Journal of Environmental Management xxx (2016) 1–11

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Review

Overview of the state of the art of constructed wetlands for decentralized wastewater management in Brazil

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ARTICLE INFO

Article history:
Received 27 August 2016
Received in revised form
3 November 2016
Accepted 7 November 2016
Available online xxx

Keywords:
Constructed wetlands
Macrophytes
Nutrients
Organic matter
Support matrix
Wastewater treatment

ABSTRACT

Conventional wastewater treatment plants (WWTPs) commonly require large capital investments as well as operation and maintenance costs. Constructed wetlands (CWs) appear as a cost-effective treatment, since they can remove a broad range of contaminants by a combination of physical, chemical and biological processes with a low cost. Therefore, CWs can be successfully applied for decentralized wastewater treatment in regions with low population density and/or with large land availability as Brazil. The present work provides a review of thirty nine studies developed on CWs implemented in Brazil to remove wastewater contaminants. Brazil current sanitation data is also considered to evaluate the potential role of CWs as decentralized wastewater treatment. Performance of CWs was evaluated according to (i) type of wetland system, (ii) different support matrix (iii) vegetation species and (iv) removal efficiency of chemical oxygen demand (COD), biological oxygen demand (BOD_5), nitrogen (N), and phosphorus (P). The reviewed CWs in overall presented good efficiencies, whereas H-CWs achieved the highest removals for P, while the higher results for N were attained on VF-CW and for COD and BOD_5 on HF-CW. Therefore, was concluded that CWs are an interesting solution for decentralized wastewater treatment in Brazil since it has warm temperatures, extensive radiation hours and available land. Additionally, the low percentage of population with access to the sewage network in the North and Northeast regions makes these systems especially suitable. Hence, the further implementation of CW is encouraged by the authors in regions with similar characteristics as Brazil.

Contents

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http://dx.doi.org/10.1016/j.jenvman.2016.11.015
0301-4797/

Please cite this article in press as: Machado, A.I., et al., Overview of the state of the art of constructed wetlands for decentralized wastewater management in Brazil, Journal of Environmental Management (2016), http://dx.doi.org/10.1016/j.jenvman.2016.11.015

1. Introduction

Water pollution has always been an important concern since it directly affects human health. Wastewater treatment plants (WWTPs) while effective systems to remove pollutants, commonly require large capital investments as well as operation and maintenance costs. Constructed wetlands (CWs) appear as a cost-effective treatment, since they can remove a broad range of contaminants by applying a combination of physical, chemical and biological process (Matamoros et al., 2005) and at the same time presenting low cost. Additionally, compared to conventional WWTPs they have a lower visual impact and lead to the production of smaller quantities of sewage sludge (Vymazal and Kröpfelová, 2008). These systems are particularly interesting to treat wastewater from small and rural communities that are isolated from the main municipality's sewage system, because they can operate with low energy consumption and do not need highly qualified operators (Vymazal and Kröpfelová, 2008). CWs are a land intensive treatment process, where the ratio of square meters per person will depend of the CWs type and design (Verlicchi et al., 2013). Therefore, CWs can be successfully applied in countries with low population density and/or with large land availability (Arias and Brown, 2009) as it is the case of Brazil.

CWs have conventionally been classified according to the used macrophytes type and water flow regime (Vymazal and Kröpfelová, 2008; Vymazal, 2007). They can be divided by flow regime in free water surface flow CW (FWS-CW) and subsurface flow CW (SSF-CW), where the later can be subdivided in vertical subsurface flow CW (VF-CW) and horizontal subsurface flow CW (HF-CW). These systems can be coupled, being designated as hybrid constructed wetland systems (H-CW). FWS-CWs can be further classified by dominant macrophyte type as free-floating plants, floating-leaved plants, emergent plants, or submerged plants (Vymazal and Kröpfelová, 2008).

