Journal of Applied Research in Water and Wastewater

E-ISSN: 2476-6283

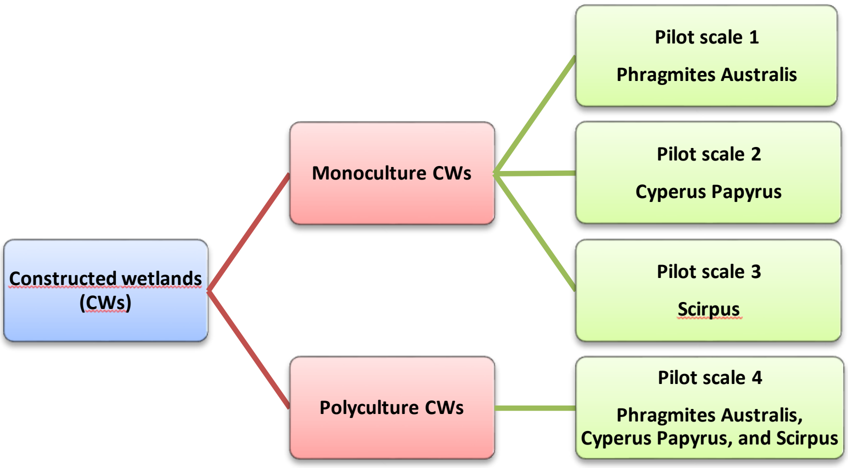
Journal homepage: https://arww.razi.ac.ir

Performance of polyculture constructed wetland compared with monoculture in treating domestic wastewater

Sara Youcef *, **Nora Seghairi**

Research laboratory in civil engineering, hydraulics, sustainable development and environment (larghyde). Mohamed Kheider University, Biskra, Algéria.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 16 February 2022
Reviewed 18 April 2022
Received in revised form 27 June 2022
Accepted 28 June 2022
Available online 28 June 2022

Keywords:
Constructed wetland
Cyperus Papyrus
Phragmites Australis
Scirpus
Polyculture CWs

Article type: Research Article

ABSTRACT

This study aimed to determine the performance of polyculture constructed wetlands compared with monocultures and to monitor plant type influence in treating wastewater. Four pilot scales were used and planted with three plant kinds (Phragmites Australis, Cyperus Papyrus, and Scirpus). Three of them were monoculture systems, and the last one was a polyculture system with all these plants. The filters had identical sizes and the same density. After seven days of retention time, results showed that the pH obtained was around neutral ranging from 6.91 to 7.32; the electrical conductivity increased significantly and it was between 4.47-5.47 mS/cm. Removal efficiencies of phosphate, ammonium, nitrite, and chemical oxygen demand were between 75.29-79.90%, 91.27-92.51 %, 83.33-86.32%, and 84.61-88.52%, respectively. Papyrus filter had the higher removal efficiencies in most of these parameters, and the polyculture system didn't increase the filter performance; however, the differences between these filters were not significant, except for the electrical conductivity.

1. Introduction

In developing countries, most of the domestic wastewater amounts are discharged in nature without any advanced treatment, which degrades the receiving aquatic system quality (Zurita et al. 2011). Because of the high costs of conventional treatment systems, constructed wetlands (CWs) can be used instead of theme, especially in the rural areas with a population up to 2000 EH (Carballeira et al. 2016; Leiva et al. 2018). CWs are economical and have good performance (Leiva et al. 2018; Stefanakis et al., 2009). Also, they are eco-friendly and use the same process in the natural wetland for treating wastewater (Türker et al. 2016a) and provide aesthetic value (Chang et al. 2012).

CWs can remove contamination in wastewater, like nutrients, pathogens, organic and inorganic contaminants, and provide public health protection (Abou-Elela and Hellal 2012). They can treat a

*Corresponding author Email: e_yusefi_31@birjand.ac.ir

Please cite this article as: S. Youcef, N. Seghairi, Performance of polyculture constructed wetland compared with monoculture in treating domestic wastewater, *Journal of Applied Research in Water and Wastewater*, 9 (1), 2022, 46-51.

variety of wastewater, like domestic wastewater, storm runoff, non-point source pollution, eutrophic water bodies, agricultural drainage, and secondary wastewater (Chang et al. 2012). CW body consists of wetland plants, soils, and associated microorganisms (Giri and Kumar 2013), where plants play an essential role (Calheiros et al., 2015). Most previous studies have shown that planted CWs achieved higher treatment efficiency than unplanted systems(Akratos and Tsihrintzis 2007; Carballeira et al. 2016); and plant type influenced the removal rate of some pollutants such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrogen (N) and total phosphorus (TP)(Abou-Elela and Hellal 2012).

