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Influence of the Stage Number on the Quality of Domestic Waste Water Treated with *Typha domingensis* Filter Plants

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

To achieve “good ecological status for water and aquatic environments”, extensive treatment techniques have been developed. The goal of this work is to study the two stages efficiency of filters planted with *Typha domingensis*. Two tanks in series of filters planted with reeds were used. Each tank consists of a tank of $1m^3$ in volume fitted with drainage pipes pierced with holes. Three different layers of gravel were laid over the drain pipes. From the comparison of the characterization of raw domestic wastewater and treated water, it appears that the reductions obtained at the outlet of the 2nd floor are more satisfactory than at the outlet of the 1st floor. The reductions at the exit of the 2nd floor are: 91.7% for total suspended solids; 98.3% for COD; 94.7% for BOD_5; 79.9% for NTK and 49.8% for Pt.

Keywords: Planted filters; Typha domingensis; stage; domestic waste water.

1. INTRODUCTION

Currently, Benin is experiencing a rapid population increase, about 10,008,749 in 2013 and a forecast of 12,120,000 in 2021, according to INSAE 2013 RGPH4 [1]. This galloping increase leads to a significant increase in the volumes of domestic wastewater discharged by users depending on the type of activity. The increasing volumes of domestic wastewater discharged into nature due to lack of infrastructure pose a threat to the environment. To achieve "good ecological status of water and aquatic environments", it is necessary to set up suitable infrastructures called treatment plants. Nevertheless, the choice of process must be established beforehand. Several types of treatments exist. These are physico-chemical treatments and biological treatments. Physico-chemical treatments require the use of chemicals that are expensive and dangerous for the environment [2]. As for biological processes, there are two categories: intensive systems (activated sludge, biodisk, etc.) and extensive systems (lagooning and filters planted with reeds). Intensive systems require high technical expertise and enormous financial costs for installation and operation [3]. Extensive processes use natural systems and rely on the natural purification capacity of aquatic plants. These extensive treatment processes are now a viable alternative. The German Käthe Seidel, quoted in Vymazal [4], was the first to experiment with this type of domestic wastewater treatment system in the 1960s with the aim of improving knowledge related to the functioning of natural wetlands. Then the wastewater treatment process by planted filters was developed by adapting to all types of wastewater.

