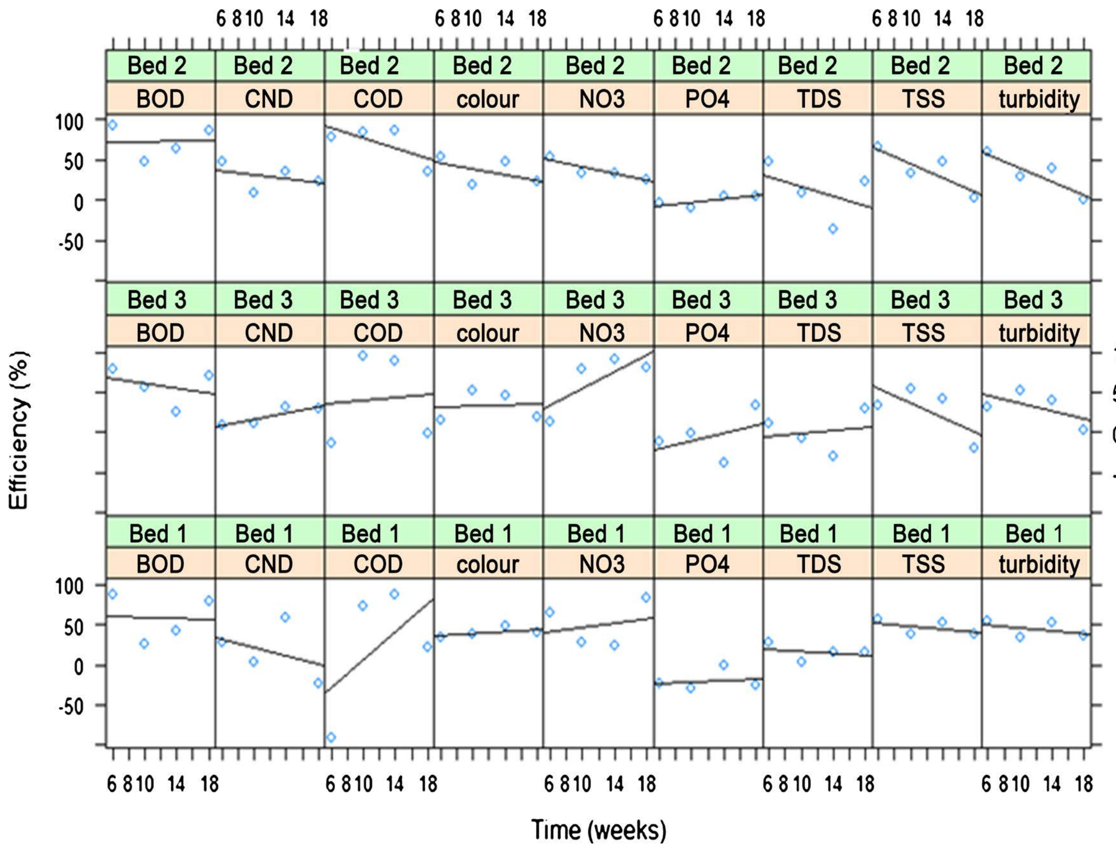
Wastewater is rich in nutrients that enrich and nourish the soil. Plants growing in wastewater constructed environment make use of these nutrients for their growth and development [15] [17]. The plants species in the CW showed increase in plants height and diameter has a function of the rich nitrate and phosphate habitat that the plants absorded for its metabolism. Hence, plants heights and diameters increased in the wastewater treatement station than in the natural wetland evidently due to the high uptake of nitrate and phosphate compounds in the wastewater [30]. Nevertheless, there was more phosphate in the outflow effluent than in the inflow of the beds indicating that aerobic and anaerobic breakdown of organic matter occurred in the treatment beds such that reduction efficiency had negative values. Moreover, since there was no significant difference between the inflow and outflow in nutrient reduction, these could be as a result of more aerobic breakdown of the organic matter in the presence of oxygen released at rhizosphere in the vegetated beds and anaerobic breakdown and filtration time in both the vegetated and non vegetated beds [13] [31]. A high concentration of phosphorus in the outflow wetland bed vegetated with *Brillantaisia bauchiensis* than the inflow was prove that more breakdowns occurred in the beds. The relatively large and numerous roots of the *Brillantaisia bauchiensis* plant species probably provided more oxygen for aerobic breakdown at the root level. It is observed that more biodegradation of organic matter occurred in the wetland treatment beds such that the amount of phosphate in the outflow was more than the inflow especially in the treatment bed vegetated with *Brilantaisia bauchiensis* followed by the bed with *Polygonum salicifolium*. The high growth and the linear growth of these plants in the wastewater treatment station is probably due to the availability of nutrients particularly Nitrogen and phosphorus present in the water which probably resulted from the transformations of nitrates and phosphates since these compounds were abundantly available in the wastewater but were removed more in the vegetated beds than in the control [14] [15]. It is evident that the presence of wastewater significantly increased growth of shoots and plant density in CW [15] [32]. The high growth of *Brilantaisia bauchiensis* in the CW was probably due to large surface area exposed for maximum sun light and an intimate relationship between growth of the plant and chlorophyll content as wastewater contains nutrients that promote growth in the number of green leaves and leaf area per plant [33]. The large leaves provide leaf protein for the plant growth which could be extracted or used for food and feed purposes [34] because phytochemicals are naturally occurring substances found in fruits, vegetables and grains [35] that enable the plants to overcome stress [36] [37] [38]. Wastewater or sewage water and sewage sludge is used nowadays to improve physical, chemical properties and fertility index of soil in order to increase production per unit area [39]. The increase in plants growth, shoot production and high density corroborates other studies which stated that residual effect of sewage or sewage sludge applications increased significantly the plant height, fresh weight, grain yield, leaf area, leaf biomass, chlorophyll content and Oxygen evolution as well as total soluble sugars and sucrose content [40] [41] [42].

