Wastewater Treatment Using Vertical Subsurface Flow Constructed Wetland in Indonesia

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Abstract: Problem statement: A constructed wetland to treat wastewater from farm house has been built in Padjadjaran University farming research station in Jatinangor, Indonesia, in July 2009. **Approach:** Water samples from both influent and effluent were taken every two weeks and analysed for COD, BOD_5, NO_3-N, NO_2-N, NH_4-N, total-N, PO_4-P, total coliform bacteria, pH, O_2 and settleable solids. **Results:** The objective of this study was to install one constructed wetland with a vertical flow system to treat sewage from farm house by using an aquatic macrophyte (*Phragmites karka*). The average treatment efficiencies during the period from August 2009 to January 2010 for BOD_5, COD, NH_4-N, total- N, PO_4-P and total coliform bacteria were 76,03, 78,89, 88,18, 71,70, 91,06 and 99,45% respectively. The average concentration in effluent from period of August to January for BOD_5 was 21.87 mg L^{-1}, COD (57.66 mg L^{-1}), NH_4-N (0.82 mg L^{-1}), NO_3-N (1,36 mg L^{-1}), total-N (2.68 mg L^{-1}), PO_4-P (0.07 mg L^{-1}) and total coliform bacteria (4880 MPN/100 ml). **Conclusion/Recommendations:** The overall results show that all effluent concentration from constructed wetlands except BOD_5 were still low and fall considerably short of Indonesian effluent standards for irrigation water. These results were very promising to be used in treating wastewater from agricultural industry and produce clean water which then can still be used for other purposes such as irrigation water, fisheries and other necessities.

Key words: Constructed wetland, *Phragmites karka*, wastewater treatment, total coliform bacteria, subsurface flow, effluent concentration, irrigation water, vertical flow system

INTRODUCTION

Environmental pollution in Indonesia, especially at rivers, lakes and other public waters in recent years continues to increase. The main sources of water pollution in Indonesia are domestic wastewater (40%), industrial wastewater (30%) and the rest is contributed from agricultural wastewater, animal husbandry wastewater or others. Currently only around 25% of the wastewater has been given treatment before discharge into public waters, while the rest is discharged directly into public waters. This has created severe environmental pollution problem such as eutrophication and transmission of waterborne diseases (cholera, typhoid, dysentery and hepatitis). Water pollution in developing countries causing a lot of diarrheal diseases (Butler *et al*., 1990). Each day approximately 35,000 women and children died from diarrheal disease in many developing countries (Denny, 1997). Treatment of wastewater before entering the river or other public waters in Indonesia is still less done because of high

cost of making adequate wastewater treatment facility. Constructed wetland for wastewater treatment is one of wastewater treatment alternative to conventional wastewater treatment system in Indonesia which is expensive and high-technology base. This method is derived from Germany in the 1960s. Since then many systems have been made in various countries. These systems use a variety of different configurations such as types of media (soil, sand and gravel) as well as various kinds of aquatic plants. This method is widely known by different names such as soil filter trench, biological-macrophytic, marsh bed, submerged vegetated bed, reed bed treatment system and in Germany is called pflanzenkläranlagen. Constructed wetlands for wastewater treatment by using aquatic plants have been widely used in various countries such as Germany (Geller *et al*., 1990) ; America (Byers and Young, 1995); Australia (Greenway and Simpson, 1996); England (Cooper and Boon, 1987); China (Yang *et al*., 1995), India (Juwarkar *et al*., 1995) and Czech (Vymazal *et al*., 1995; Faten *et al*., 2009). Until now this system is still

used in rural areas of England because land costs are relatively cheap and sufficiently available. Some results showed that the efficiency of this system in reducing wastewater contaminants was high enough (Cooper and Boon, 1987). This system can reduce 99% BOD_5, COD (95-99%), total N (71-97%) and total P (97-99%) (Geller, 1997). Other researchers reported that this system can decrease by 77-98% BOD_5, COD (59-91%) and SS (77-99%) (Vymazal, 1996). Constructed wetland to treat house wastewater by using *Phragmites karka* in Sumedang, Indonesia can reduce BOD_5 98.94%, COD 96.76%, PO_4-P 91.92%, total nitrogen 53.71% and more than 98% for *E.coli* bacteria (Kurniadie and Kunze, 2000).

The objective of this study was to install one constructed wetland with a vertical flow system to treat sewage from farm house by using an aquatic macrophyte (*Phragmites karka*).

