Asian Journal of Chemical Sciences

Volume 14, Issue 2, Page 97-112, 2024; Article no.AJOCS.114513
ISSN: 2456-7795

Wastewater Phytopurification Monitoring with Congolese Planted Filters, Republic of Congo

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Authors' contributions

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

Article Information

DOI: 10.9734/AJOCS/2024/v14i2297

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/114513

Original Research Article

Received: 09/01/2024
Accepted: 13/03/2024
Published: 18/03/2024

ABSTRACT

The present study aimed to evaluate the purifying power of two Congolese plant filters or emerging macrophytes EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) on wastewater coming from the Total market, the largest national market of Brazzaville in Congo. To do this, we set up an experimental device composed of gravel, fine sand and two plants. These plants were cultivated in an experimental pilot consisting of 8 tanks of 42,000 cm^3 of wastewater at treat each one, in addition to 2 tanks used as controls. The purifying performance study of the system after 90 days of treatment showed a significant reduction in physical, organic and mineral pollution. Using the planted filter EP-F (*Echinochloa pyramidalis (Lam)Hutch*), we obtain reduction rates of almost 100% for turbidity and for suspended matter (SM), 75.42% for COD, 76.5% for NH_4^+ ions, 99.5% for NO_3^- ions and 99.73% for PO_4^{3-} ions. In the case of the CA-F (*Cyperus alternifolius*

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L) planted filter, we obtain reduction rates of almost 100% for turbidity and SM, 80.94% for COD, 93% for ions. NH_4^+, 89.11% for NO_3^- ions and 98.93% for PO_4^{3-} ions. Furthermore, we also noted an increase in organic and mineral pollutants concentrations in the two plants compared to the raw plants before wastewater passage. This study showed that *Echinochloa pyramidalis (Lam) Hutch and Cyperus alternifolius* L. are effective macrophyte filters to eliminate physical, organic and mineral pollution.

Keywords: Phytoremediation; phytoepuration; urban discharges; wastewater.

1. INTRODUCTION

Water pollution coming from untreated effluents have become a growing concern for developing countries. The increase of wastewater discharges that have not undergone appropriate treatment resulting from economic and industrial development, the intensification and expansion of agriculture and wastewater volumes in urbanizing areas, further promote the degradation of surface water and groundwater quality worldwide [1]. However, attention to managing water after it has been used is often a neglected part of the water cycle [2]. In fact, most of the world's wastewater is neither collected nor treated. 71% of wastewater generated is treated in Western countries while 32 out of 48 countries in sub-Saharan Africa have no data on wastewater treatment [3]. One of the main challenges related to wastewater in Africa is the general lack of infrastructure for collection and treatment, which generates physical, chemical and biological pollution on water surface into which it is discharged. The toxicity, mobility and load of pollutants have a significant impact on water resources, human health and environment [4]. According to the Congolese coastline environmental audit report on the coasts of Pointe-Noire city, economic capital of the Republic of Congo, wastewater from industrial, hotel and hospital establishments is discharged without prior treatment into the natural environment, notably into sewers and the Tchinouka and Songolo rivers [5]. For two decades, we have witnessed the evolution of technical depollution methods with the gradual transition from so-called traditional biodegradation technics whose costs are much lower. Professionals present on the treatment market are increasingly moving towards less cumbersome and less expensive techniques such as phytoremediation [6]. Phytoremediation is a plant biotechnical method based on plants ability to extract or block pollutants, whether in porous, liquid or gaseous media.

This technical method with promising advantages is based on biodegradation principle by the combined action of plant roots and microorganisms. It is used for the treatment of organic and inorganic pollution. It is therefore an interesting alternative to other physicochemical depollution processes due to their reduced environmental impact and their low cost [7]. Also, tropical plants continue to provide support in wastewater treatment processes. These tropical plants are used successfully for the wastewater depollution and can be combined with conventional purification techniques [8]. Research has shown that some Cameroonian tropical plants such as E. indica, C. dactylon and A. sessilis can survive and develop in environments polluted with domestic fuel while possessing good phytoremediation capacities [9]. In Algeria, phytoremediation processes currently represent 56% of wastewater treatment processes, with 60 lagooning stations, with approximately 941 phytoremediaton biodiversity species, used in pollutants bioaccumulation and biodegradation, dominated by microscopic algae, duckweed, reeds, oleander, hibiscus, canna, papyrus, pomegranate and rush [10]. This study aimed to compare the purifying effectiveness of artificial marsh system composed of the Congolese plants *Echinochloa Pyramidalis (Lam) Hutch* and *Cyperus alternifolius* L, in elimination of pollutants coming from the wastewater of the largest market in Brazzaville, namely the Total market.

2. MATERIALS AND METHODS

2.1 Study Site

This study was carried out at Brazzaville in the Republic of Congo. Brazzaville, political capital of the Republic of Congo, is located between 15°20' and 15°25' East longitudes, and between 4°10 and 4°25' South latitudes. Its geoical position places it in the heart of Africa, therefore in intertropical zone characterized by high temperatures and abundant precipitation. This study was carried out near the Total Market in Bacongo in district number 2 of Brazzaville city.