3.5. Efficiencies of Constructed Wetland Beds in the Removal of Physicochemical Characteristics

Figure 10 shows the variations in the removal efficiencies of the some physicochemical parameters with time in the treatment beds. Electrical conductivity

(CND) was generally higher at the inflow (2738 µS/cm) than at the outflow of the wastewater treatment beds ranging between 1885 to 2325 µS/cm. The CND at the outflow of the vegetated beds with *Brillantaisia bauchiensis* (2215 µS/cm) and *Polygonum salicifolium* (2325 µS/cm) were higher than the outflow of the control bed (1885 µS/cm) corresponding to the mean reduction efficiency of 16.24% and 15.93% comparatively lower than the control bed of 28.64%. There were no significant differences at ($P = 0.05$) between the inflow and outflows of the respective beds and between the outflows of the vegetated and non-vegetated control beds. Conductivity and total dissolved solids were higher in the control bed than in the vegetated beds though not significant. This was normal because the macrophytes absorbed the nitrates and orthophosphates for their biochemical synthesis and reduce the conductivity and the amount of total dissolved solids. However, the fact that there was no significant difference showed that there was more aerobic breakdown of the wastewater and release of mineralized pollution as the oxygen at the rhizosphere by the plant roots [15].

The total suspended solids (TSS) at the outflows of the treatment beds varied between 133 and 153.5 mg/l compared to the inflow (243.3 mg/l). Total suspended solids were significantly reduced in the outflows of the treatment beds



Bed 1 = Bed planted with *Brillantaisia bauchiensis*; Bed 2 = Control/Non-vegetated bed; Bed 3 = Bed planted with *Polygonum salicifolium*; BOD = Biochemical Oxygen Demand, COD = Chemical Oxygen Demand, CND = Eectrical Conductivity, TDS = Total Dissolved Solids, TSS = Total Suspended Solids, NO_3^- = Nitrates, PO_4^{3-} = Phosphates.