The most frequent plants used around the globe are Phragmites, Typha, Scirpus spp. (Tsihrintzis 2017; Zamora et al. 2019), rush (Juncus effusus L.), yellow flag (Iris pseudacorus L.), mannagrass (Glyceria maxima), and giant reed (Arundo donax L.) (Białowiec et al. 2014). Plants contribute to the pollutants removal and affect their pathways(Türker et al. 2016b) by their physical effects (like reduction in the velocity of water flow, promotion of sedimentation, stabilizing the sediment surface, less erosion, prevention of immediate clogging) (Sandoval et al. 2019), and by the nutrients' uptake. Further, they stabilize the bed surface and insulate it against coldness and the microorganism hosting (Belmont et al. 2004; Carballeira et al. 2016; Leiva et al. 2018). Furthermore, they release oxygen, provide organic carbon and enzymes through root exudates (Zhang et al. 2018; Zheng et al. 2020). Moreover, plants can tolerate high concentrations of heavy metals and accumulate them in their tissues (Stottmeister et al. 2003). The role and the effects of different plant species as mono or polyculture in wastewater treatment are controversial (Karathanasis et al. 2003; Leiva et al. 2018). Most world's CWs systems are monocultures despite polyculture systems provide better distribution of the root biomass, more diverse microbial population(Abou-Elela and Hellal 2012; Calheiros et al. 2015), and increase the root exudates, which stimulate the uptake of N and P in CWs (Calheiros et al., 2015). Furthermore, the roots' diversity slows wastewater flow through the system, thus increasing the retention time (Abou-Elela and Hellal 2012). Their removals of most nutrients were higher than those in monoculture and unplanted control (Zhu et al. 2018). Interspecific competition intensifies plants' nitrogen and phosphorus uptake (Zheng et al. 2020). All these reasons seem to improve treatment efficiency and give better removal rates. In Algeria and especially in the arid areas, CWs represent suitable solutions to reduce environmental pollution risk by wastewater. However, studies on it are still limited. This research is one of a group related to the application of this system in these areas and using local materials such as plant species available there. This present study aimed to evaluate the performance of many local plant types in treating wastewater in CWs, and observe the difference between them in organic compounds and nutrient removal. In addition, to make a comparison between the monoculture and polyculture systems and see if the latter improves the system's efficiencies.

2. Materials and methods

2.1. Site description and design

The experiment pilot was carried out at the station of the hydraulics department in Biskra's University, located in the south-east of Algeria and characterized by an arid climate with a hot, dry summer; and a mild winter.

Four pilot-scales were established to monitor the difference between three plant species in monoculture and polyculture filters. Four identical plastic basins were used with round shapes and 36cm in height; they were equipped with plastic taps at the bottom to evacuate water and a PVC tube of 2cm diameter to ensure aeration. These pilots were planted in the following manner: with Phragmites Australis, Cyperus Papyrus, and Scirpus, as monoculture wetlands, and the last one was planted as a polyculture system combining these entire species. These plants were collected from near places around the university. The substrate consists of three layers of gravel of different sizes that have been washed. The density was maintained the same in all these units to keep the same conditions. These pilots were filled with domestic wastewater from Biskra's discharge. Samples were taken on 3, 5, and 7 days and the analyses were carried out at the LARGHYDE laboratory according to the analytical standard methods described by Rodier et al (Rodier et al. 2009).

3. Results and discussion

3.1. Evolution of pH

Water pH is an essential physicochemical parameter through which we can control the metal biogeochemistry in aquatic environments (Xu et al. 2019). It influences the removal of nitrogen and organic matter in a CW (Merino-Solís et al. 2015). Fig. 1 shows the pH values in the outlet of the four tanks; these values fluctuated around neutrality, ranging from slightly acidic to slightly alkalic (6.91-7.32). These results are suitable with other studies where pH values ranged from (6.5–7) to (7–7.5) (Leiva et al. 2018; Stefanakis and Tsihrintzis 2012; Xu et al. 2019). Compared to the influent wastewater (pH 6.8), there was a low elevation due to the interactions between the substrate, the biofilm, and the plant (Stefanakis and Tsihrintzis 2012). On the other hand, there were no significant differences between monocultures and polyculture filters and between the three plant species.