2.2 Experimental Device

The Congolese plants used in this study are *Echinochloa pyramidalis (Lam)Hutch* (Fig. 1) and *Cyperus alternifolius* L. (Fig. 2). The experimental device is presented in Fig. 3. The plastic tanks of experimental device, in which a horizontal distribution pipe is placed at the bottom, have a volume of 50 liters (Fig. 3-a). The tanks have an upper diameter of 40 cm maximum, a lower diameter of 35 cm and a height of 30 cm. Three superimposed layers are then placed in the bins as follows:

- the first layer 4cm high, is a layer of coarse gravel (Fig. 3-b) whose stones have a diameter between 6 and 10 mm. it is placed at the level of the distribution pipe in order to facilitate effluent passage,
- the second layer 15cm high, is a layer of fine sand poor in organic matter, installed at the same time as an aeration pipe (Fig. 3-c). The layer of fine sand is trapped between two layers of gravel,
- the third layer 4cm high, is a layer of fine gravel (Fig. 3-d) with a diameter between 2 and 3 mm placed at surface level. Fine gravel was used to avoid soil compensation at tank bottom which can cause root asphyxiation conditions due to excess water. Fig. 3-d constitutes the control filter (T-F).

The experimental device consists of two (2) tanks placed in the open air and filled with a substrate composed of sand and gravel (Fig. 4). A first tank is planted with *Echinochloa pyramidalis (Lam) Hutch* (Fig. 4-a) and constitutes the planted filter EP-F. The second tank is planted with *Cyperus alternifolius* L. (Fig. 4-b) and constitutes the planted filter CA-F.

2.3 Wastewater Sampling

The wastewater samples to be analyzed were taken from the gutters (Fig. 5) of the Total market in district 2 Bacongo in Brazzaville (Fig. 6).

These wastewater samples were then packaged in 5-liter plastic bottles (Fig. 7), previously rinsed with tap water.

2.4 Measurements of Wastewater Physicochemical Parameters before and after Treatment

For each sampling, the physicochemical parameters relating to turbidity, suspended matter, dissolved oxygen, chemical oxygen demand, ammonium ions, nitrate ions and phosphate ions were measured.

2.4.1 Measurements of dissolved oxygen (O_{2d}) content

The dissolved oxygen (O_{2d}) content was analyzed using a DO-66A type oximeter, which uses the electrochemical reduction of molecular oxygen [11]. The oximeter electrode is immersed vertically in a beaker containing 50 ml of the sample. The reading is taken after stabilization of the displayed value.

Fig. 1. *Echinochloa pyramidalis (Lam) Hutch*

Fig. 2. *Cyperus alternifolius* L.

Fig. 3. Experimental device assembly

(a): PVC tank and distribution pipe; (b): filling of coarse gravel;
(c): filling of sand and aeration pipe; (d) filling of fine gravel also called control filter (T-F)

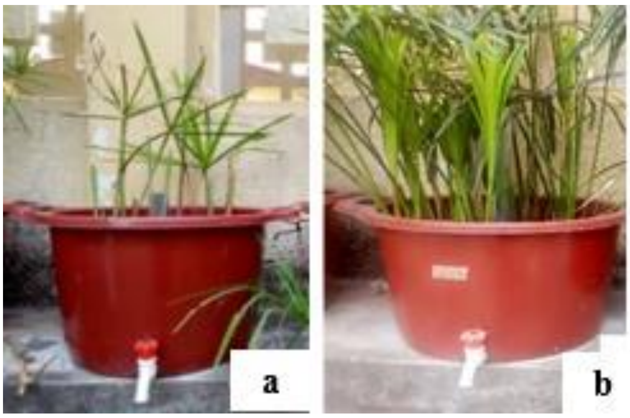

Fig. 4. Planted filters experimental device

(a): Echinochloa pyramidalis (Lam) Hutch or EP-F; (b): Cyperus alternifolius L.*or CA-F*

Fig. 5. Total market gutter

Fig. 6. Wastewater sampling

Fig. 7. Conditioning of wastewater from the total market gutter

2.4.2 Suspended Matter (SM) measurement

Suspended matter (SM) were determined by the wastewater filtration method. To do this, the filter paper is first dried in an oven at 105°C. Then the mass of filter paper (Mempty) is weighed. 50ml of the sample is filtered through filter paper before being placed in an oven at 105°C during 24 hours to be dehydrated. Finally, the filter paper is reweighed after dehydration ($M_{105°C}$). The suspended matter content is calculated using the dry matter mass obtained after separation of SM from wastewater, then dehydration at 105°C in an oven. According to the formula:

SM= M105°C-M(empty)/ Vsample

With:

$M_{105°C}$ = sample mass (mg) after deshydratation in oven at 105°C;

M (empty) = membrane mass (mg) when empty;

V_{sample}= volume of the water sample studied (l).

2.4.3 Turbidity measurement

Turbidity was determined by the light scattering method (NFT 90-033) using the Turbiquant Orion AQ3010 turbidimeter. The measurement using the turbidimeter is done by introducing at least 50 ml of the sample into a tank and the reading is taken after stabilization of the displayed value.

2.4.4 Chemical oxygen demand (COD) measurement

Chemical oxygen demand (COD) was measured by using AFNOR standard (NF, T90-101) which consists of introducing 2 ml of sample into an acidic medium containing the appropriate reagent (commercial solution composed of $HgSO_4$, H2SO4, Ag_2SO_4). The whole is heated in a COD oven at 150°C for two hours. After cooling, the calculation of the COD is carried out using the Pottier Method (1993) by applying the following formula:

$$COD = 336 \times Abs - 48.8 \times R$$

With:

R (Correlation coefficient) = 0.95
Abs: Absorbance measured with wavelength (λ=330 nm).