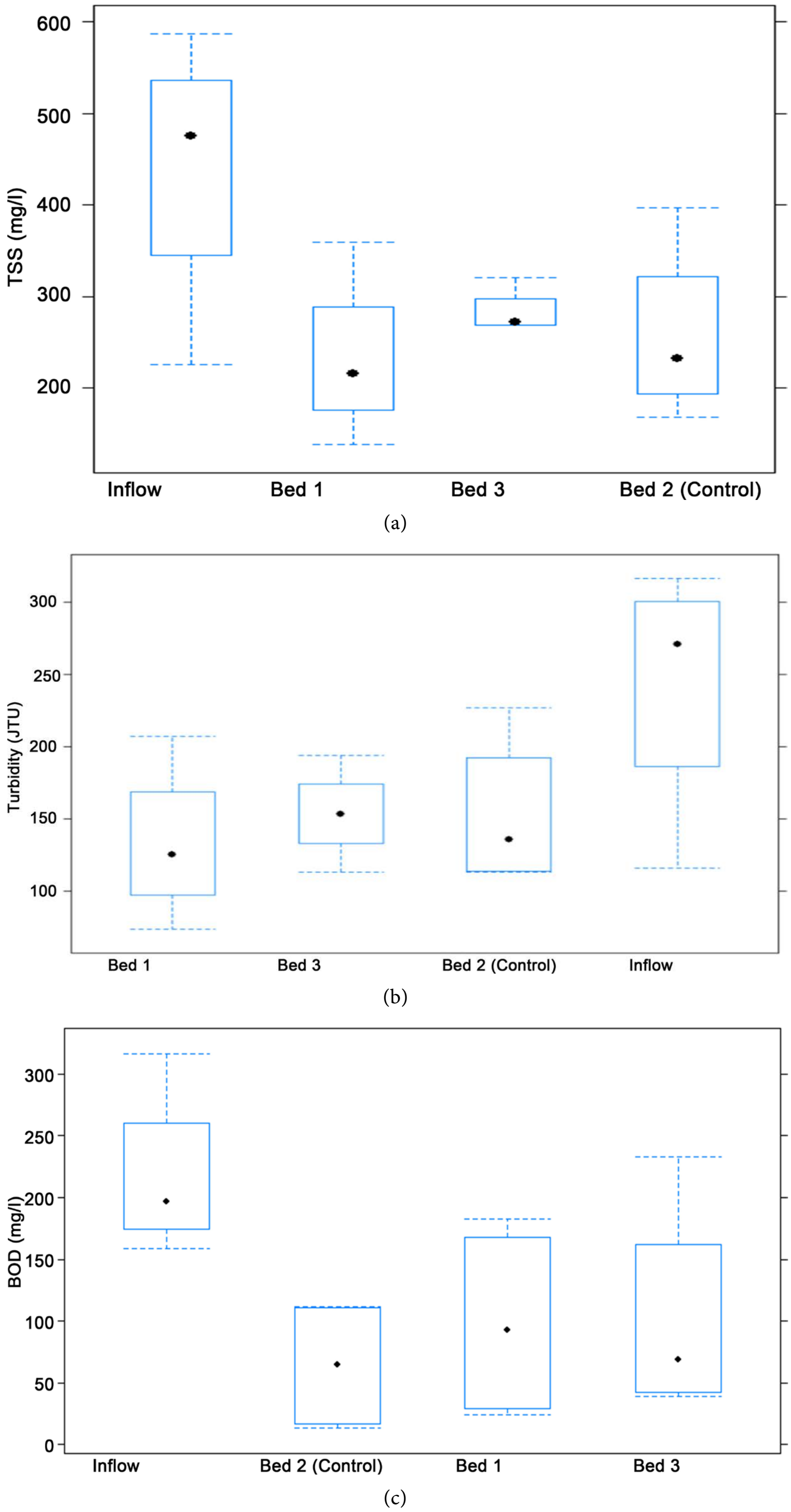
Figure 10. Removal efficiency in physicochemical parameters at the outflow of treatment beds.

