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Purifying performances of different plants in domestic waste water treatment with reed beds

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Abstract

The rejection of untreated waste water in the nature decreases groundwater quality. Waste water treatment plants like activated sludge plant and stabilization pond plant built in Benin show their limits. Due to these problems, reed beds have to be experimented to bring a durable solution to waste water treatment problems in Benin. Compare to activated sludge plant and to stabilization pond plant, reed beds are the cheapest based on the technical and economical point of view. On addition to that, reed beds are easy to build and to maintain. The experiment plant is composed of four basins. The first basin is unplanted. The second basin is planted with *Echinochloa pyramidalis*. The third basin is planted with *Panicum maximum* and the last basin is planted with *Typha domingensis*. Each basin is a 1 m^3 tank with drilled drain pipes. Three differentl ayers of gravel have been put on drilled drain pipes. Treated water analysis showed that the *Typha domingensis* basin has the best purfiying performances with final concentrations : 0 mg/L ; 21,10 mg/L ; 10 mg/L ; 0 mg/L et 12,20 mg/L respectively for TSS, COD, BOD_5, TKN and TP. These final concentrations reached the discharge standards for municipal wastewater treatment plant in Benin. Consequently, *Typha domingensis* beds can be popularized by the beninese government to solve waste water treatment problems.

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Introduction

In Benin, available fresh water is more and more polluted by domestic waste water. This pollution decreases groundwater quality and leads to hydric diseases. This pollution also increases the drinking water price. Hydric diseases in volve thousand children deaths each year in Benin. In Benin, poor people consume polluted water without treatment. According to Kivaisi, reed bed plant is a cheaper waste water treatment process based on technical and economical point of view. On addition to that reed beds can be used to solve waste water treatment problems in developing countries like Benin (Kivaisi, 2001). Moreover, reed beds are easy to build and to maintain (Denny, 1997; Haberl, 1999; Konnerup *et al.*, 2009). Hounkpe demonstated that the domestic waste water management in Benin is very critical. Benin has only three waste water treatment plants to treat waste water conveyed by emptying trucks. There are a waste water treatment plant in Ekpe, Porto-Novo and Parakou. Sadly these waste water treatment plants show their limits (Hounkpe, 2014). Due to all these problems, reed beds have to be experimented to bring a durable solution to waste water treatment problems in Benin (Aina *et al.*, 2012). Benin is a developing country. So reed bed plant is a new idea to explore in order to treat waste water in Benin. Deguenon has been the first scientist to assess purification performance of planted filters in Benin using phragmites (Deguenon, 2013). Now, three other species of plant will be tested and their purification performances will be compared. So that a technical document will be written and given to each municipal authority to popularize reed bed process in every household in Benin.

The purification of waste water in reed beds occurs in different stages. These stages are known and have been developed by many scientists (Salt *et al.*, 1998; Williams, 2002; Vymazal, 2005; Imfeld *et al.*, 2009; Reiche *et al.*, 2010). According to Calheiros *et al.* (2009), purification's mechanism of waste water in reed beds leans on physical, chemical and biological processes (Microbiological degradation in the rhizosphere, absorption and plant metabolism).

The wastewater treatment process by planted filters is based on the principle of fixed cultures that is to say of aerobic biological treatment in gravel layers fine to coarse (Poulet *et al.*, 2004). The gravel is not regularly renewed or washed. In planted filter, wastewater are treated by firstly a filtration and then anaerobic biological degradation (Seidel, 1967; Prigent, 2012). There are two kinds of planted filtert ypes according to the flow direction: vertical flow's planted filters and horizontal flow's planted filters. Only vertical flow's planted filters are experimented in this study. Several plants have been used by scientists in reed beds. All Beninese plants have been listed in a book named « flore analytique du Bénin ». To popularize reed beds in Benin, plants have to be available and accessible to people. According to the combination of information provided by the book named « flore analytique du Bénin » and the list of plants often used in reed beds, three plants can be used in Benin for reed beds:

Typha domingensis, *Panicum maximum* and *Echinochloa pyramidalis*

Ouattara experimented one *Panicum maximum* planted filter basin to treat domestic waste water. These domestic wastewater have the following characteristics: 1519 ± 247 mg/l; 1256 ± 571 mgO_2/l; 128 ± 58 mg/l et 6, 2 ± 2,2 mg/l respectively for TSS, COD, NH_4^+, PO_4^{3-}. With these domestic wastewater Ouattara obtained the following purification yields: 91,4%, 85, 5%, 86, 5%, 74% respectively for TSS, COD, NH_4^+, PO_4^{3-} (Ouattara *et al.*, 2008). Korboulewsky tested one *Typha latifolia* planted filter basin to treat domestic waste water. These domestic waste water have the following characteristics : 7360 mg/L, 6055 mg/L,211 mg/L, 37mg/L respectively for TSS, COD, TKN, TP. With these domestic waste water Korboulewsky obtained the following purification yields: 99,9%; 98,5%; 99,5% et 99,2% respectively for TSS, COD, TKN, TP. Ouattara and Korboulewsky used vertical flow for their planted filter. Korboulewsky's domestic waste water are higher concentrated than Ouattara's domestic waste water. Nevertheless, when Ouattara's purification yields are compared to Korboulewsky's yields,

Typha latifolia's yields seems to be upper than *Panicum maximum*'s yields. So despite the fact that Korboulewsky used higher concentrated waste water, *Typha latifolia*'s purification yields is upper than *Panicum maximum*'s purification yields. In other words, *Typha latifolia*'s purification capacity is exceptional. Kengne experimented one *Echinochloa pyramidalis* planted filter basin to treat faecal sludge. Kengne obtained the following purfication yields : 92%, 98% and 78% respectively for COD, TSS and NH_4^+ (Kengne, 2008). If a purification capacity classification from higher to lower is made for these three plants (*Typha latifolia*, *Panicum maximum* and *Echinochloa pyramidalis*), Echinochloa pyramidalis will be the first in this diagram, then *Typha latifolia* and *Panicum maximum* will be the last one. The aim of this study is to compare the purification capacity of three plants (*Typha domingensis*, *Panicum maximum* and *Echinochloa pyramidalis*) in order to show if *Echinochloa pyramidalis*is is also the highest purification plant in Beninese weather conditions.

Materials and methods

The setup conditions of the planted filters is located in Abomey-Calavi University in Benin. The domestic wastewater come from the university's student residences. Since there is no wastewater collection system, the sewage was taken straight from the septic tanks. Two septic tanks were used. The wastewater from the first septic tank wasused to feed the reed bed system for 2 months. This wastewater was only slightly concentrated. The wastewater from the second septic tank was used to test the reed bed's purification performances. This wastewater was much more conce-ntrated than those from the first septic tank. The Abomey-Calavi University has a subequatorial climate. Each year is divided into four seasons: two rainy seasons and two dry seasons. The first rainy (heavy) season begins in April and ends in July. The second rainy season is short and lasts from the end of September to November. The first dry season starts in August and ends in September and the second one (longer) lasts from December to March. The average monthly temperature varies between 27°C and 31°C with a tolerance of ± 3.2°C between the hottest month (March) and the coldest month (August).

The yearly average rainfall is around 1200 mm (IITA, 2011). The pilot is composed of four beds. Each bed was a cubic tank made of PVC, 1.10 m long, 0.90m wide and 1.00m high. Drainpipes were installed at the bottom of the tank to collect the treated wastewater. These drainpipes are made of PVC (32 mm in diameter) and have slits. The slits (5 mm in diameter, with 15 cm of space between them) are turned towards the bottom of the tank. The end of the drainpipes is linked to the atmosphere by watertight tubes, which are covered by ventilation hats. The watertight tubes, the ventilation hats, and the drainpipes have the same diameter. Watertight tests, as well as other tests, were performed before and after setting the gravel system in order to ensure that the treatment plant functioned properly. The bed is comprised of three layers (Molle *et al.*, 2005):

- The filtering layer is composed of grave lbetween 2 and 8 m diameter and 30 cm in depth
- The transition layer is composed of grave lbetween 5 and 10 m diameter and 15 cm in depth
- The drain layer is composed of gravel between 20 and 40 mm diameter and 15 cm in depth