2.4.5 Ammoniums ions (NH_4+) measurement

Ammonium ions (NH_4^+) concentrations were determined by the Nessler method which consists of taking 1ml of the sample which is adjusted to 25ml with distilled water. Three (03) drops of mineral stabilizer and 3 drops of polyvinyl alcohol are successively added to the mixture. After stirring, the mixture is supplemented with 1ml Nessler's reagent. Then, the cell is introduced into the Aqualytic AL800 type spectrophotometer. The reading was taken at λ=425 nm.

2.4.6 Nitrates ions (NO_3^-) measurement

Nitrates (NO_3^-) concentrations were determined by colorimetry method according to standard NF T90-012. According to this method, 1mL of sulfuric acid is added to each capsule. We wait 10 min before adding approximately 10 mL of water and 10 mL of ammonia to each capsule. The contents of each capsule are transferred into a series of 25mL volumetric flasks. Then, we adjust to 25mL with the capsule rinsing water. The photometric measurements are carried out at the maximum of the absorption curve (wavelength close to 415 nm) after having adjusted the device to zero absorbance relative to water.

2.4.7 Orthophosphate ions (PO_4^{3-}) measurement

Orthophosphates ions (PO_4^{3-}) concentrations were determined by the calorimetric method. 20 ml of water are introduced into a 25 ml volumetric flask, 1 ml of ascorbic acid solution is then added and the procedure is continued as for establishing the calibration curve. Reading is done with the AQUALYTIC-AL800 spectrophotometer at a wavelength λ= 700 nm or 880 nm.

2.5 Dosage of Pollutants in Plants

The harvested plants were washed with tap water then rinsed with distilled water to avoid atmospheric contamination. They were then spread out and dried at ordinary temperature. Then, they were crushed and reduced to powder using a porcelain mortar. A mass of 15 g of plant powder was weighed then transferred to an Erlenmeyer flask, adding approximately 125 ml of distilled water. The mixture was then mixed well with a magnetic stirrer. The mixture was then left to settle for 30 minutes. We then filtered the mixture to recover the liquid phase. Nitrate, ammonium and orthophosphate ions as well as COD were quantified in the filtrate using the same techniques used for wastewater and treated water.

3. RESULTS AND DISCUSSION

3.1 Evolution of the Dissolved Oxygen (O_{2d}) Content in Wastewater Filtered Using Plants

Fig. 8 presents the dissolved oxygen (O_{2d}) content evolution as a function of time in the raw wastewater (RW) from the Total market gutter and in the three distinct filters: T-F (control filter without plant), EP-F (*Echinochloa pyramidalis (Lam) Hutch* planted filter) and CA-F (*Cyperus alternifolius* L. planted filter). We note that dissolved oxygen evolution shows higher concentrations in the filters (T-F, EP-F, CA-F) than those of raw wastewater (RW). We note that:

- the dissolved oxygen (O_{2d}) content in raw wastewater (RW) remains less than 0.85 mg/l throughout the study duration,
- the O_{2d} levels increase slightly over time after the wastewater passes through the T-F control filter,

- the O_{2d} levels increase enormously over time after the wastewater passes through the 2 planted filters EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.), with better oxygenation for the planted filter EP-F (Echinochloa pyramidalis (Lam) Hutch),
- the dissolved oxygen content of T-F, EP-F and CA-F planted filters are respectively 0.85 mg/l; 4.00 mg/l and 2.85 mg/l on the 90th day of treatment.

The low levels of dissolved oxygen content observed in the supply water are due to organic load of urban discharges emanating from Brazzaville districts without any prior treatment. Dissolved oxygen (O_{2d}) content is reduced by the activity of bacteria by decomposing the organic matter present [12]. The high levels of dissolved oxygen content in the EP-F and CA-F filtrates, compared to the T-F control filtrate, can be explained essentially due to the high wind speeds provided by the plants (Echinochloa p and Cyperus A) used which generate continuous mixing of the water mass and consequently enrich the dissolved phase with dissolved oxygen or the reduction in water temperature created by the shade of the plants used; because cold water contains a greater quantity of dissolved oxygen than hot water [13]. Overall, these results show that the filtrate waters are more oxygenated than the wastewaters.

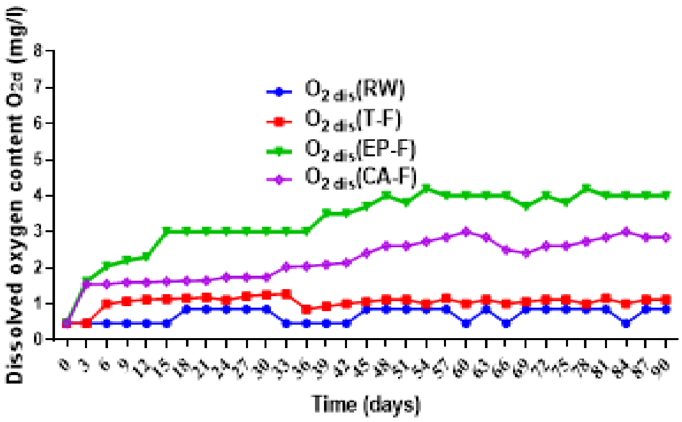

Fig. 8. Dissolved oxygen O_{2d} content evolution as a function of time in raw wastewater (RW) and in T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters

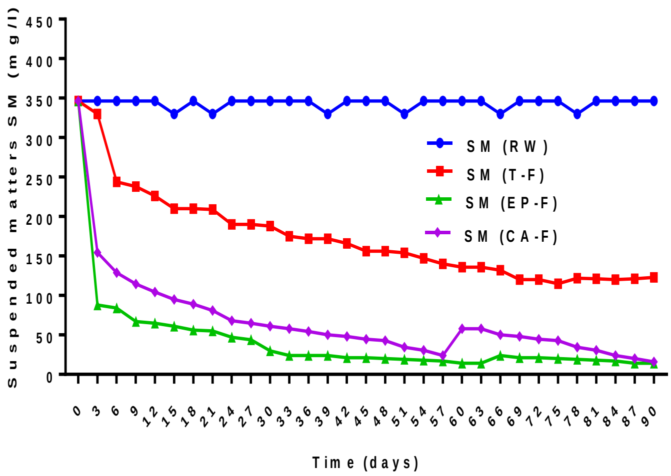

Fig. 9. Suspended matters (SM) content evolution as a function of time in raw wastewater (RW) and in T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters

3.2 Suspended Matter (SM) Content Evolution in Wastewater Filtered Using Plants

Fig. 9 shows the evolution of the suspended matter (SM) content as a function of time in the raw wastewater (RW) from the Total market gutter and in the three distinct filters: T-F (control filter without plant), EP-F (*Echinochloa pyramidalis (Lam) Hutch* planted filter) and CA-F (*Cyperus alternifolius* L. planted filter). We notice that:

- The SM content in raw wastewater (RW) is initially around 350 mg/l,
- The SM content drops enormously in filtered wastewater. On the 36th day, we note that SM content went from 350 mg/l to 188 mg/l, 30 mg/l and 61 mg/l respectively in the 3 filters T-F (control filter without plant), EP-F (*Echinochloa pyramidalis (Lam) Hutch* planted filter) and CA-F (*Cyperus alternifolius* L. planted filter). The reduction rate is therefore at 36 days of the order of 45.72% for the control filter T-F, 91.33% for the EP-F (*Echinochloa pyramidalis (Lam) Hutch*) planted filter and 82.39% for the CA-F (*Cyperus alternifolius* L.) planted filter,
- The SM content at 90 days is almost zero for the two planted filters EP-F (*Echinochloa pyramidalis (Lam) Hutch* planted filter) and CA-F (*Cyperus alternifolius* L.). The SM content of the T-F control filter remains around 123 mg/l at 90 days. The SM reduction rate at 90 days is almost 100% for the two planted filters EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) while that of the control filter is around 64.85%.

We can note a continuous decrease in the SM content up to the 60th day in the two planted filters (EP-F and CA-F). A slight increase in the SM content is observed around the 60th day for the CA-F planted filter and around the 66th day for the EP-F planted filter before decreasing again. This is due to the development of plants root and rhizomatous system which creates tunnels in the filter bed through which fine materials can pass and end up in the filtrates [14].

3.3 Turbidity Evolution in Wastewater Filtered Using Plants

Fig. 10 presents the turbidity evolution as a function of time in the raw wastewater (RW) from the Total market gutter and in the three distinct filters: T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters. We notice that:

- Turbidity in raw wastewater (RW) is initially around 432 NTU,
- Turbidity drops enormously in filtered wastewater. At 30 days, we note that the turbidity decreases from 432 to 168, 28.2 and 44.7 NTU respectively in the 3 filters T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (Cyperus alternifolius L.) planted filters. The turbidity reduction rate is therefore at 30 days in order of 61.11% for the control filter T-F, 93.47% for the EP-F (E*chinochloa pyramidalis (Lam) Hutch*) planted filter and 89 .65% for the CA-F (*Cyperus alternifolius* L.) planted filter.
- The turbidity at 90 days is almost zero for the two planted filters EP-F (*Echinochloa pyramidalis (Lam) Hutch* lter) and CA-F (*Cyperus alternifolius* L.). The turbidity of the T-F control filter remains around 150 NTU at 90 days. The turbidity reduction rate at 90 days is almost 100% for the two planted filters EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) while that of the control filter is around 65%.

These results are explained by the fact that the implanted bed allows good elimination of suspended matter degraded by bacterial activity at the roots because turbidity is directly linked to the SM in wastewater. The presence of macrophytes prevents clogging and significantly improves the settling capacity, moreover its density presents a physical obstacle for the particles and allows the clarification of the water which was initially cloudy [15]. These curves are also similar to those obtained for suspended matter.

3.4 Chemical Oxygen Demand (COD) Evolution in Wastewater Filtered Using Plants

Fig. 11 presents the COD evolution as a function of time in the raw wastewater (RW) from the Total market gutter and in the three distinct filters: T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters. The evolution of curve relating to chemical oxygen demand (COD) shows a decreasing trend. Indeed:

- The COD in raw wastewater (RW) is initially around 524.84 mg O_2/l,
- COD drops enormously in filtered wastewater. On the 30th day, the COD decreases from 524.84 mg O_2/l in raw wastewater (RW) to 273.18 mg O_2/l, 85.7 mg O_2/l and 142.1 mg O_2/l respectively in the 3 filters T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters. The COD reduction rates are therefore at 30 days in the order of 47.94% for the control filter T-F, 84.05% for the EP-F (*Echinochloa pyramidalis (Lam) Hutch*) planted filter and 72.92% for the CA-F (*Cyperus alternifolius* L.) planted filter,
- The COD at 90 days is 129 mg O_2/l for the EP-F (*Echinochloa pyramidalis (Lam) Hutch)* planted filter and 100 mg O_2/l for the CA-F (*Cyperus alternifolius* L.) planted filter. The COD of the T-F control filter remains around 161 mg O_2/l at 90 days. The reduction rate of COD at 90 days is around 75.42% for the EP-F (*Echinochloa pyramidalis (Lam) Hutch*) planted filter and 80.94% for the CA-F (*Cyperus alternifolius* L.) planted filter while that of the control filter is around 69.32%.