compared to the inflow. However, the reduction was higher (46%) in filter bed vegetated with *Brillantaisia bauchiensis* $\left(\hat{\beta} = -208.50 \pm 72.77, P < 0.01\right)$ followed by that vegetated with *Polygonum salicifolium* 43.08%. Although the TSS concentration at the ouflow of the control bed was significantly lower than the inflow (**Figure 11(a)**), this value was still higher than the minimum required value of 50 mg/l for wastewater discharge [43] [44].

The turbidity values at the outflow of all the beds ranged between 232 and 283.3 FTU but were not significantly lower than the inflow value of 440.5 FTU except for the bed vegetated with *Brillantaisia bauchiensis* $\left(\hat{\beta} = -110.25 \pm 42.97, P < 0.02\right)$ with turbidity value of 232 FTU corresponding to reduction efficiency of 44.46% (**Figure 11(b)**). On the other hand, the true colour of the domestic wastewater was clearer in the bed vegetated with *Brillantaisia bauchiensis* (521.8 PtCo) with a percentage reduction of 39.82% higher than the control bed (544.3 PtCo) and the bed vegetated with *Polygonum salicifolium* (562.3 PtCo) having percentage reduction of 35.28% and 33.22% respectively.

The COD of the non vegetated control bed was lower (87 mg/l) than those of the vegetated beds (193.3 and 273.5 mg/l) which were still lower than the COD value at the inflow (297.8 mg/l). The percentage reduction efficiency was however higher in the control bed (70.64%) than in the vegetated beds (22.92% and 41.92%). However, the outflow of the vegetated beds had higher COD than the inflow so that the efficiency of reduction was negative rather. The BOD values of the outflow of the treatment beds ranging between 63.75 mg/l and 102.4 mg/l generally lower than the mean BOD at the inflow of the beds. The non-vegetated/control bed had the lowest mean BOD value of 63.75 mg/l corresponding to 72.79% reduction efficiency $\left(\hat{\beta} = -153.5 \pm 52.78, P < 0.01\right)$ while the bed vegetated with *Brillantaisia bauchiensis* followed with a mean BOD value of 98.3 mg/l with a reduction efficiency of 58.37% $\left(\hat{\beta} = -118.95 \pm 52.78, P < 0.04\right)$ lower than the guideline value of 100 mg/l [43] [44] (**Figure 11(c)**). The bed vegetated with *Polygonum salicifolum* had a mean reduction of 102.4 mg/l corresponding to a reduction efficiency of 57.98%. The wetland bed vegetated with *Brillantaisia bauchiensis* was more performant in the reduction of total suspended solids, turbidity, and BOD than the bed with *Polygonum salicifolium* probably due to its large leaves and size that provided a large surface area for photosynthesis to release more oxygen into the beds at the root zones through the relatively large and numerous roots [15]. The significantly high reduction efficiency of total suspended solids, turbidity and BOD in the vegetated beds than the control bed showed that the plant rhizome and root zones are capable of filtering and absorbing substances in wastewater [15] [31] [45].

The reduction of nitrate in the effluent at the outflow of treatment beds was between 1.85 mg/l and 2.45 mg/l, lower than the inflow value of 4.1 mg/l. The wetland bed vegetated with *Polygonum salicifolum* had the best removal percentage of 65.66% followed by the wetland bed vegetated with *Brilantaisia bauchiensis* (49.85%) while the non vegetated bed was the least (36.53%). There