Many types of plants grow in Abomey- Calavi. In this study *Echinochloa pyramidalis*, *Panicum maximum*, *Typha domingensis* were chosen. Twelve young plants from their natural area were dug up and transplanted into the bed. The experiment plant is composed of four basins. The first basin is unplanted. The second basin is planted with *Echinochloa pyramidalis*. The third basin is planted with *Panicum maximum* and the last basin is planted with *Typha domingensis*. The beds were fed for two months with slightly concentrated wastewater coming from one of the septic tanks of university's student residences. This period is necessary because it allows plants to accustom themselves to the bed and allows the biofilm to develop. The experiment was carried out based on a batch system. The volume of each batch has to permit the obtainment of a water blade, with a maximum height of 5 cm on top of the filtering layer (CEMAGREF, 2004). This is equivalent to a batch volume of: $V = L * l * h = 1.10 * 0.90 * (0.60 + 0.05) = 0.644m^3$ Formula 1.

Picture 1. The planted filter pilot. Left to right: 1-Typha domingensis basin, 2-Panicum maximum basin, 3- Echinochloa pyramidalis basin and 4-Unplanted basin.

Samples of 2L were taken three times every day at the same time in each basin during eight days. The dissolved oxygen, the pH and the conductivity were measured in situ. The dissolved oxygen, the pH and the conductivity were respectively measured 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 TKN concentration was determined after mineralization with selenium (AFNOR, 1994). The total phosphorus content was obtained by the use of a spectrophotometer (Hach Lange DR2800). To obtain the Chemical Oxygen Demand (COD) and the Total Suspended Solid (TSS), the volumetric method and the filtering method were used respectively (AFNOR, 1988; AFNOR, 1996). As for the determination the Biochemical Oxygen Demand at 5 days of incubation (BOD_5), membrane manometers (Oxitop) were used.

Undesirable microorgnaisms are pathogenic germs which provide information about fecal contamination of waste water. According to AFNOR (2000); solid medium counting with incorporation in agar was used to identified fecal coliforms and E. Coli.with Rapid-E Coli medium (24 hours at 44°C). According to AFNOR (1999); Streptococci were analysedwith Slanetz and Bartley medium (from 24 hours to 48 hours at 37°C). The results were expressed as the number of colony-generating units in the reference amount specified samples (100 ml).

Results and discussion

Characterization of domestic waste water before treatment.

Table 1. Characterization of domestic waste water before treatment (second tank) .

Parameters	TSS	COD	BOD_5	TKN	TP
Units	mg/L	mgO_2/L	mgO_2/L	mg/L	mg/L
Waste water (second tank)	3400.00 ± 20.00	1955.00 ± 10.00	850 ± 10	168.00 ± 2.00	36.50 ± 1.00
Common values	100-400	300-1000	150-500	30-100	10-25

According to table 1, waste water from second tank before treatment were highly concentrated. In fact, the concentration of these waste water werehigher than the concentrations typically encountered in these types of domestic wastewater.

Evolution of treated water concentrations

The evolution of TSS, COD and BOD_5 concentrations in treated water taken from the fourth basins all along the eight days is presented respectively in Fig. 1, 2 and 3. The evolution of TSS, COD and BOD_5 concentrations in treated water taken from the fourth basins is the same indeed these three concentrations decreaseexponentially all along the fourth first days of residence time.

Then these concentrations begin to steady from the fifth day to the eighth day of residence time. If TSS, COD and BOD_5 concentrations in treated water taken from the fourth basins are stable after the fourth day of residence time consequently the optimum residence time is four days in reed beds. The evolution of TSS, COD and BOD_5 concentrations in the three planted filters is different from the unplanted filter. In the unplanted filter the TSS, COD and BOD_5 concentrations decrease slowly all along the eight days of residence time. The lack of plant in the unplanted filter is responsible for this kind of TSS, COD and BOD_5 concentration evolutions. So gravel can only holds back a part of polluted matters. Planted filter efficiency is in fact due to the combination of gravel and plant actions.

A part of polluted matters are removed by the gravel physically then the residual polluted matters are degraded biologically and chemically by the plant rhizosphere. The reed bed process of purification is confirmed by other scientists (Kouki *et al.*, 2009 ; Lienard *et al.*, 2005 ; Ouattara *et al.*, 2008; Paulus, 2011 ; Rousseau *et al.*, 2004). Actually in reed beds, suspended solids are filtered by the different layers of gravel. Consequently a layer of particules is accumulated above the layer of fine gravel. As for the root system, it is a more cosy niche for the biomass responsible for biological degradation.