Planted filter technology is a recently developed technique. In France, for example, the first planted filters were developed by Cemagref through a few units in the units in the 1980s [5]. Various modifications aimed at simplifying the system and making it more reliable were its operation were made before proceeding with its development [6]. The planted filter technology is a technique that has seen its development increased since 1997. Currently, there is a strong demand for this type of treatment from elected officials is real. Indeed, it is a reliable technology, simple to operate and facilitating sludge management. In addition, this process is well accepted by the population because of its perceived 'natural' image, reinforced by its ability to integrate into the rural landscape [7]. Constructed Wetland is the accepted term used in international communications. The choice of these two words is justified by the fact that the process began by constructing (Construted) wetland-like structures in the hope of restoring their purifying power. These artificial wetlands refer to two biological and natural purification techniques: free water surface (FWS) and subsurface flow (SSF) [8]. The planted filter wastewater treatment process is based on the principle of fixed cultures i.e. aerobic biological purification in fine to coarse granular media. The filter bed is not regularly renewed or washed. The treatment of wastewater is therefore carried out by filtration and aerobic biological degradation [7]. Planted filters have many advantages. But they also have some shortcomings that do not detract from their effectiveness. Several studies have shown that the planted filter treatment process effectively treats domestic wastewater in developed countries with a temperate climate [9-11]. This technique has been used in developed countries for decades and to regulate the construction of these facilities, some governments have published guidelines [12,6,13,14]. In developed countries, the planted filter treatment process has also proven to be a successful method for treating wastewater. In developed countries, the planted filter treatment process has also proven its worth in the treatment of industrial wastewater. The process is known for the removal of pollutants from wastewater from food processing industries: milking wash water [15]; vineyard wastewater [16]; Aina et al. [17] and fish farm sludge [18]. But also for more polluting industries industries such as refineries [19]. Grove goes further by highlighting the ability of Juncus effusus planted filters to purify polar organic solvents such as acetone, ammonia and solvents such as acetone, tetrahydrofuran (THF) and 1-butanol added to domestic wastewater [20]. One study highlighted the possibility of treating leachate from reed filters [21]. In general, the treated water from reed filters can be used for crop irrigation [22]. There is a growing interest in this process in tropical developing countries through recent studies. In Africa for example, Kivaisi [23] in Tanzania; demonstrated the exceptional capabilities of constructed wetlands to treat domestic wastewater in developing countries. For the treatment of domestic wastewater, constructed wetlands in tropical developing countries studies have proven the effectiveness of Panicum maximum [24] in Côte d'Ivoire) and Typha [8] in Tunisia. In Asia, planted filters of Typha angustifolia and Cyperus involucratus [25] in Thailand); Phragmites karka and Phragmites australis (Parco et al. 2000 [26] in the Philippines) have shown satisfactory results in the treatment of highly loaded synthetic domestic wastewater and wastewater from laundries, respectively. The Echinochloa pyramidalis planted filters have also proven to be effective in the treatment of sludge in tropical climates [27]. Developed countries were early adopters of planted filters because they are both efficient and cheap [4], fits perfectly into the landscape [28] and produce a low amount of sludge (1.5 cm/year according to REEB workshop, 2005 [29] and 10-15 mm/year according to Poulet and al. [30], which adapts to flow variations [31] and which is simple to implement [32]. A good abatement is obtained even with high loads [33]. According to the Reeb workshop, the maintenance of planted filter installations is similar to gardening (the staff is poorly qualified and the valves, cutting the reeds "mowing" if they have grown sufficiently once a year and scraping the surface of the beds once every 10 years) and their investment and operating costs are lower, mainly because of their low electrical energy consumption. low electrical energy consumption. The French guide for the installation of planted filters assures that the yields respect the standards for discharge into a watercourse and even go beyond them in certain stations [34]. In addition, life cycle comparisons of wastewater treatment processes have shown that planted filters have a low environmental impact in terms of resource consumption and greenhouse gas emissions [35]; Chiemchaisri et al. [36]). The reeb workshop (2005) states that the construction of planted filters requires a minimum height difference of 3 m for gravity flow, otherwise a lifting station will be required. He also recommends a total surface area of 5 m^2 per inhabitant, which results in a large footprint for the technique. Luederitz recommends a minimum surface area of 50 m^2/m^3 per day for good load reduction [37]. The French guide for the installation of planted filters recommends this process only for small municipalities with a population not exceeding 2000 inhabitants [7]. The Danish guide on the subject recommends it exclusively for individual sanitation [12]. The monitoring of about fifteen planted filter treatment plants in France has shown that below 10°C, i.e. approximately above 1200 m altitude, the process is unsuitable. The seasons therefore have an influence on the efficiency of planted filters. Indeed, the study conducted by Garfi revealed that in summer, the load reductions in the planted filters are higher than in winter. Furthermore, regardless of the season, planted filters located in a region with a warm climate show better performance [38]. Finally, the treatment efficiency is low for nutrients, especially nitrogen and phosphorus [10]. Therefore several stages are needed to remove nitrogen and phosphorus pollution [39].

The general objective of this study is to study the influence of the use of two stages of filters planted with *Typha domingensis* on the removal of pollutants from domestic wastewater. Specifically, it will be necessary to characterize the raw effluents at the filter inlet and the treated water at the filter outlet. This characterization will make it possible to evaluate the water purification performance of the filters. Thus the efficiency of each filter stage will be determined.

2. MATERIALS AND METHODS

The methodology adopted is divided into four steps. First, the experimental pilot was set up then, the plants were installed in the pilot and two (2) months of adaptation were necessary. Then sampling took place and consisted of taking raw wastewater from the inlet of each filter stage and taking treated water from the outlet of each filter stage. Finally, the data analysis was devoted to determining the abatements for each parameter analyzed according to the formula:

$$Yield\ (X) = \frac{Ci(X) - Cf(X)}{Ci(X)} 100 \qquad (1)$$

Ci : initial concentration ; Cf : final concentration.

This research work was carried out on the University Campus of Abomey-Calavi, located in the commune of Abomey-Calavi in Benin. The domestic wastewater used comes from university residences. In the absence of a wastewater disposal network on the Abomey-Calavi University Campus, domestic wastewater was taken directly from septic tanks. The filters planted with reeds were fed for two months with the raw wastewater used for the experiment.