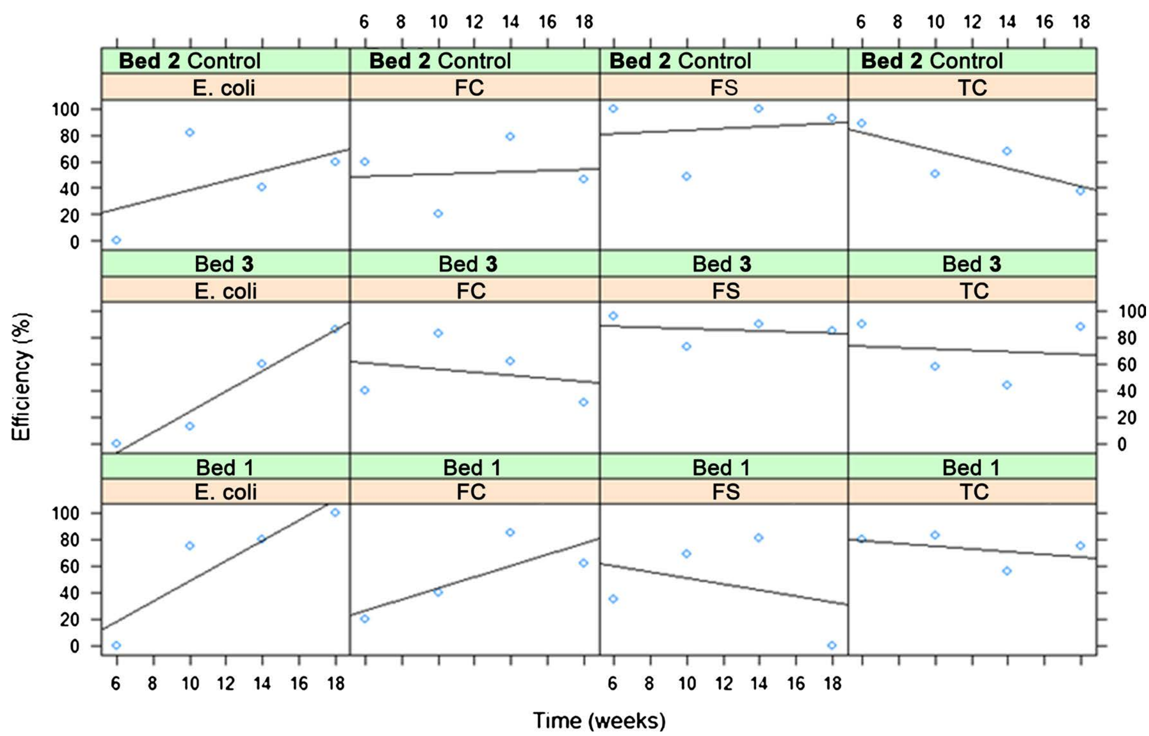
Significant difference at probability level of 5%, n = 4; Bed 1 = Bed planted with *Brillantaisia bauchiensis*; Bed 2 = Control/Non-vegetated bed; Bed 3 = Bed planted with *Polygonum salicifolium.*

Figure 11. Median removal efficiency of physicochemical parameters at the inflow and outflow of treatment beds (a) Total suspended solids (TSS) (b) Turbidity (c) Biochemical Oxygen Demand (BOD).

were no significant differences in the mean phosphate concentration between the inflow 6.218 mg/l and the outflows of the treatment beds were not significantly different with each other: *Brillantasia* bauchiensis (7.618 mg/l), non-vegetated/control bed (6.023 mg/l) and *Polygonum salicifolium* (5.243 mg/l). The control bed had the highest reduction efficiency (−1.16%) followed by the bed with *Polygonum salicifolium* (−4.45%) and then the bed vegetated with *Brillantaisia bauchiensis* (−20.16%). These results differ from those of [13] [15] who obtained nitrates and orthophosphates removal of 62% and above in the vegetated beds. The phosphate concentration in the outflow of the treatment beds was more than the concentration in the inflow giving negative removal efficiencies. These showed that there was more retention time and more biodegradation in the treatment beds to produce more orthophosphates than in the inflow despite the fact that the plants absorbed some for their metabolisms to produce more new shoots produce more new shoots, much still remained in the wastewater. The symbiotic relationship between plant roots and substrates stabilizes the substrates in the beds and provides the surface area for clogging of bacteria multiplication and biodegradation of more phosphates [17].