These results confirm the effectiveness of wastewater treatment by filters planted with macrophytes according to the elimination of organic matter. These results are in agreement with those of Mahunon [16] who worked on the phytoremediation of pigsty wastewater using Eicchornia crassipes as a purifying plant. Furthermore, after 50 days, we observe a gradual increase in planted filtrates COD content. This can be explained by the aging or death of certain macrophytes in the filters. Indeed, the decomposition of macrophytes in water following this mortality causes the environment enrichment in nutrients and organic compounds [17,18].

3.5 Ammoium NH_4^+ ions Concentration Evolution in Wastewater Filtered Using Plants

Fig. 12 shows the NH_4^+ ammonium ions concentration evolution as a function of time in the raw wastewater (RW) from the Total market gutter and in the three distinct filters: T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters. The curves relating to NH_4^+ ions concentration also show a decreasing trend. Indeed, on the 30th day, it went from 80 mg/l in raw wastewater (RW) to 47.80 mg/l, 22.2 mg/l and 20 mg/l respectively after passing the raw wastewater into in the 3 filters T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters. The reduction rates in NH_4^+ ion content are therefore at 30 days in order of 40.25% for T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters. At 90 days, the reduction rates in the NH_4^+ ion content are in order of 54.12% for T-F (control filter without plants), F-EP (*Echinochloa pyramidalis (Lam) Hutch*) and F-CA (*Cyperus alternifolius* L.) planted filters. Planted filters present a better drop in NH_4^+ ions content certainly due to nitrification (the passage of N-NH_4 into N-NO_3) favored by suitable nutritional and oxygenation conditions [19].

3.6 Nitrate NO_3^- Ions Concentration Evolution in Wastewater Filtered Using Plants

Fig. 13 shows the NO_3^- nitrate ions concentration evolution as a function of time in raw wastewater (RW) from the Total market gutter and in the three distinct filters: T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters. The curves relating to NO_3^- ions concentration also show a decreasing trend. We notice a rapid drop in the NO_3^- concentration from the 6th day. On the 90th day, this decreased from 90 mg/L in the raw wastewater (RW) to 45 mg/l, 0.45 mg/l and 9.80 mg/l respectively after passing the raw wastewater into the 3 filters T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters. The reduction rates in the NO_3^- ions concentration are therefore at 90 days in order of 50% for the T-F control filter, 99.5% for the EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and 89.11% for the CA-F (*Cyperus alternifolius* L. *F-CA*) planted filters. This reduction could be explained by the rapid growth of macrophytes which consume a lot of nitrates ions given that it is the soluble form of nitrogen which is easily absorbed by plants [20].

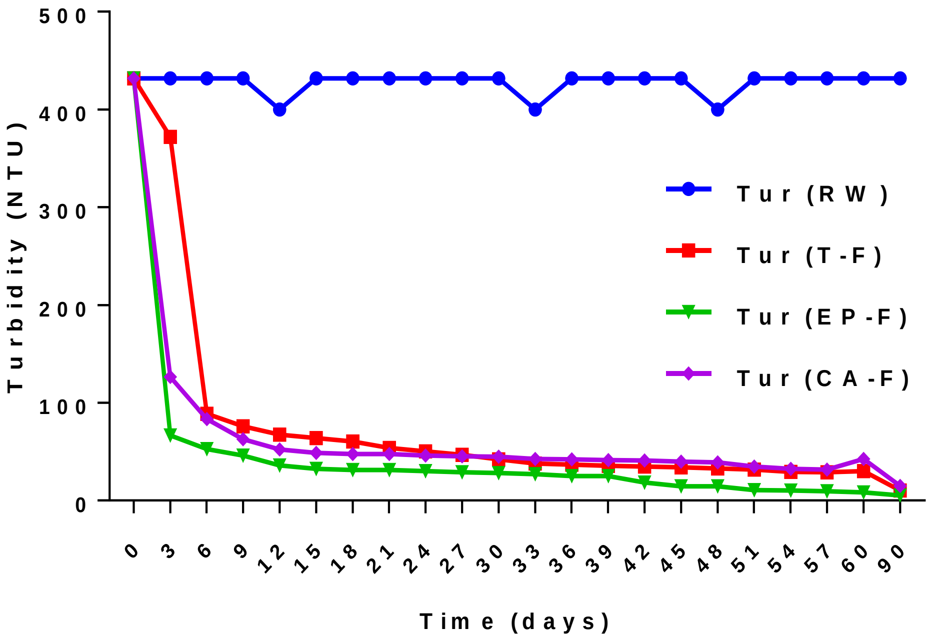

Fig. 10. Turbidity evolution as a function of time in raw wastewater (RW) and in T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters

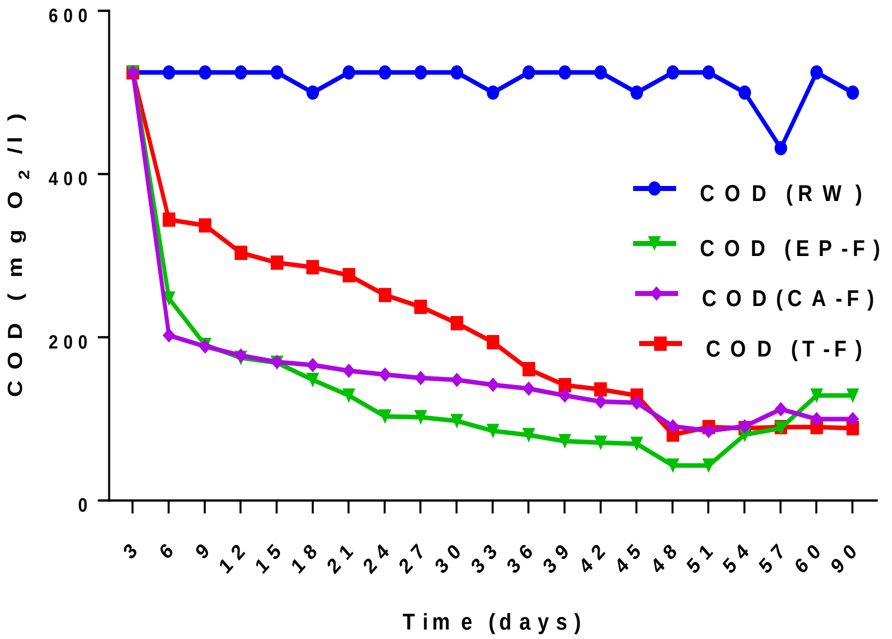

Fig. 11. COD evolution as a function of time in raw wastewater (RW) and in T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters

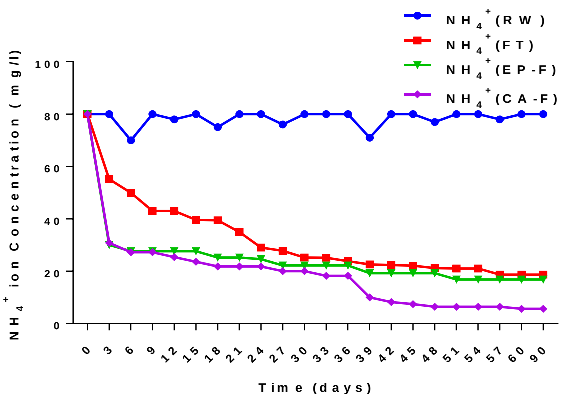

Fig. 12. NH_4^+ ions concentration evolution as a function of time in raw wastewater (RW) and in T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters

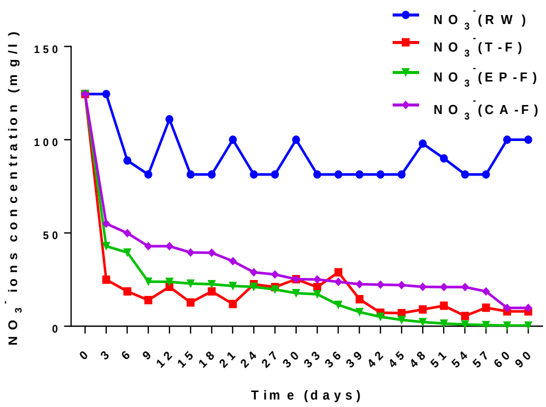

Fig. 13. NO_3^- ions concentration evolution as a function of time in raw wastewater (RW) and in T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters

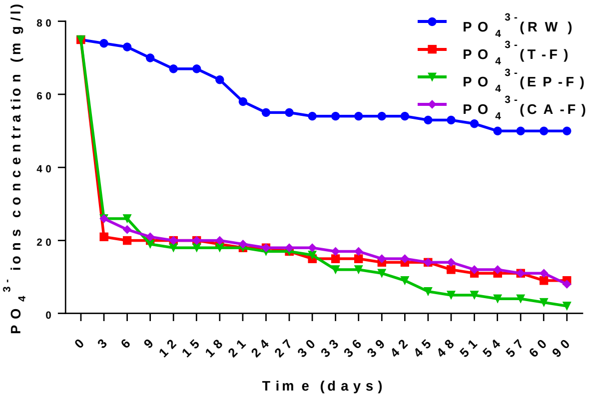

Fig. 14. PO_4^{3-} ions concentration evolution as a function of time in raw wastewater (RW) and in T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters

3.7 Orthophosphates PO_4^{3-} Ions Concentration Evolution in Wastewater Filtered Using Plants

Fig. 14 shows the PO_4^{3-} orthophosphate ions concentration as a function of time in raw wastewater (RW) from the Total market gutter and in the three distinct filters: T-F (control filter without plants), EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and CA-F (*Cyperus alternifolius* L.) planted filters. A drop in the PO_4^{3-} ions concentration in filtered wastewater is also observed. On the 30th day, the PO_4^{3-} ions concentration decrease from 75 mg/l in raw wastewater (RW) to 35 mg/l, 16 mg/l and 18 mg/l respectively in the 3 filters T-F (control filter without plant), EP-F (*Echinochloa pyramidalis* (Lam) Hutch) and CA-F (*Cyperus alternifolius* L.) planted filters.

The PO_4^{3-} ions reduction rates are therefore at 30 days in order of 42.64% for the T-F control filter, 72.63% for the EP-F (*Echinochloa pyramidalis (Lam) Hutch*) and of 69.20% for the CA-F (*Cyperus alternifolius* L.) planted filters. At the end of treatment at 90 days, the PO_4^{3-} ions concentration is around 29 mg/l for the EP-F (*Echinochloa pyramidalis (Lam) Hutch*) planted filter and 2 mg/l for the CA-F (*Cyperus alternifolius L*) planted filter. Or a reduction rate at 90 days of 99.73% for the EP-P (*Echinochloa pyramidalis (Lam) Hutch*) planted filter and 98.93% for the CA-F (*Cyperus alternifolius* L.) planted filter while that of the control filter T-F is around 61.33%. This can be explained by the direct use of P-PO_4 by plants [21] or attributed to adsorption on the soil particles [22] and precipitation reactions [23]. At the same time, microbial populations that reside in submerged roots can assimilate PO_4^{3-} ions present in wastewater [24].

