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Research paper

Effect of plants and the combination of wetland treatment type systems on pathogen removal in tropical climate conditions

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ABSTRACT

Although there are different treatment technologies to reduce water pollution, a few of them are efficient in pathogenic organism removal. Nowadays, near-nature systems like constructed wetlands (CWs) have been encouraged as alternative to remove this kind of organisms, due to their low operational and maintenance cost. The aim of this research was to evaluate different combinations (vertical and horizontal flow) of constructed wetlands as a possible technology for pathogen reduction under tropical climate (Colombia), as a result of the few research made about this kind of hybrid systems (train with vertical and horizontal systems) in tropical regions. The combination of vertical and horizontal subsurface flow CW showed the highest performance for the removal of total coliform, *Escherichia coli* (3 log units and 4 log units, respectively) and Helminth eggs (90%) allowing water reuse. Also for nitrogen reduction, this wetlands combination displayed the best results (more than 90%). Besides pathogen parameters, BOD_5, COD, TSS were evaluated in the different experimental units and the results achieved a removal rate of >85% for all experimental units.

1. Introduction

One of the main health problems in developing countries are waterborne diseases associated with pathogenic organisms in inadequately treated or untreated domestic wastewater discharged to the environment. In the case of Colombia, pathogen removal is compulsory for those discharges that affect possible water uses downstream, therefore the legislation is based on pathogen indicators like total coliform and fecal coliform. The maximum pathogen concentrations allowed range between 1000 and 20,000 MPN/100 mL for total coliform (primary contact and water supply prior to conventional treatment uses, respectively) and between 200 and 2000 MPN/100 mL for fecal coliform (primary contact and water supply prior to disinfection as the only treatment method uses, respectively). In water rich countries like Colombia, where precipitation is relatively constant throughout the year and receives more than 2000 mm/year, the main problem caused by wastewater discharges from small cities, communities or villages (population lower than 2000 inhabitants), is not the oxygen depletion in water bodies but the increase of pathogen indicator concentrations (Guerrero, 2007).

Wastewater collection and treatment in those areas is often problematic and expensive. In most of the cases, centralized wastewater treatment solutions are not suitable due to several reasons, including long distances to the wastewater sources, topographic limitations and/or investment and operational costs. In those cases, decentralized sewage treatment is the only possibility and technology selection become a central task. Existing traditional technologies can effectively remove organic matter, suspended solids and even nutrients, however still there are some limitations for the removal of pathogens (Madigan et al., 2002). In the case of viruses, primary treatment is not effective whereas secondary treatments like trickling filters can achieve as much as 40% removal and activated sludge system can reach removal rates between 90% and 98% (Cheremisinoff, 2002). A more detailed survey by Zhang and Farahbakhsh (2007), showed that primary plus secondary treatment can remove between 2 and 3 log units for total and fecal coliform, somatic coliphage and F-specific coliphage; primary + secondary + tertiary (chlorination, sand filtration or rotating biological contactor) treatment allow to remove between 4 and 5 log units of those pathogen indicators, and the removal rates can be increased up to 6–7 log units for fecal and total coliform with the use of membrane bioreactors. However, the main disadvantages for using those technologies are associated with high investment and running costs (Arias and Brown, 2009).

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In recent years, natural systems have been promoted for the removal of different pollutants from domestic wastewater. Stabilization ponds, land application and constructed wetlands have been applied to wastewater treatment from small communities (Reinoso et al., 2008). Natural systems cannot be applied to all cases, as this is dependent on the wastewater flow, local soil, climate conditions and the availability of land and prices (Oron et al., 1999).

Constructed wetlands have been used over the years for the treatment of several kind of polluted water (Kadlec and Wallace, 2009). These natural systems are classified according to the direction of water flow in the system, and include subsurface vertical flow (SSVF) constructed wetlands, subsurface horizontal flow (SSHF) constructed wetlands and free water surface constructed wetlands. In general numerous reports have been done regarding the removal of organic carbon (expressed as BOD_5, COD and TOC) (Stottmeister et al., 2003; Langergraber et al., 2006; Kadlec and Wallace, 2009), nutrients (Wießner et al., 2005; Paredes et al., 2007a; Vymazal, 2007) and heavy metals (Paredes et al., 2007b).

It also has been demonstrated that CW can remove pathogens (Arias et al., 2003; Hansen et al., 2004; Molleda et al., 2008) and different mechanisms have been proposed. The first studies about pathogen removal mechanisms which began in the 1970s, suggested the excretion of antibiotics as a removal mechanism, however this has been hard to prove (Stottmeister et al., 2003). Other direct or indirect mechanisms associated to systems with the presence of plants, such as filtration, adsorption and aggregation, predation by protozoa and bacteriophages have been recently proposed (Kadlec and Wallace, 2009). Predation has been pointed out as the main mechanism for pathogen removal in constructed wetlands; however the exact role of bacteriophages and competition with protozoa is still an open topic.