The Technology Center for Drinking Water and Sanitation served as a venue for hands-on experiments. The mini-station used to evaluate the performance of the filter planted with reeds was installed there. The University Campus of Abomey-Calavi enjoys a subequatorial climate. The year is divided into four seasons: two rainy seasons, the first with heavy rains from April to July, the second less important from late September to November and two dry seasons including the first from August to September and the great one from December to March.

The bed consists of a cubic Polyvinyl chloride (PVC) tank 1.10 m long, 0.90 m wide and 1.00m high. Drains made of PVC tubes (Ø 32 mm) notched with slots were installed at the bottom of the tank to collect the treated effluent on the bottom of the filter. The holes (5 mm slots spaced 15 cm apart) are turned downwards. The ends of the drains were connected to the atmosphere by sealed tubes and vents covered with caps.

The tubes and vents have diameters comparable and compatible with those of drains. Leak tests and tests were carried out before and after the materials were installed to verify the correct operation of the pilot. The bed of planted filters consists of three layers according to the recommendations of Molle [5] quote from Deguenon, 2013 :

- The filter layer composed of gravel with a diameter between 2 and 8 mm and a thickness of 30 cm
- The transition layer composed of gravel with a diameter between 5 and 10 mm and a thickness of 15 cm.
- The draining layer composed of gravel with a diameter between 20 and 40 mm and a thickness of 15 cm.

Several types of reeds develop in the municipality of Calavi. We chose to experiment with *Typha Domingensis*. 12 seedlings were then introduced into the bed. The bed was fed for two (2) months with lightly charged domestic wastewater from the septic tank of one of the university residence buildings.

This period of acclimatization allowed the plants to adapt to the environment and allow time for the biofilm to develop. The experiment was carried out based on a tarpaulin system. According to Molle [5], the volume of each tarpaulin must make it possible to obtain a water slide of 5 cm maximum height above the filter layer. This is equivalent to a tarpaulin volume of:

$$V = L * l * h = 1{,}10 * 0{,}90 * (0{,}60 + 0{,}05) = 0{,}644m \qquad (2)$$

V : volume ; L : lenght ; l : width ; h : height.

The dissolved oxygen, the pH and the conductivity were measured in situ with the dissolved oxygen meter (OXI 730 type WTW), the pH-meter (pH 3110 SET 3WTW type), and the conductivity meter (HI 98311 HANNA type Instrument). The turbidity was measured with a turbidimeter (Turbiquant 1100 IR type MERCK). The Total Kjeldahl nitrogen (TKN) concentration was determined after mineralization with selenium, according to AFNOR standards [40]. The total phosphorus (TP) content was obtained by the use of a spectrophotometer (DR2800). To obtain the Chemical Oxygen Demand (COD) and the Total Suspended Solid (TSS), the volumetric method and the filtering method were used respectively according to AFNOR standards (NFT 90-101 [41] and NF EN 872 [42]). As for the determination the Biochemical Oxygen Demand at 5 days of incubation (BOD_5), membrane manometers (Oxitop) were used.

The average annual rainfall is around 1200 mm. The average monthly temperature varies between 27°C and 31°C with a difference of ± 3.2°C between the hottest month (March) and the coldest month (August) [43].

Table 1. Methods used for parameter analysis

Parameters	Méthods	Norms
Dissolved Oxygen	Electrochemical Method	NFT 90-106
Temperature		
pH and eH	Potentiometric method	NF T 90-008
Conductivity	Electrochemical measure	NF EN 27888
TSS	Method by filtration	NF EN 872
COD	Volumetric method	NF T 90-101
DBO_5	Manométric method	
TKN	Method by minéralisation	NF EN 25663
TP	Atomic absorption spectrophotometry	-

3. RESULTS AND DISCUSSION

In this part, we will present the results from the characterization of domestic wastewater.

Table 2. Physico-chemical parameters at the filter inlet

Parameters	Units	Values
pH	-	5,87
Temperature	°C	26,2
eH	mV	59,6
rH	-	15,2
Conductivity	µS/cm	734,7
Dissolved oxygen	mgO_2/L	3,5

Table 2 presents the values of the parameters resulting from the analysis of domestic wastewater at the inlet of filters. The wastewater discharged must meet standards set out in Decree No. 2001-109 of 4 April 2001 setting standards for the quality of waste water in the Republic of Benin [44]. The pH of domestic wastewater entering the filters is between 6 and 9. This pH value meets Beninese standards. Beninese regulations require a temperature of 25°C at the level of water discharged into watercourses. Consequently, the temperature of the domestic wastewater studied (26.2 ° C) is not in line with the standards in force in Benin.