3.8 Evolution of COD and NH_4^+, NO_3^-, PO_4^{3-} ions Concentrations in the EP (*Echinochloa pyramidalis (Lam) Hutch)* and CA (*Cyperu Alternifolius* L.) plants

3.8.1 Evolution of COD and NH_4^+, NO_3^-, PO_4^{3-} ions concentrations in the EP (*Echinochloa pyramidalis (Lam) Hutch)* plant

We evaluated the effectiveness of the experimental device by measuring the contents of COD and NH_4^+, NO_3^- and PO_4^{3-} ions in EP (*Echinochloa pyramidalis (Lam) Hutch*) plant before and after raw wastewater (RW) passage into this planted filter. It appears for the EP plant (*Echinochloa pyramidalis (Lam) Hutch*) that (Fig. 15): the COD increases with time after raw wastewater (RW) passage into the plant compared to the plant before raw wastewater passage. It goes from 17.5 mg O_2/l before treatment to 51.84 mg O_2/l after 30 days of treatment with wastewater and to 89.84 mg O_2/l after 90 days of treatment with wastewater. The NH_4^+ ions concentration also increases over time inside the plant. In fact, it goes from 8.4 mg/kg before raw wastewater passage to 41.35 mg/kg after 30 days of treatment with wastewater and to 49.95 mg/kg after 90 days of treatment with wastewater. The NO_3^- ions concentration also increases with time inside the plant. Indeed, it goes from 13.40 mg/kg before raw wastewater passage into the plant to 45.95 mg/kg after 30 days of treatment with wastewater and to 65.35 mg/kg after 90 days of treatment with wastewater. The PO_4^{3-} ions concentration increases until the 30th day of treatment with wastewater then decreases at 90 days inside the plant. In fact, it goes from 4.3 mg/kg before raw wastewater passage to 21.87 mg/kg after 30 days of treatment with wastewater and to 16.54 mg/kg after 90 days of treatment with wastewater.

3.8.2 Evolution of COD and NH_4^+, NO_3^-, PO_4^{3-} ions concentrations in CA (*Cyperus alternifolius* L. plant

We evaluated the effectiveness of the experimental device by measuring the contents of COD and NH_4^+, NO_3^- and PO_4^{3-} ions in CA (*Cyperus alternifolius* L.) plant. Concerning the CA (*Cyperus alternifolius* L.) plant, we noted the following (Fig. 16): the COD increases with time after raw wastewater (RW) passage into the plant compared to the plant before raw wastewater passage into plant. It goes from 20.5 mg O_2/l before treatment with wastewater to 40.68 mg O_2/l after 30 days of treatment with wastewater and to 63.68 mg O_2/l after 90 days of treatment with wastewater.

The NH_4^+ ions concentration also increases over time inside the plant. Indeed, it goes from 7.4 mg/kg before treatment with wastewater to 20.46 mg/kg after 30 days of treatment with wastewater and to 34.79 mg/kg after 90 days of treatment with wastewater. The NO_3^- ions concentration

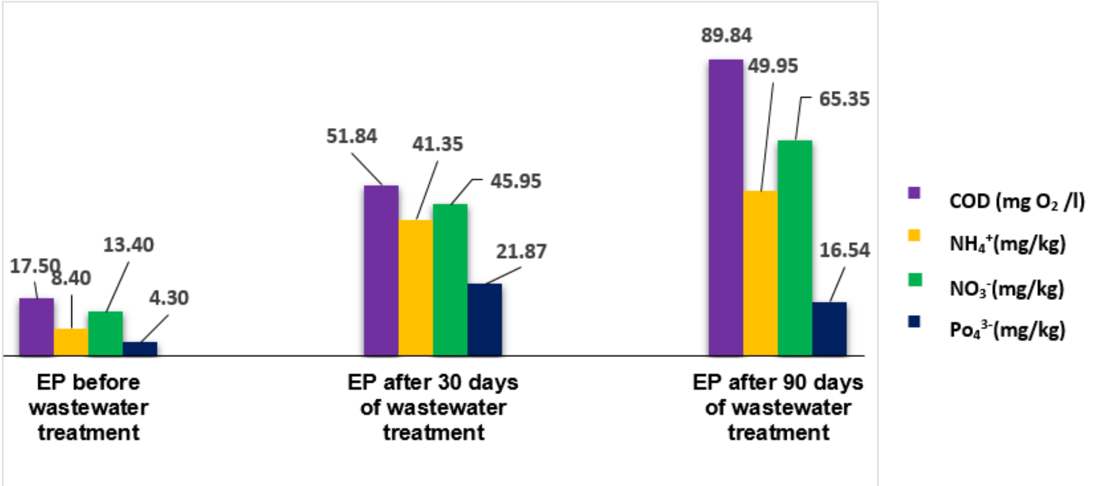

Fig. 15. Evolution of COD and NH_4^+, NO_3^- and PO_4^{3-} ions concentration as function of time in the EP (*Echinochloa pyramidalis (Lam) Hutch*) plant before and after 30 and 90 days of treatment with wastewater