MATERIALS AND METHODS

A constructed wetland (6 m long, 5 m wide and 1.2 m deep) to treat sewage from farm house of Padjadjaran University Research Station has been built in Jatinangor campus in July 2009. The constructed wetland is a subsurface flow constructed wetland (8 p.e., 30 m^2, vertical flow, continous feeding and drainage system spread over the whole bed area), planted with *Phragmites karka* at a density 16 plants per m^2. The wastewater was mechanically pre-treated in a sedimentation tank (4 m^3) and flowed into the filter bed via polyethylene pipe (15 m long) by gravity. Clay soil and polyethylene membrane were used to seal the filter bed. The filter bed was built from multi layers with sand as the main media (Fig. 1). Small size gravel (8-16 mm) was used in the first top layer (15 cm), followed by 15 cm of bigger size gravel (16-32 mm). River sand was used as the main layer (60 cm deep), followed by 15 cm of small size gravel (8-16 mm) and finally, at the bottom, 15 cm larger size gravel (16-32 mm). The treated water was collected in a drain at the bottom of the filter bed and used again as irrigation water for gardening or directed to the nearest public waters.

The water samples from both inflow and outflow were taken every two weeks for period of six months (August 2009 till January 2010) and analysed in the wastewater Laboratory, Faculty of Agriculture, Padjadjaran University, Bandung Indonesia and Wastewater Laboratory of PDAM Bandung, Indonesia, for COD, BOD_5, NO_3-N, NO_2-N, NH_4-N, total nitrogen, PO_4-P, pH, total coliform bacteria, O_2 and settleable solids.
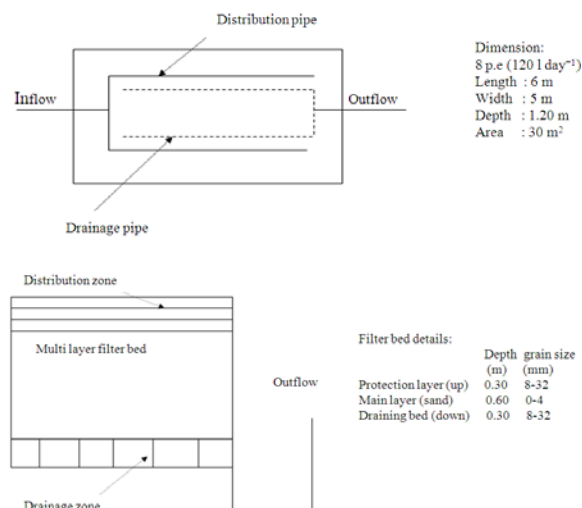

Fig. 1: Schematic view of Constructed Wetland in Padjadjaran University Campus

RESULTS

The treatment efficiency of constructed wetland to treat agriculture-based households in Jatinangor Indonesia, was already relatively high, although this constructed wetland was in operation for only six months (Table 1). During this study period (August 2009-January 2010), the treatment efficiency for NH_4-N varied from 74.19-97.95%, total-N (61.05-89.15%), PO_4-P (84-95.84%), BOD_5 (48.16-97.29%), COD (49.02-98.96%) and total coliform bacteria (99-99.97%). These results were still highly variable. This was probably because of the filter bed and the sedimentation tank was newly constructed.

The treatment efficiency of nitrogen in constructed wetlands was measured in term of NH_4-N, NO_3-N, NO_2-N and total-N. Nitrogen discharge parameters are generally measured in term of NH_4-N, NO_3-N and NO_2-N levels due to a) high biological oxygen demand, b) the toxicity of unionized ammonia (NH_3) to various forms of aquatic life under certain pH condition, c) toxicity of NO_3-N and NO_2-N and their contribution to the eutrophication of lake and reservoirs (Hammer and Knight, 1994). The average concentration of NH_4-N, NO_3-N and NO_2-N both in outflow and inflow (Table 1), indicating that nitrification processes had occurred in constructed wetlands. The average concentration of NO_3-N in outflow was 1.36 mg L^{-1} was lower than Indonesian standard for irrigation water and fishery 20 mg L^{-1}.

The average concentration of PO_4-P and total coliform bacteria in outflow from period of August-January was 0.07 mg L^{-1} for PO_4-P and 4880 MPN 100 L^{-1} for total coliform bacteria (Table 2).

Table 1: Monthly treatment efficiency of constructed wetland for wastewater treatment In Padjadjaran University Campus Jatinangor Indonesia during the period of August 2009-January 2010

Parameter	Treatment efficiency (%)						
	August	September	October	November	December	January	Average
$NH_4.N$	96.32	74.19	83.23	97.84	79.57	97.95	88.18
$NO_2.N$	-72.72	-43.58	62.50	-69.23	-76.74	-6.25	55.16
NO_3-N	-94.11	-92.96	-87.50	-98.26	-95.38	-88.28	-92.74
BOD_5	48.16	81.81	93.78	92.31	83.36	97.29	76.03
COD	49.02	80.00	94.91	94.99	98.96	97.50	78.89
$PO_4.P$	95.84	94.78	89.40	92.60	84.00	89.78	91.06
Total-N	77.04	61.05	72.55	64.62	65.83	89.15	71.70
Total coliform bakteri	99.86	99.79	99.97	99.82	99.00	99.72	99.45