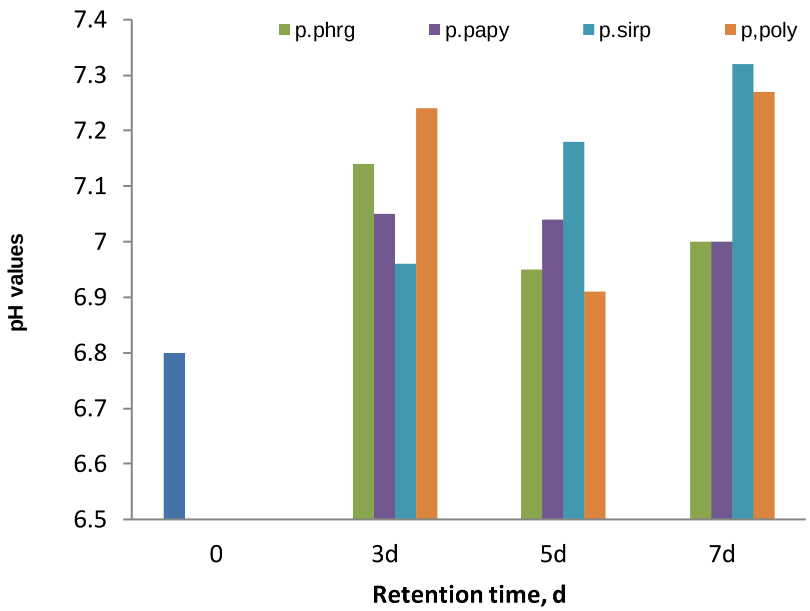


Fig. 1. pH values in the inlet and the outlets of the pilot-scales.

3.2. Electrical conductivity (EC)

Fig. 2 shows the variation of EC. It increased significantly in the outlets of all filters compared with the inlet 3.4 mS /cm. As in the literature, the effluent EC values were higher than the influent values in all CWs systems (Yalcuk and Ugurlu 2009). EC was more important in the filter planted with Phragmites with values between (5.45-5.47 mS/cm) than in the Papyrus filter with values between (5.04-5.08 mS /cm); In the filter planted with Scirpus it was (4.11- 4.49 mS /cm) and (4.52-4.48 mS/cm) for the polyculture filter. There was a significant difference between filters (Phragmites and Scirpus), (Phragmites and Polyculture), and (Papyrus and Scirpus). This variation is due to the evapotranspiration phenomenon which varies from one plant to another, which increases the concentration of water, thus raising the EC. Phragmites and papyrus have more intense rhizome and leaf systems than Scirpus, which increases evapotranspiration capacity.

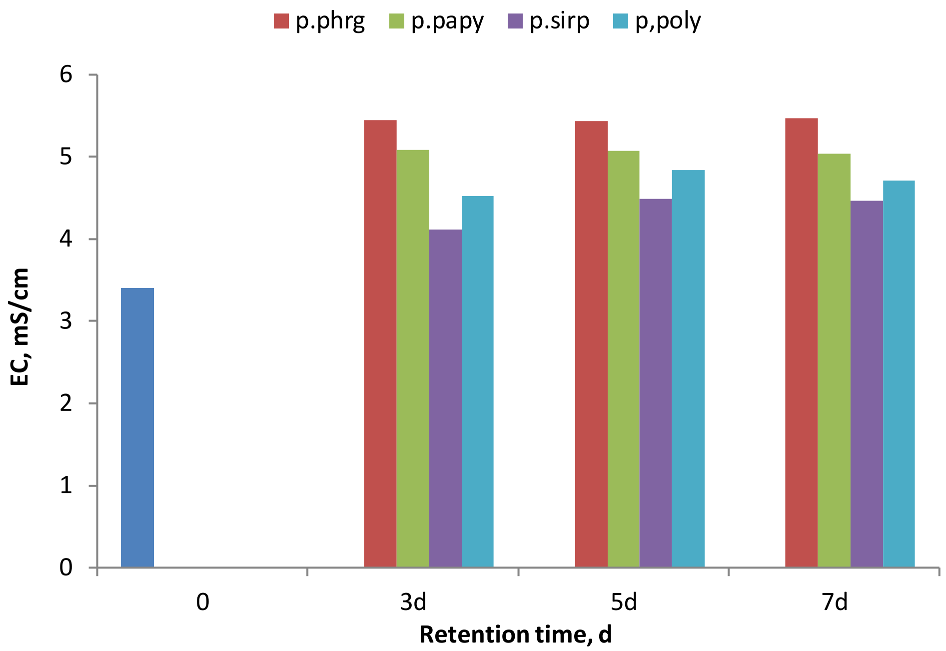


Fig. 2. Electrical conductivity values in the inlet and outlets of the pilot-scales.