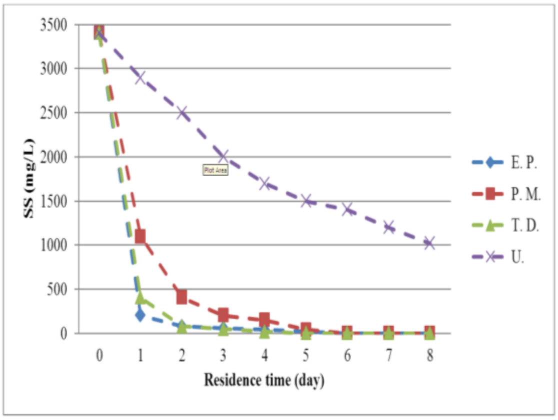

Fig. 1. Evolution of SS concentration depending on the residence time E. P. Echinochloa pyramidalis basin, P. M. Panicum maximum basin, T. D. Typha domingensis basin, U. Unplanted basin.

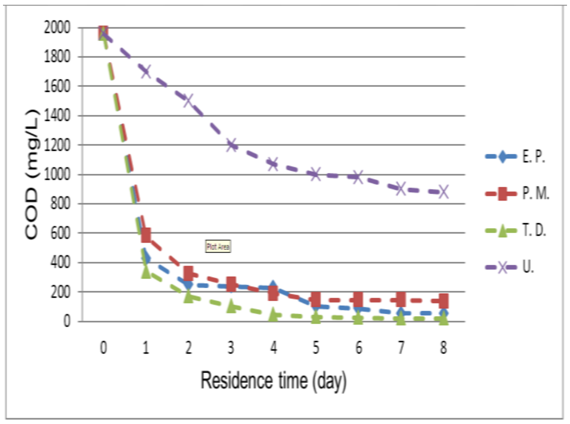

Fig. 2. Evolution of COD concentration depending on the residence time E. P. Echinochloa pyramidalis basin, P. M. Panicum maximum basin, T. D. Typha domingensis basin, U. Unplanted basin.

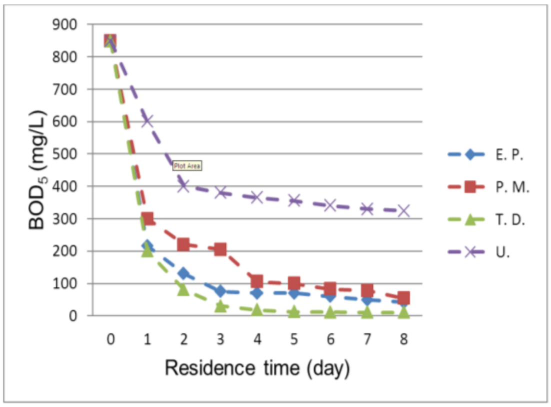

Fig. 3. Evolution of BOD5 concentration depending on the residence time E. P. Echinochloa pyramidalis basin, P. M. Panicum maximum basin, T. D. Typha domingensis basin, U. Unplanted basin.

Elimination of organic matters in planted beds

At the fourth day treatment, elimination yields of TSS, COD and BOD_5 were calculated and presented in Fig. 4. Removal yield standards in Benin are 70%, 75% and 70% respectively for TSS, COD and BOD_5 (Decret n° 2001-109). These yields are the minima yields. Elimination yields of organic matters (TSS, COD and BOD_5) at the fourth day treatment reached almost 100 % in the three planted basins. These yields are higher than the standard yields in Benin.

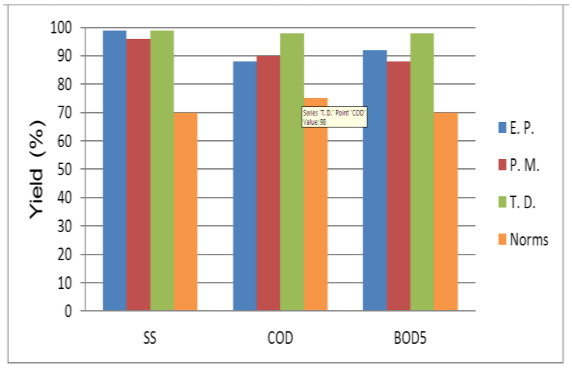

Fig. 4. Purification yield of organic matters at fourth days of residence time E. P. Echinochloa pyramidalis basin, P. M. Panicum maximum basin, T. D. Typha domingensis basin.