Removal efficiencies in CWs will mostly depend on the hydraulic conductivity of the support matrix, type and amount of microorganisms, oxygen supply for the microorganisms, the substrate chemical characteristics (Saeed and Sun, 2012), as well as the region climate and latitude (Zhang et al., 2015). Temperature can play an important role on the CWs treatment performance, especially between FWS and SSF systems. SSF-CWs show a better insulation capacity being less sensitive to temperatures fluctuations. In contrast, FWS-CWs are more sensitive to solar radiation that can promote higher degradation rates. Furthermore, these systems are particularly effective in regions with warmer climate, as well as in regions with high light radiation to enhance plant growth (Kyambadde et al., 2004). Kivaisi (2001) reports that disease vectors, hazardous animals invasion and odours are important factors to take into account on the type of CW to be selected, especially in developing tropical regions. SSF-CWs will be less prone to insect infestation and odours compared to the open FWS-CWs, a key aspect for nearby population health. However, in terms of lifetime, FWS-CWs have a longer lifespan when compared to SSF-CWs, especially because of the support matrix clogging, one of the main limiting factors of these systems (Saeed and Sun, 2012).

The main difference between the two types of subsurface flow systems is related to the area requirements. HF-CWs have a much higher area demand when compared to VF-CWs, 5 m^2 PE^{-1} and 1–3 m^2 PE^{-1} (PE-person equivalent) respectively. Nevertheless, HF-CWs with the higher area requirement also allows these systems to have a higher flow distance, and hence, more removal potential, compared with VF-CWs. Another main difference is associated to the system feeding, that while HF-CWs are usually used with a continuous flow, the VF-CWs are fed by intermittent pulses (Vymazal, 2011). The later will allow the renovation of oxygen in the support matrix, enhancing the nitrification processes while continuous flow in the HF-CWs will allow the denitrification.

CW can be used as an effective treatment for a wide range of wastewaters: domestic (Fountoulakis et al., 2009; Paulo et al., 2013), municipal (Ávila et al., 2010), industrial (Vymazal, 2014) and agricultural runoff (Vymazal and Březinová, 2015). Likewise, several studies report that CW can also achieve a good efficiency to treat urban stormwater (Schmitt et al., 2015), polluted rivers (Borges et al., 2008; Jia et al., 2014) and reservoirs (Gomes et al., 2014).

CWs are complex systems where their efficiency depends of several variables: inlet contaminants concentrations, the presence of the bacteria in the rhizosphere and physicochemical characteristics such as the hydraulic loading, pH, redox conditions, temperature (Kadlec and Wallace, 2009). To optimize the performance of this treatment system is necessary to take into account variables such as climate conditions (Maine et al., 2007), CW design and selected support matrix, inlet quality and load, as well as the operating conditions (Brix et al., 2011; Saeed and Sun, 2012; Sezerino et al., 2015). Another key factor is to achieve a balance between the CW components macrophytes/microorganisms (Brisson and Chazarence, 2009; Song et al., 2009).

CW components selection is dependent of multiple factors. Several different types of substrates can be used as support matrix in CWs (Dordio and Carvalho, 2013; Vohla et al., 2011). The more common material used in CW are gravel, sand or a mixture of both. These materials are usually selected since they have a combination of high hydraulic conductivity with low prices (Dordio and Carvalho, 2013). According to Brix (1994) wetland aquatic plant have an important role in CW by adding oxygen to the system, improving the media filtration capacity, lowering the clogging formation prospective on HF-CW, increasing the potential area for microorganism growth, stabilize the beds surface, as well as helping to reduce the bed frosting in the cold seasons. Additionally, as part as CW maintenance these plants can be harvest and used for fertilisers or animal feeds. They are highly rich in nutrients and provided that they are without toxic levels of metal and emergent contaminants, is a further economic advantage of these systems. The work Verma and Suthar (2014) that used *Lemna gibba* to polish an urban wastewater, conclude that is was feasible to use the harvest plant for animal feed, being material with high protein and carbohydrate percentage.

These systems as a water pollution treatment have been used in Europe (Haberl et al., 2003) and North America (Vymazal, 2010) for a long time. In the last decades, studies on the application and sustainability of CWs in developing countries started to appear, due to their low cost operation requirements (Zhang et al., 2015) or in countries as China due to the fast increase of water pollution (Zhang et al., 2009). Zhang et al. (2015) report that CWs have a great