3.3. Phosphate

Phosphorus (P) removal is one of the major target services of CWs in treating wastewater (Geng et al. 2017). Phosphate concentration in the influent wastewater was 3.88 mg/L. Fig. 3 shows the variation of phosphate concentrations; they were constant in the filter planted with polyculture with a removal efficiency of 76.29 %. After seven days, the elimination is more important in filters with Phragmites and Papyrus with an efficiency of 79.79 % than the filter with Scirpus 78.35 %. But no significant difference between the four filters. Phosphorus removal is related to the physical–chemical and hydrological properties of the substrate material (Vohla et al. 2007). P-PO_4^{3-} removal is due to bacteria and plant uptake (Akratos and Tsihrintzis 2007). In the existing literature, Geng mentioned that in CWs, total P removal increased with species richness due to higher biomass production and larger plant P pool (Geng et al. 2017).

Some studies showed that monoculture and polyculture systems gave the same performance in removing N and P (Calheiros et al., 2015; Geng et al. 2017; Zhang et al. 2007). In another study, Canna was better than Phragmites for nitrogen and phosphorus uptake, and Cyprus was much better than them in removing nitrogen, phosphorus, and heavy metals from wastewater (Abou-Elela and Hellal 2012). The species composition was more effective than species richness, so assembling proper plant composition is more important than simply increasing species richness for treating wastewater nutrients (Geng et al. 2017). Our results were due to the rhizosphere density of Phragmites and Papyrus, which gives a high assimilation capacity and a large subsoil storage reservoir; also, the colossal biomass of these two plants compared to Scirpus, and they provide a large above-ground P reservoir.

3.4. Ammonium

Fig. 4 shows ammonium concentrations in the effluent and influent wastewater. After a residence time of 7 days, the filter planted with Phragmites was more efficient with a removal efficiency of 92.51%, and then the polyculture filter with 92.25%, which was more efficient than the Papyrus filter with 92.04%, and the Scirpus filter with 91.27%; however the difference between all these filters were not statistically significant. The removal of nitrogen in CWs occurs through many pathways by bacteria, plant uptake, adsorption (ionized ammonia reacts with the media in SF constructed wetland), and volatilization (ammonia is transformed to free nitrogen) (Akratos and Tsihrintzis 2007). Vegetation type has an important role in nitrogen removal which is more significant than organic matter removal (Akratos and Tsihrintzis 2007). In literature, ammonium removal in some studies was higher in monoculture CWs than the polyculture during the first operation year (Liang et al., 2011). But later, it was significantly higher in the polyculture systems (Calheiros et al. 2015). Kyambadde mentioned in his study that Cyperus Papyrus showed higher ammonium removal than Miscanthidium violaceum and unplanted filters (Kyambadde et al. 2004). In another comparative study, there was no significant difference between them (monoculture and polyculture systems) (Zhang et al. 2007). While In Zhu's 2018 study, the polyculture system showed better removal efficiency as compared to monoculture or unplanted filters (Zhu et al. 2018).

Fig. 5 shows the concentration of nitrite in different filters. It noted after seven days that the nitrite concentration was less in the Papyrus filter with a removal efficiency of 86.32 %, where it was is more important in this filter, than in the Phragmites filter, where the efficiency was 85.64 %, while in the polyculture filter, it was 85.04% and 83.33 % in the Scirpus filter. But these differences were not statistically significant.