At the fourth day treatment, TSS, COD and BOD_5 residual concentrations were analysed. These residual concentrations are presented in Fig. 5. TSS, COD and BOD_5 residual concentration standards are 60 mg/L, 125 mg/L and 25 mg/L respectively for TSS, COD and BOD_5 in Benin (Decret n° 2001-109).

These residual concentrations are the maximum residual concentrations for treated water. Compare to the other planted filters, residual concentration in *Typha domingensis* basin are the lowest concentrations and these concentrations are under the standards. So in regard to organic matter elimination, *Typha domingensis* is the best plant.

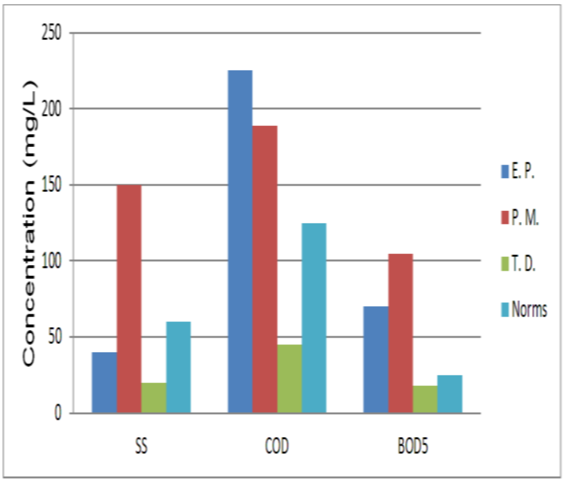

Fig. 5. Residual concentrations in organic matters at the fourth day treatment E. P. Echinochloa pyramidalis basin, P. M. Panicum maximum basin, T. D. Typha domingensis basin.

Elimination of nutriments

Purification nutriment (TKN et TP) yields are presented in Fig. 6. Nitrogen elimination yield reached 77% in *Typha domingensis* basin and it is the highest yield compare to other planted basins while the minimum yield standard is 70% for nitrogen.

Therefore nitrogen elimination yield in *Typha domingensis* basin is upper to standard and is in line with the standard. All phosphorus yields in the three planted filters are under the standard which is 80% for phosphorus. For example, phosphorus yield in the *Typha domingensis* basin is 46%.

Consequently one planted filter can not reach the phosphorus yield standard in Benin. It is necessary to treat domestic waste water in successively several planted filters in order to reach all the standards.

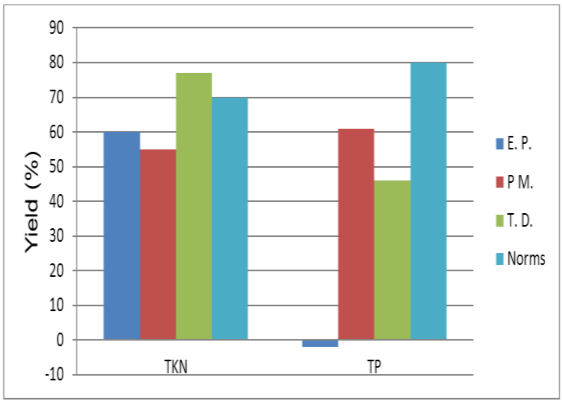

Fig. 6. Purification yield of nutriments at fourth day of residence time E. P. Echinochloa pyramidalis basin, P. M. Panicum maximum basin, T. D. Typha domingensis basin.

Residual concentrations in nutriments (TKN and TP) are presented in Fig. 7. Concentrations in *Typha domingensis* basin are respectively 38,6 mg/L for TKN and 19,8 mg/L for TP. These residual concentrations are upper maxima residual standard concentrations (15 mg/L for TKN and 2 mg/L for TP). Despite the fact that nitrogen elimination yield in *Typha domingensis* basin is in line with standard, the nitrogen residual concentration is not in line with standard in *Typha domingensis* basin. So one *Typha domingensis* planted filter is insufficient to reach nitrogen and phosphorus standards. Successive basins of *Typha domingensiss* hould be built to overcome nitrogen and phosphorus matters.