3.6. Efficiencies of Constructed Wetland Beds in the Removal of Bio-Indicators of Faecal Contamination from Domestic Wastewater

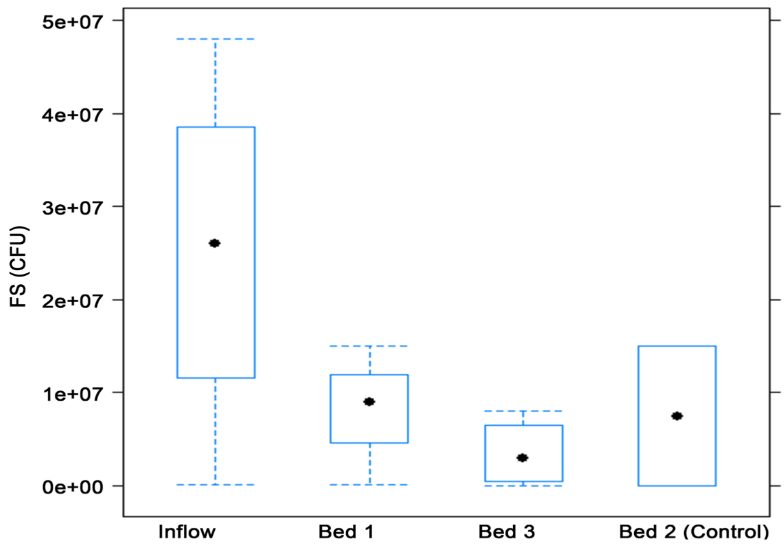
Figure 12 presents the faecal bacteria removal efficiencies in the treatment beds with time. The vegetated beds showed high percentage removal of Total coliforms



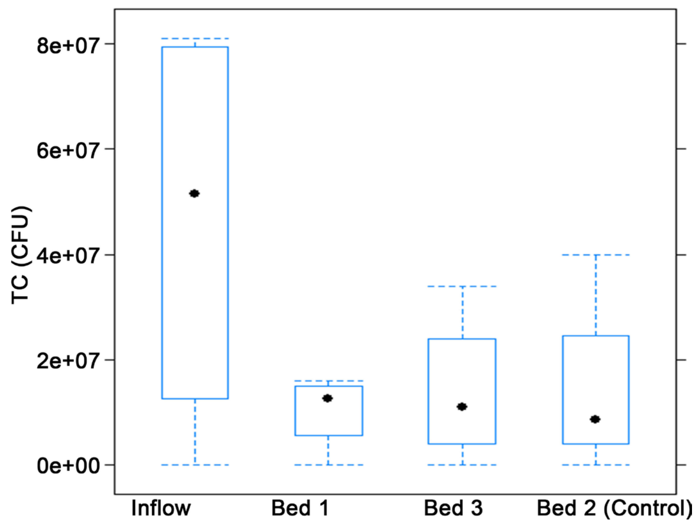
E. coli = *Escherichia coli*, FC = *Faecal coliforms*, FS = Faecal streptococci, TC = Total coliforms.

Figure 12. Faecal bacteria removal efficiency at the outflow of treatment beds.

(69.82% - 73.3%) than the control bed (61.14%). Generally, there was reduction of faecal bacteria from the effluent in the outflow of the treatment beds compared to the log concentration number in the inflow effluent. There was a significant difference in the log units of faecal bacteria concentrations between the inflow and outflow of the treatment bed vegetated with *Polygonum salicifolium* in bed 3 $\left(\hat{\beta}=-2.15\pm 84, P<0.01\right)$ in Faecal streptococci removal (Figure 13(a)) and the bed vegetated with *Brillantaisia bauchiensis* in bed 1 in $\left(\hat{\beta}=-3.16\pm 16, P<0.05\right)$ Total coliforms removal (Figure 13(b)). The vegetated wetland beds showed high efficiencies in faecal bacteria removal which



(a)



(b)

Significant difference at probability level of 5%, n = 4; Bed 1 = Bed planted with *Brillantaisia bauchiensis*; Bed 2 = Control/Non-vegetated bed; Bed 3 = Bed planted with *Polygonum salicifolium*; FC = *Faecal coliforms*, Faecal streptococci, TC = Total coliforms, EC = *E. coli*; CFU = Colony forming units.