3.6. COD

Expresses the organic matter, which is decomposed in a constructed wetland by aerobic, anaerobic microbial, and physical processes such as sedimentation and filtration(Abou-Elela and Hellal 2012; Merino-Solís et al. 2015). Fig. 6 shows COD concentrations in the effluent. After 7 days, COD removal was higher in the Papyrus filter with an efficiency of 88.52% than in the Phragmites, polyculture, and Scirpus filters with efficiencies of 84.87 %, 84.77%, and 84.61%, respectively, without significant differences between all these filters. Porous media and plant roots provide the necessary surfaces and oxygen for aerobic bacteria to grow (Akratos and Tsihrintzis 2007) and degrade organic matter. Papyrus root structures provided more

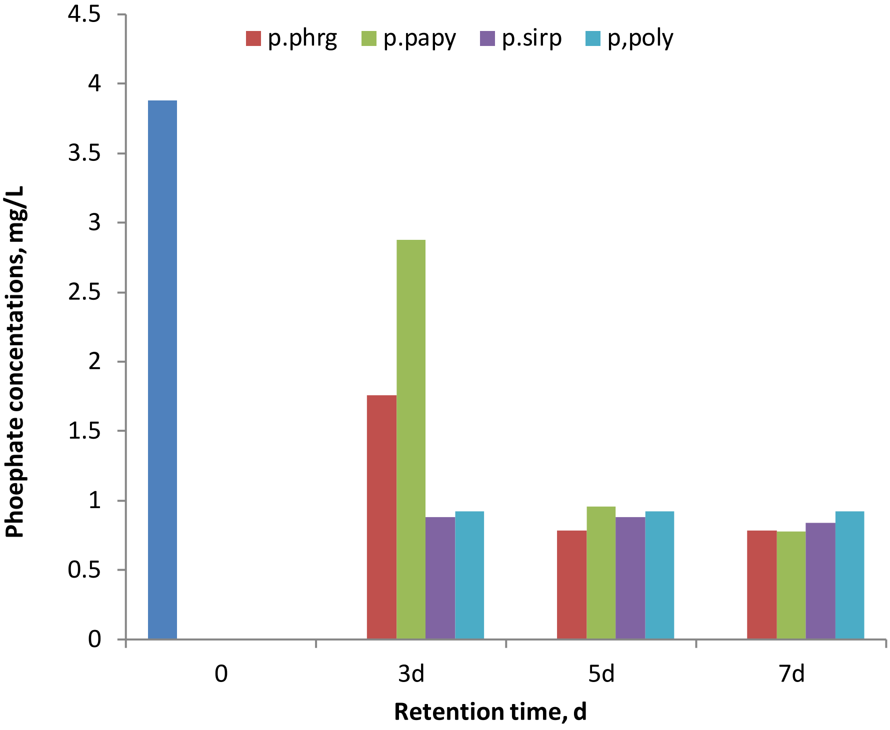


Fig. 3. Phosphate concentrations in the inlet and the outlets of the pilot-scales.

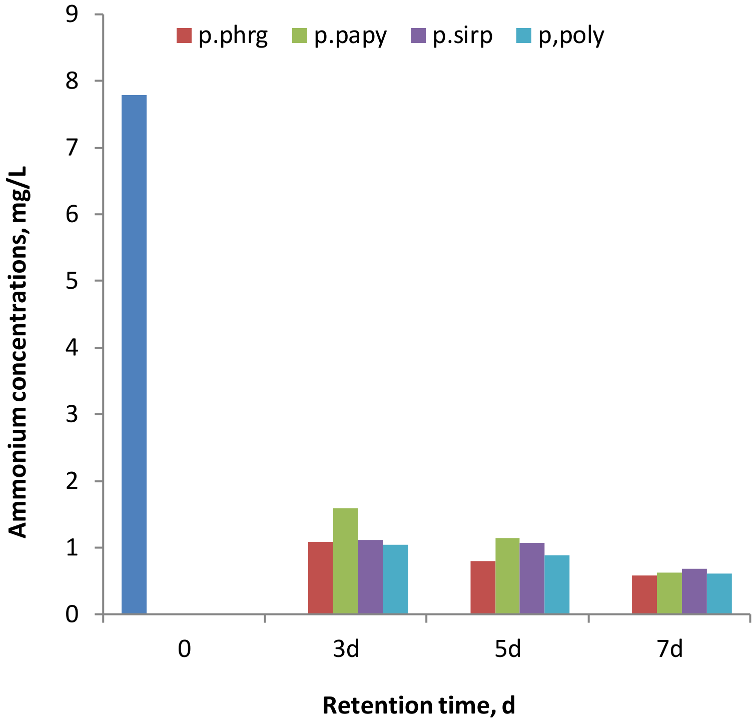


Fig. 4. Ammonium concentrations in the inlet and the outlets of the pilot-scales.