The value of the rH is between 15 and 23. The medium is therefore favorable to the oxidation of organic compounds. Thus, domestic wastewater has the characteristics of an anoxic receiving environment. As for the value of conductivity, it is greater than 500 µS/cm. Therefore, the domestic wastewater studied is highly mineralized. The dissolved oxygen value is high (3.5 mgO2/L) compared to the values generally encountered. This dissolved oxygen value may be due to the existence of a small permanent opening when designing the septic tank from which domestic wastewater originates.

Table 3 shows the values of the global pollution measurement parameters, obtained at the end of the analysis of domestic wastewater at the inlet of the filters.

The values of the MES and COD observed correspond to the values generally encountered at the level of urban wastewater. While the BOD_5, NTK and Pt values are lower than the usual values for urban wastewater. When comparing the values of the global pollution parameters to the limit concentrations of the standards, we see that the domestic wastewater studied must not be discharged into the environment without treatment. Without treatment, the organic matter contained in this domestic wastewater will lead to the consumption of dissolved oxygen present in the receiving watercourse and consequently the decrease or even the disappearance of aquatic fauna. Without prior treatment, the TSS of this domestic wastewater will lead to the limitation of the life of photosynthetic organisms and the appearance of deposits that will disturb benthic life. The input of nitrogen and phosphorus material into the receiving watercourse will cause eutrophication.

Table 4 shows the concentrations obtained at the end of the treatment cycle on each floor.

At the end of the four days of treatment, we find that the concentrations obtained at the first stage for TSS, COD and BOD_5 are below the limit concentrations. These concentrations therefore comply with the standards in force in Benin. Water from the second stage has also been treated. Indeed, we find that the concentrations at the exit of the second stage are lower than the concentrations at the exit of the first stage. In addition, the second-stage output concentrations for TSS, COD and BOD_5 are also below the standard limit concentrations. The concentrations at the exit of the second stage for TSS, COD and

Table 3. Global pollution measurement parameters at filter inlet

Parameters	***Values***	***Usual values***	**Norms**
TSS (mg/L)	120	100-400	60
COD (mgO_2/L)	539,1	300-1000	125
BOD_5 (mgO_2/L)	81,33	150-500	25
TKN (mg/L)	3,73	1030-100	15
TP (mg/L)	5,54	30-100	2

Table 4. Global pollution measurement parameters at the outlet of filters

Parameters	**Ci (entry)**	**Cf (exit1)**	**Cf (exit2)**	**Norms**
TSS (mg/L)	120	**20**	**10**	60
COD (mgO_2/L)	539,1	**34,66**	**9,2**	125
BOD_5 (mgO_2/L)	81,33	**8,33**	**4,33**	25
TKN (mg/L)	3,73	**4,85**	**0,75**	15
TP (mg/L)	5,54	**2,91**	**2,78**	2

BOD_5 comply with the regulations. These concentrations are in line with the Beninese standard.

Regarding TSS, COD, and BOD_5, the first stage of filter planted with *Typha domingensis* allows us to reach concentrations of TSS, COD and BOD_5 that are in line with Beninese regulations. The second stage of *Typha domingensis* planted filter allows us to refine the treatment at the level of TSS, COD, and BOD_5. The value of the TKN concentration at the outlet of the first stage is higher than the concentration of TKN at the entrance of the first stage. This means that during the stay of domestic wastewater in the first floor, there was an input of nitrogenous matter. These nitrogenous materials can come from the products of the degradation of organic matter.

In addition, we can say that the nitrogenous materials present in the domestic wastewater at the entrance of the first floor have not undergone any treatment. This may be justified by the fact that to break down nitrogenous materials, microorganisms need oxygen. However, the oxygen present in the environment is used to degrade organic matter. As a result, there is no more oxygen available in the first stage to degrade nitrogenous matter. The water leaving the first stage contains little organic matter.