Figure 13. Removal efficiency faecal bacteria at the outflow of treatment beds compared to the inflow (a) Faecal streptococci (b) Total coliforms.

were significant for Faecal streptococci and total coliforms compared to the inflow. There was no significant difference for the other treatment beds in *Faecal coliforms* bacteria. The bed vegetated with *Brillantaisia bauchiensis* was more efficient in *E. coli* removal (85%) and in Total coliforms (73.3%) than the other beds. These results corroborate those of [13] [15]. The wetland bed vegetated with *Polygonum salicifolium* removed more Faecal streptococci (85.57%) comparable to the non vegetated control bed (85.15%). The roots of *P. salicifolium* may be producing substances that not favour the proliferation of these bacteria while the non-vegetated bed creates an anaerobic condition that does not favour its growth. Total coliforms and *E. coli* were reduced more in the *Brillantaisia bauchiensis* bed than in the control bed and bed vegetated with *P. saliciflolium* while Faecal streptococci were more reduced in the bed vegetated with *P. salicifolium* and non-vegetated control bed. The reduction in *Brillantaisia bauchiensis* bed could be as a result of the massive root system of this plant species and probably the presence of oxygen at the rhizosphere or the release of some chemicals by the plant roots that may not favour the survival of these bacteria [15]. High removal efficiency of Faecal streptococci and Total coliforms in the vegetated bed than the control, and *Faecal coliforms* in non-vegetated/control bed than the vegetated beds was also observed. These high removal efficiencies observed in the vegetated beds could be as a result of the interaction between the sand substrate and root of the plants or the production of antibiotic properties by the roots of these plants that reduce or eliminate these bacteria [13] [14] [15].

4. Conclusions

The objective of this study was to evaluate the growth and wastewater treatment potentials of *Brillantaisia bauchiensis* and *Polygonum salicifolium* in vegetated beds. Overall, it was shown that both plants species increased in growth parameters in both wetlands but *B. bauchiensis* in the constructed wetland was significantly higher than *B. bauchiensis* in the natural wetland and *P. salicifolium* from both wetlands. Moreover, *B. bauchiensis* from the constructed wetland was more proficient in shoot/biomass production than *P. salicifolium* and there was a correlation between increased height, diameter, leave and shoot production by the plants species in the constructed wetland treatment station with respect to nutrient uptake. Even though the plants grew rapidly after the domestication period, there was not relationship between plant growth rate and its purification efficiency.

As concerns the phytoremediation potentials of the two plant species, the mean faecal bacterial removal was higher in the vegetated (treatment) beds for some faecal bacteria than in the non-vegetated control bed. There was a significant difference in the mean reduction efficiency of TSS and BOD at the outflow in all the beds compared to the inflow but the percentage reduction was higher in the vegetated beds. The bed vegetated with *Brillantaisia bauchiensis* performed better than the bed with *Polygonum salicifolium* in faecal bacterial reduction. Despite the variability of the characteristics of the primarily treated water, the plants grow best in the CW showing its great potentials in domestic wastewater remediation.

Nevertheless, the two plants species are suitable in domestic wastewater management. There was evidently high biomass production in the constructed wetland species than those of the natural wetland. We recommend that tissue culture and examination for the presence of faecal bacteria and heavy metals be conducted in case of conservation of the two plant species in wastewater treatment station and productivity in high quantity for other advantages.

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Conflicts of Interest

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

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