3.5. Nitrite

Microbial attachment sites, surface area for pollutant adsorption, uptake, assimilation in plant tissues, and oxygen for organic and inorganic matter oxidation in the rhizosphere (Kyambadde et al. 2004). In literature, Zhou found in his comparative study that the polyculture system is more efficient in the removal of COD with 1.2 times higher than monoculture (Zhou et al. 2017). In Leiva's study, results showed that there was no significant difference between monoculture (planted with Cyperus papyrus) and polyculture (planted with Cyperus papyrus and Zantedeschia aethiopica) systems in COD removal efficiencies (Leiva et al. 2018).

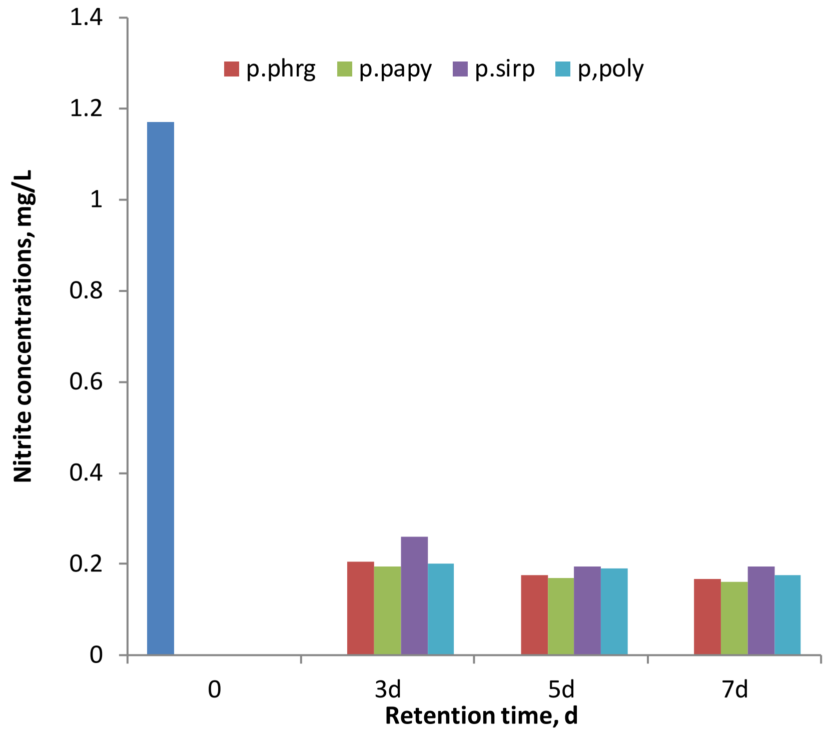


Fig. 5. Nitrite concentrations in mg/l in the inlet and the outlets of the pilot-scales.

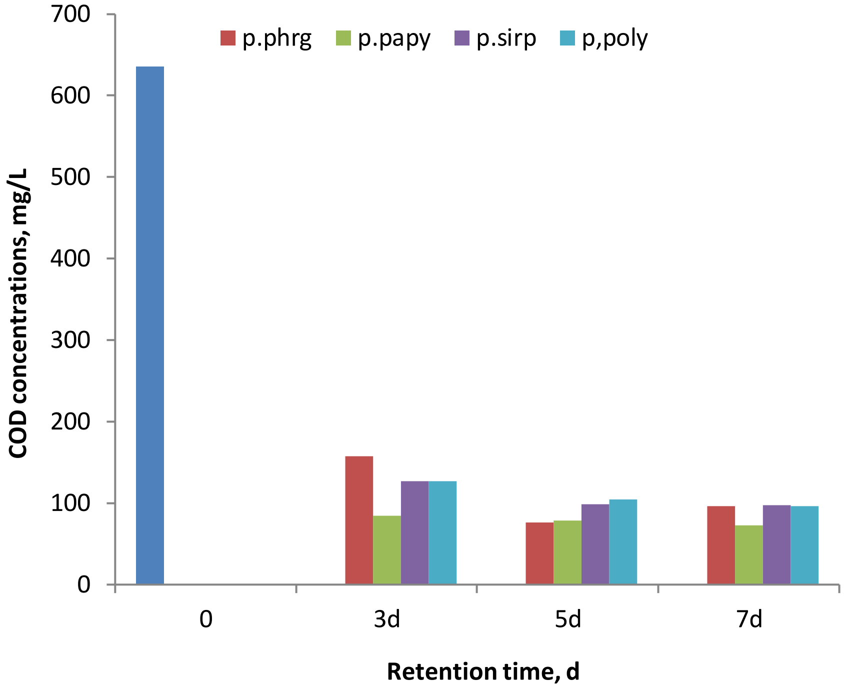


Fig. 6. COD concentrations in the inlet and the outlets of the pilot-scales.