In addition to the removal mechanisms, different studies have been developed to establish which type of wetland can produce the highest pathogen removal. In most of the cases, no significant differences have been found between vertical and horizontal systems. In both cases, removal rates of 2 log units for total coliform and fecal coliform have been reported (Hansen et al., 2004; Vacca et al., 2005; Fountoulakis et al., 2009). However, some authors have suggested that vertical flow systems remove higher rates due to the existence of more aerated areas (Kadlec and Wallace, 2009). In a similar way, the combination of different flow systems have shown fecal coliform removal rates of 4 log units of magnitude with the advantage of the reduction of the required area (Bederski et al., 2004; Masi et al., 2004). For most of the published experiences, the design criteria and guidelines have been developed in countries under temperate climates; however there is scarce information about the pathogen removal capacity in CWs in tropical climates.

The aim of this work is to assess and compare the performance of different combinations of treatment wetlands running under tropical conditions. Twelve lab scale units were constructed and operated in six different wetland treatment configurations, two experimental units for each configuration for comparison: (a) SSHF–SSHF planted, (b) SSHF–SSHF unplanted, (c) SSVF–SSVF planted, (d) SSVF–SSVF unplanted, (e) SSVF–SSHF planted, and (f) SSVF–SSHF unplanted. All units operated in parallel receiving primary treated domestic wastewater.

2. Materials and methods

2.1. Experimental unit description

To assess the capacity of pathogen removal by CWs, a combination of treatment trains with two experimental factors was used. The first factor, vegetation, included the absence and presence of plants. The second factor was a combination of two different types of CWs, vertical/horizontal, vertical/vertical and horizontal/horizontal flow constructed wetlands, for a total of 6 treatment combinations. Fig. 1 shows a general scheme of the experimental system.

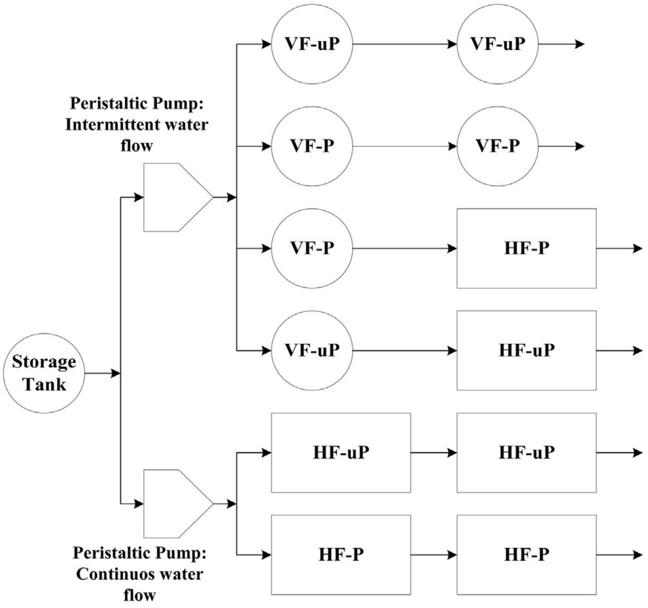

Fig. 1. Scheme of experimental unit configuration (VF, vertical flow constructed wetland; HF, subsurface horizontal flow constructed wetland; P, planted; uP, unplanted). All treatments trains (6) were fed in parallel with domestic wastewater pre-settled in a 1 m^3 storage tank.

All experimental units were located at the research facilities at the wastewater treatment plant of the Technological University of Pereira, in Colombia (N 04°47′38.2″; E 75°41′39.2″). The altitude is 1400 m, the average precipitation is 2500 mm/year and the temperature ranges between 18 and 30 °C, with a mean value of 22 °C.

The horizontal flow wetlands were built in rectangular fiberglass tanks (0.3 m width, 0.8 m length 0.8 m depth) and the vertical flow wetlands in round plastic containers (0.55 m diameter, 0.8 m depth). In both cases the surface area of the CWs was 0.24 m^2 and all systems filled with gravel (diameter of 1 cm, porosity 0.50). Papyrus (*Cyperus* sp.) was used in the vegetated systems. Each treatment train was operated in parallel and all were fed with settled domestic wastewater at a flow rate of 24 l/d (equivalent to HLR = 0.1 m/d) taken from the influent of the wastewater treatment plant of the Technological University of Pereira (generated by a total population of 15,000 people).

2.2. Sampling and analysis

Weekly water samples were taken as grab samples from the influent, between the CWs, and from the effluent of each treatment train. The performance of every treatment was measured by the determination of Helminth eggs (Bailenger method, WHO, 1996), total coliform and *Escherichia coli* (membrane filtration, standard methods, APHA, 2005). In addition to the bacteriological parameters, BOD_5, COD, TSS, NH_4–N, NO_2–N, NO_3–N and TKN were also evaluated in the influent and effluent of each combined wetland treatment (standard methods, APHA, 2005). ANOVA and Tukey post hoc analysis were used for comparison and results discussion (SPSS 12).