The oxygen available in the second stage will be used mainly to degrade the nitrogenous materials, hence the value of the TKN concentration which is almost zero at the exit of the second stage. Given the low concentration of TKN in raw domestic wastewater, the increase in this concentration at the outlet of the first stage is not significant. Nevertheless, the concentrations of TKN at the exit of the first and second stages comply with Beninese standards. The degradation of phosphorus in the first stage reduces the initial concentration by a factor of 2. Phosphorus treatment in the second stage is low. Phosphorus concentrations at the outlet of the first and second stages do not comply with regulations.

Table 5. Pollution elimination

Parameters	**Exit1**	**Exit2**	**Norms**
TSS (%)	83,3	91,7	70
COD (%)	93,6	98,3	75
BOD_5 (%)	89,8	94,7	70
TKN (%)	**0**	79,9	70
TP (%)	**47,5**	**49,8**	80

Table 5 shows the yields obtained for physico-chemical parameters at the end of the treatment cycle on each floor. These efficiencies were calculated from filter inlet concentrations, first stage outlet concentrations and second stage output concentrations. We note that at the exit of the first and second stage for TSS, COD and BOD_5, the yields obtained are above the limit yields required by Beninese standards. Consequently, these yields in TSS, COD and BOD_5 comply with the standards in force in Benin. The TKN yield on the 2nd floor is in line with Beninese regulations. Unlike the TKN yield on the 1st floor. As far as phosphorus is concerned, yields are very low well below the yield required by Beninese regulations.

Table 6. Elimination yields from different Typha filter studies

Parameters	MES	DCO	DBO_5	NTK	PT
Units	mg/L	mgO_2/L	mgO_2/L	mg/L	mg/L
Waste water concentrations 1	3400	1955	850	168	36,5
Treated water concentrations 1	20	45	18	38,6	19,8
Deguenon, 2016 [45]					
Yields 1	99%	98%	98%	77%	46%
Waste water concentrations 2	7360	6055	1910	211	37
Treated water concentrations 2	17	219	------	1,7	0,62
Yields 2	99,9%	98,5%	------	99,5%	99,2%
Korboulewsky et al. 2012 [46]					

Purification performance comparison of differents Typha species.

Others *Typha domingensis* basin results are presented in Table 6. In the study 1 purification yields of organic matters in SS, COD and BOD_5 are almost 100%. Other scientists obtained the same results. higher concentrated waste water treat by Typha latifolia planted filter basin got organic matters removal yield of almost 100% (Korboulewsky and al., 2012). This study is presented in Table 6 as study 2. Typha latifolia acquired more than 86% of organic matter elimination yield [22].

Despite the fact that Korboulewsky waste water is higher concentrated, his purification yields are excellent. This result is due to the special substrate used. This substrate is optimized to have good results. This substrate has an heterogeneous composition. Indeed, the tank was filled with two layers of cobblestones at the bottom and one layer of an organic substrate (mixture of peat and crushed pine bark). On addition to that Korboulewsky substrate height is 55 cm while the study 1 substrate height is 60 cm. As to Morari his substrate height is 150 cm. The purification yield of a Typha filter depends on the substrate height and his composition [45].

In this study, the inlet wastewater concentrations are lower than in others studies. Thus yields are close to 100%. Furthermore in this study substrate height is 60 cm like in the study 1. The inlet wastewater concentrations seem to be an important influence parameters too.

4. CONCLUSION

The study focused on the treatment of domestic wastewater by planted filters of vertical flow *Typha domingensis*. The experiment gave very good results except for phosphorus. Indeed, at the level of TSS, COD, BOD_5 and TKN, the concentrations and yields obtained at the first and second stages are in line with Beninese regulations. In addition, the results obtained on the second floor are better compared to the result on the first floor. Nevertheless, phosphorus removal remains the major problem of filters planted with reeds. The installation of a third stage is necessary to remove phosphorus materials. We suggest a third floor consisting of either a water lettuce lagoon basin or a planted bed where the gravel layer will be replaced by a more absorbent granular support such as quartz or apatite. Overall, this study shows that filters planted with multi-storey reeds are suitable for treating domestic wastewater. This study can be popularized with town halls so that filters planted on several floors are installed in all households in Benin. This is in order to reduce the impact of domestic wastewater discharged into nature without treatment; on the quality of water resources in Benin.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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