4. Conclusions

This comparative study was between four pilots-scales planted with three different plants as monoculture and polyculture systems. After seven days of retention time, pH values fluctuated around neutrality, EC values increased significantly, and removal efficiencies of phosphate, ammonium, nitrite, and COD were between (76.29%-79.90%), (91.27%-92.51%), (83.33%-86.32%), and (84.61%-88.52%), respectively. It appears that Papyrus had better removal in most parameters, and the polyculture system didn't increase the filter performance, but these differences were not significant, except for CE where it was noted more important in the filter planted with Phragmites, and there was a significant difference between these filters (Phragmites and Scirpus), (Phragmites and polyculture), (Papyrus and Scirpus). These results prove that species composition and plant type is more effective than species richness.

Acknowledgement

We thank everyone who supported us from near or far in carrying out this work.

References

Abou-Elela S.I., and Hellal M.S., Municipal wastewater treatment using vertical flow constructed wetlands planted with Canna, Phragmites and Cyprus, Ecological Engineering 47 (2012) 209-213.

Akratos C.S., and Tsihrintzis V.A., Effect of temperature, HRT, vegetation and porous media on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands, Ecological Engineering 29 (2007) 173-191.

Belmont M. A., Cantellano E., Thompson S., Williamson M., Sánchez A., Metcalfe C.D., Treatment of domestic wastewater in a pilot-scale natural treatment system in central Mexico, Ecological Engineering 23 (2004) 299-311.

Białowiec A., Albuquerque A., Randerson P.F., The influence of evapotranspiration on vertical flow subsurface constructed wetland performance, Ecological Engineering 67 (2014) 89-94.

Calheiros C.S., Bessa V.S., Mesquita R.B., Brix H., Rangel A.O., Castro P.M., Constructed wetland with a polyculture of ornamental plants for wastewater treatment at a rural tourism facility, Ecological Engineering 79 (2015) 1-7.

Carballeira T., Ruiz I., Soto M., Effect of plants and surface loading rate on the treatment efficiency of shallow subsurface constructed wetlands, Ecological Engineering 90 (2016) 203-214.

Chang J.-j., Wu S.-q., Dai Y.-r., Liang W., Wu Z.-b., Treatment performance of integrated vertical-flow constructed wetland plots for domestic wastewater, Ecological Engineering 44 (2012) 152-159.

Geng Y., Han W., Yu C., Jiang Q., Wu J., Chang J., Ge Y., Effect of plant diversity on phosphorus removal in hydroponic microcosms simulating floating constructed wetlands, Ecological Engineering 107 (2017) 110-119.

Giri P.M., and Kumar S., Constructed wetlands for water quality improvement, recycling and reuse, Journal of Aquatic Biology and Fisheries 2 (2013) 759-763.

Karathanasis A., Potter C., Coyne M., Vegetation effects on fecal bacteria, BOD, and suspended solid removal in constructed wetlands treating domestic wastewater, Ecological Engineering 20 (2003) 157-169.

Kyambadde J., Kansiime F., Gumaelius L., Dalhammar G., A comparative study of Cyperus papyrus and Miscanthidium violaceum-based constructed wetlands for wastewater treatment in a tropical climate, Water Research 38 (2004) 475-485.

Leiva A.M., Núñez R., Gómez G., López D., Vidal G., Performance of ornamental plants in monoculture and polyculture horizontal subsurface flow constructed wetlands for treating wastewater, Ecological Engineering 120 (2018) 116-125.

Liang M.-Q., Zhang C.-F., Peng C.-L., Lai Z.-L., Chen D.-F., Chen Z.-H., Plant growth, community structure, and nutrient removal in monoculture and mixed constructed wetlands, Ecological Engineering 37 (2011) 309-316.

Merino-Solís M.L., Villegas E., De Anda J., López-López A., The effect of the hydraulic retention time on the performance of an ecological wastewater treatment system: an anaerobic filter with a constructed wetland, Water 7 (2015) 1149-1163.