Table 2: Average concentration of BOD_5, COD, $NH_4.N$, NO_3-N, NO_2-N, total-N, O_2, pH, Settleable Solids, -P and total coliform bacteria (Augusts 2009-Januari 2010)

Parameter	Inflow	Outflow
O_2 (mg L^{-1})	1.03	5.00
$NH_4.N$ (mg L^{-1})	10.30	0.82
$NO_2.N$ (mg L^{-1})	0.20	0.52
NO_3-N (mg L^{-1})	0.21	1.36
BOD_5 (mg L^{-1})	140.65	21.87
COD (mg L^{-1})	237.63	57.66
$PO_4.P$ (mg L^{-1})	0.77	0.07
Total-N (mg L^{-1})	10.64	2.68
Total coliform bacteria (MPN 100 L^{-1})	3.37×10^6	4.88×10^3
Settleable Solids (mL L^{-1})	0.18	0
pH	6.82	6.52

These concentrations were still below the Indonesian standard for irrigation water and fishery 1 mg L^{-1} for PO_4-P and 10000 MPN 100 L^{-1} for total coliform bacteria. The average concentration of oxygen in outflow (5.0 mg L^{-1} O_2) was higher than in inflow (1.03 mg L^{-1} O_2). The average values for pH and Settleable Solids in inflow was also higher than in outflow (Table 2).

DISCUSSION

This study demonstrates that subsurface vertical flow constructed wetland in University Padjadjaran campus in Jatinangor Indonesia had high treatment efficiency in term of the Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), total-N, NH_4-N, PO_4-P and total coliform bacteria.

Constructed wetland with vertical flow system can achieve full BOD_5 and COD removal because of high amount of oxygen transfer trough the reed bed (Cooper and Green, 1995). The average concentration of oxygen in this constructed wetland was raised from 1.03 mg L^{-1} O_2 in inflow to 5.0 mg L^{-1} in outflow. Higher oxygen content in this wetland is required for bacteria to remove both organic and nutrient pollutants. Removal efficiency of constructed wetland with vertical flow system is mainly based on very efficient soil aeration

and therefore, BOD_5, COD and NH_4-N removal is high but total-N elimination is limited (Platzer and Mauch, 1997). The vertical subsurface flow system has a high oxygen content and better substrate aeration (Bahlo, 2005). Macrophyte plant roots and rhizomes in the rhizosphere leak oxygen into microzone in an otherwise anaerobic zone and stimulate the breakdown of carbonaceous compounds (Juwarkar et al., 1995). The most important function of macrophytes plant roots and rhizomes in constructed wetlands with subsurface flow in term of organic matter removal is supply of oxygen to aerobic bacteria. The colloidal and soluble BOD_5 and COD remaining in solution are removed as a result of the metabolic activity and physics-chemical interaction within the root zone (Cooper and Findlater, 1990).

The major process responsible for removal nitrogen in constructed wetlands is the nitrification-denitrification followed by plant uptake (Brix, 1994; Vymazal, 1996). Even plant uptake only substitutes 5-10% from the total nitrogen removal. In nitrification processes, ammonia either originally present in the outflow or produced during ammonification to organic nitrogen in the inflow, is oxidized to nitrate. The nitrate is subsequently reduced to nitrogen gas in dentrification processes, where biomass or other organic residues are used as the carbon and electron sources (Green et al., 1996). The oxygen requires for nitrification is delivered either directly from the atmosphere though the water or sediment surface or by leakage from plant roots (Netter, 1993).

The removal of phosphorus is dependant on the kind of substrate used (Geller, 1997). Substrate containing high Ca, Al and Fe will have high phosphorus removal efficiency (Vymazal, 1996). The higher PO_4-P treatment efficiency of this constructed wetland was probably due to the high amount of iron rich sand in the substrate. Phosphorus can be removed from the wastewater by plant uptake, microbial assimilation, precipitation with cations (Ca, Mg, Fe, Mn) and adsorption onto clay and organic matter (Reddy et al., 1989)

CONCLUSION

The contamination of organic pollutants and nutrients in many public water in Indonesia is a serious problem which threatens not only the aquatic ecosystems, but also human health. In this study showed that subsurface flow vertical constructed wetland planted with emergent plant *Phragmites karka* can be used effectively for decontamination of water with organic, nutrient and pathogen bacteria pollutants. The average of COD, NO_3-N, PO_4-P and total coliform bacteria in outflow were still lower than the Indonesian standard for irrigation water and fishery. These results were very promising with respect to the use of subsurface flow vertical constructed wetland to be installed and developed in Indonesia as a viable alternative to conventional technology, because this system is cost effective, simple technology, long-lived, easy to maintain and used materials that locally available.

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