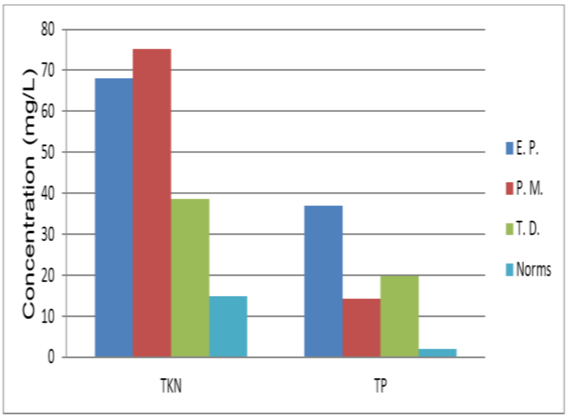

Fig. 7. Residual concentrations in nutriments at the fourth day treatment E. P. Echinochloa pyramidalis basin, P. M. Panicum maximum basin, T. D. Typha domingensis basin.

Elimination of undesirable microorganisms

Purification yield of undesirable microorganisms are 100 % in all the planted filters.

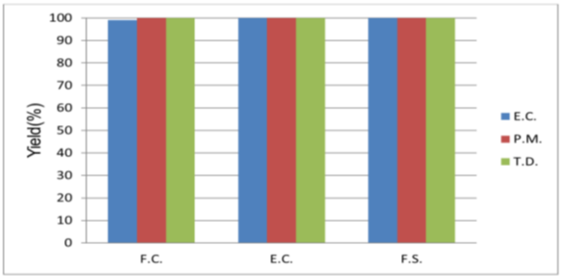

Fig. 8. Purification yield of undesirable microorganism at fourth day of residence time E. P. Echinochloa pyramidalis basin, P. M. Panicum maximum basin, T. D. Typha domingensis basin.

Residual concentrations of undesirable microorganisms

Final concentrations of undesirable microorganisms are all under standards in all the planted filters.

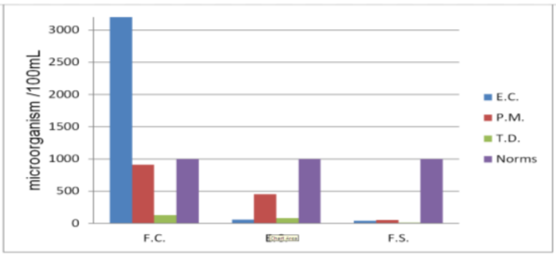

Fig. 9. Residual concentrations in undesirable microorganism at the fourth day treatment E. P. Echinochloa pyramidalis basin, P. M. Panicum maximum basin, T. D. Typha domingensis basin.

Purification performance comparison of differents Typha species

Typha domingensis basin results are presented in table 2 as study 1. In this study purification yields of organic matters in SS, COD and BOD5 are almost 100%. Other scientists obtained the same results. higher concentrated wastewater treat by *Typha latifolia* planted filter basin got organic matters removal yield of almost 100% (Korboulewsky *et al.*, 2012). This study is presented in table 2 as study 2. *Typha latifolia* acquired more than 86% of organic matter elimination yield (Morariand Giardini, 2009).

Despite the fact that Korboulewsky wastewater is higher concentrated, this 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 my study 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.

Table 2. 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
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%

Conclusion

This study shows the exceptional capacity of *Typha domingensis* to treat wastewater. Indeed with height days of treatment, the best final concentrations (0,00 mg/L ; 21,10 mg/L ; 10 mg/L ; 0,00 mg/L and 12,20 mg/L respectively in TSS, COD, BOD_5, TKN and TP) were obtained in *Typha domingensis* basin.

After height days of treatment, good purifying yields 100%, 99%, 99%, 100% and 67% respectively in TSS, COD, BOD_5, TKN and TP were also got in *Typha domingensis* basin. Nevertheless at four days of treatment, neither the final concentration in TP and in TKN nor the purifying yield in TP in the four basins is in adequation with Beninese waste water treatment standards.

Four days of optimal residence time in reed bed treatment is found. The efficient of waste water treament with reed bed is due to the combination of filtration and biological treament. It is necessary to treat domestic waste water in successively several planted filters in order to reach all the standards.

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