Rodier J., Legube B., Merlet N., Analyse de l'eau Rodier, 9th ED., Paris; (2009).

Sandoval L., Zamora-Castro S.A., Vidal-Álvarez M., Marín-Muñiz J.L., Role of wetland plants and use of ornamental flowering plants in constructed wetlands for wastewater treatment: A review, Applied Sciences 9 (2019) 685-701.

Stefanakis A.I., Akratos C.S., Gikas G.D., Tsihrintzis V.A., Effluent quality improvement of two pilot-scale, horizontal subsurface flow constructed wetlands using natural zeolite (clinoptilolite), Microporous and Mesoporous Materials 124 (2009) 131-143.

Stefanakis A.I., and Tsihrintzis V.A., Effects of loading, resting period, temperature, porous media, vegetation and aeration on performance of pilot-scale vertical flow constructed wetlands, Chemical Engineering Journal 181 (2012) 416-430.

Stottmeister U., Wießner A., Kuschk P., Kappelmeyer U., Kästner M., Bederski O., Müller R., Moormann H., Effects of plants and microorganisms in constructed wetlands for wastewater treatment, Biotechnology Advances 22 (2003) 93-117.

Tsihrintzis V.A., The use of vertical flow constructed wetlands in wastewater treatment, Water Resources Management 31 (2017) 3245-3270.

Türker O. C., Türe C., Böcük H., Çiçek A., Yakar A., Role of plants and vegetation structure on boron (B) removal process in constructed wetlands, Ecological Engineering 88 (2016a) 143-152.

Türker O.C., Türe C., Böcük H., Yakar A., Phyto-management of boron mine effluent using native macrophytes in mono-culture and poly-culture constructed wetlands, Ecological Engineering 94 (2016b) 65-74.

Vohla C., Alas R., Nurk K., Baatz S., Mander Ü., Dynamics of phosphorus, nitrogen and carbon removal in a horizontal subsurface flow constructed wetland, Science of the Total Environment 380 (2007) 66-74.

Xu X., Mills G., Lindell A., Peck E., Korotasz A., Burgess E., The performance of a free surface and metal-removing constructed wetland: How a young wetland becomes mature, Ecological Engineering 133 (2019) 32-38.

Yalcuk A., and Ugurlu, A., Comparison of horizontal and vertical constructed wetland systems for landfill leachate treatment, Bioresource Technology 100 (2009) 2521-2526.

Zamora S., Sandoval L., Marín-Muñíz J.L., Fernández-Lambert G., Hernández-Orduña M.G., Impact of ornamental vegetation type and different substrate layers on pollutant removal in constructed wetland mesocosms treating rural community wastewater, Processes 7 (2019) 531-540.

Zhang L., Lyu T., Zhang, Y., Button M., Arias C.A., Weber K.P., Brix H., Carvalho P.N., Impacts of design configuration and plants on the functionality of the microbial community of mesocosm-scale constructed wetlands treating ibuprofen, Water Research 131 (2018) 228-238.

Zhang Z., Rengel Z., Meney K., Nutrient removal from simulated wastewater using Canna indica and Schoenoplectus validus in mono-and mixed-culture in wetland microcosms, Water, Air, and Soil Pollution 183 (2007) 95-105.

Zheng Y., Yang D., Dzakpasu M., Yang Q., Liu Y., Zhang H., Zhang L., Wang X. C., Zhao Y., Effects of plants competition on critical bacteria selection and pollutants dynamics in a long-term polyculture constructed wetland, Bioresource Technology 316 (2020) 123927.

Zhou Q., Zhu H., Bañuelos G., Yan B., Liang Y., Yu X., Cheng X., Chen L., Effects of vegetation and temperature on nutrient removal and microbiology in horizontal subsurface flow constructed wetlands for treatment of domestic sewage, Water, Air, & Soil Pollution 228 (2017) 1-13.

Zhu H., Zhou Q.-w., Yan B.-x., Liang Y.-x., Yu X.-f., Gerchman Y., Cheng X.-w., Influence of vegetation type and temperature on the performance of constructed wetlands for nutrient removal, Water Science and Technology 77 (2018) 829-837.

Zurita F., Belmont M., De Anda J., White J., Seeking a way to promote the use of constructed wetlands for domestic wastewater treatment in developing countries, Water Science and Technology 63 (2011) 654-659.