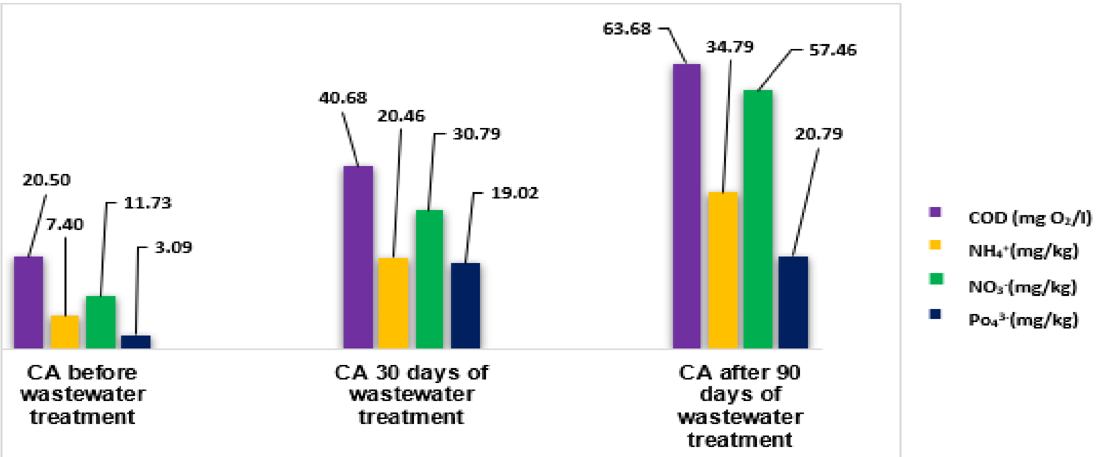

Fig. 16. Evolution of COD and NH_4^+, NO_3^- and PO_4^{3-} ions concentration as function of time in the CA (*Cyperus alternifolius* L.) plant before and after 30 and 90 days of treatment with wastewater

also increases with time inside the plant. Indeed, it goes from 11.73 mg/kg before treatment with wastewater to 30.79 mg/kg after 30 days of treatment with wastewater and to 57.46 mg/kg after 90 days of treatment with wastewater. The PO_4^{3-} ions increases with time and slightly between 30 and 90 days inside the plant. In fact, it goes from 3.09 mg/kg before treatment with wastewater to 19.02 mg/kg after 30 days of treatment with wastewater and to 20.74 mg/kg after 90 days of treatment with wastewater.

The results obtained show an increase in the COD content within the plant itself. This shows that organic pollution and organic oxidizable materials are the main sources of plant nutrition [25]. The high concentrations of nitrate NO_3^- ions and ammonium NH_4^+ ions found in EP (*Echinochloa pyramidalis (Lam) Hutch*) CA (*Cyperus alternifolius* L.) plants after wastewater treatment were extracted from wastewater because macrophytes mainly absorb inorganic nitrogen in the form of nitrates (NO_3^-) and ammonium (NH_4^+) which are essential for plant tissues growth and can be stored in the different organs (roots, rhizomes, stems and leaves) [26]. This explains the reduction in these elements, observed in our study for filters installed during wastewater treatment. Concerning the high PO_4^{3-}

ions orthophosphate concentrations in EP (*Echinochloa pyramidalis (Lam) Hutch*) CA (*Cyperus alternifolius* L.) plants after wastewater treatment could result from plant assimilation and by the absorption of PO_4^{3-} in the plant [27]. Indeed, phosphate is an essential constituent for the development of plants, assimilated in the form of orthophosphates at their roots and transported to the rest of the plant. These results confirm the reduction of PO_4^{3-} ions concentrations in wastewater at the outlet of two purification systems that was observed upstream of this study.

4. CONCLUSION

This study aimed to evaluate the purifying power of two Congolese plant filters EP-F *(Echinochloa Pyramidalis (Lam)Hutch*) and CA-F (*Cyperus alternifolius* L.) on wastewater from the Total market in Brazzaville (Congo). The results showed that wastewater from the Total market gutter had low oxygenation and significant concentrations of suspended matter (SM), turbidity, COD, NH_4^+ ions, NO_3^- ions and PO_4^{3-} ions. The planted filters device entirely irrigated by wastewater made it possible to obtain their purification by the removal of nutrients contained in wastewater and by the supply of oxygen into the environment. For the two planted filters, the purification efficiency or the rate of reduction for turbidity is almost 100%, between 45%-80% for SM, between 75%-93% for COD, between 76%-93% for NH_4^+ ions, between 89%-99% for NO_3^- ions and between 98%- 99% for PO_4^{3-} ions. However, we noted that CA-F (*Cyperus alternifolius* L.) plant filter had a purification efficiency slightly higher than EP-F (*Echinochloa Pyramidalis (Lam)Hutch*) plant filter for SM, COD and NH_4^+ ions. The EP-F (*Echinochloa Pyramidalis (Lam)Hutch*) plant filter ensured better oxygenation of wastewater and has a purifying efficiency slightly higher than CA-F (*Cyperus alternifolius L)* plant filter for NO_3^- ions and PO_4^{3-} ions. The quantification of organic and minerals materials in the macrophytes EP (*Echinochloa Pyramidalis (Lam)Hutch*) and CA (*Cyperus alternifolius* L.) after wastewater treatment showed higher levels of these elements in the plants compared to the plants before wastewater treatment. This would suppose that there is indeed a link between the purification of this wastewater and the plants. In view of the various results obtained, this plants treatment technique or phytopurification can be considered for improving the wastewater quality for their reuse or before their release into the environment.

ACKNOWLEDGEMENTS

The authors express their deep gratitude to the UC2V laboratory located in Faculty of Sciences and Technics (University Marien NGOUABI) at Brazzaville for carrying out this research.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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