Nutrients and Water Quality of the Ecological Components of the BioEcological Drainage System (BIOECODS), USM, Penang, Malaysia

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Abstract

Urban runoff is responsible for water quality deterioration of receiving water downstream of urban areas. Lately new engineering approaches that integrate ecological consideration had been used to combat urban drainage issues such as erosion and water quality. BioEcological Drainage System (BIOECODS) is an example of integration of engineering and ecological components to solve urban runoff. BIOECODS at USM Engineering Campus in Nibong Tebal, Penang, combines three engineering techniques to manage storm water based on control at source approach by integrating the drainage components with ecological components (i.e constructed wetland, detention pond, wading stream and recreational ponds). This paper reports our findings of the water quality parameters of water bodies in the ecological components conducted from April 2003–September 2003 every fortnight water sampling strategy. Results suggested that most of the water quality parameters improved from detention pond towards recreational pond after flowing through wetlands ponds. Turbidity for example reduced from 15-25 FTU in detention ponds to between 5-10 FTU downstream of wetlands. Conductivity was also reduced from a range of 140-200 µS/cm to a range of 100-180 µS/cm. Mean suspended sediment concentration declined from about 10-32 mg/l to about 5 mg/L. Nutrient such as ammonia, nitrite and nitrate also showed a declining trend before and after flowing through wetlands. Ammonia decline from 0.12 to 0.06 mg/L; nitrite from 0.035 mg/L to 0.028 mg/L; and nitrate from 0.13 – 0.28 mg/L to about 0.09 – 0.18 mg/L. Orthophosphate was on the other hand increased from 0.08-0.2 mg/L to 0.15–0.23 mg/L. As a conclusion, wetland systems play an important role in controlling and maintaining a good water quality of the runoff water and the whole Bio-Ecological Drainage System (BIOECODS) is found to be effective way to treat runoff before discharging to the river.

INTRODUCTION

Urban storm water runoff is being recognized as a major source of pollutants to receiving waters and a number of recent investigations have evaluated stormwater runoff quality characteristics and best management technologies to minimize pollutant input to receiving waters (Davis et al., 2001). Urban runoff is responsible for water quality deterioration of receiving water downstream of urban areas.

Lately new engineering approaches that integrate ecological consideration had been use to combat urban drainage issues such as erosion and water quality. The interest to incorporate constructed and natural wetland to monitor water quality by controlling pollutants eg non-point source pollutants that are in much lower concentrations than those found in wastewater (Meyer 1985; Mitsch and Reeder, 1991). Wetlands often function as sinks for nutrients in high concentrations (Nixon and Lee 1986). Constructed wetlands can be use effectively to remove excess nutrients and other pollutants in the rural area where sewage treatment plants are not feasible due to high cost of construction and maintenance (Kadlec and Knight, 1996; Solano et al., 2004). Success of natural and constructed wetlands for water quality improvement with high concentration of nutrients has been documented in a number of studies since the end of 1970s (cited in Mitsch et al., 1995).

BioEcological Drainage Systems (BIOECODS) at USM

BIOECODS at USM Engineering Campus in Nibong Tebal, Penang, combines three engineering techniques to manage storm water based on control at source approach by integrating the drainage components with ecological components (Fig. 1). BIOECODS is designed to provide time for natural processes of sedimentation, filtration and biodegradation to occur, which reduces the pollutant load in the surface water runoff. BIOECODS is an example of integration of engineering and ecological components to solve urban runoff (Zakaria et al., 2004). The ecological component located at the downstream end of BIOECODS is a community facility that include wet pond (WP), and a detention pond (DP), a constructed wetland (WL) as a water treatment device, a wading river (WR) connecting the wetland and a recreational pond (RP) containing the treated water before final discharge to Kerian River (Fig. 2).

The wet pond (4500m^2; volume: 5000m^3) receives storm water runoff from the main catchment, which is referred to as Engineering School sub-catchment. The detention pond (area: 10000 m^2; volume: 18,000 m^3) is designed to temporarily stored excess stormwater runoff from student hostels sub-catchment. The wetland is a surface flow type consisting of an inlet zone, a macrophyte zone and an open water zone. The designed criteria of the constructed wetland are shown in Table 1. The wetland components in the BIOECODS were planted with macrophytes such as cattail (*Typha angustifolia*), Bakong (*Hanguana malayana)*, *Eleocharis variegata*, *Eleocharis dulcis*, tube sedge (*Lepironia articulate)*, common reed (*Phragmites karka.)*. Many studies have shown that wetland plants are efficient sediments and nutrients filters. A range of wetland plants have shown this property, but the common reed (*Phragmites australis*), and the reedmace (*Typha latifolia*) are particularly effective. They have a large biomass both above (leaves) and below (underground rhizome system) the surface of the soil or substrate. The subsurface plant tissues grow horizontally and vertically and create an extensive matrix which binds the soil particles and creates a large surface area for the uptake of nutrients and ions (Shutes, 2001).

The distributions of weedy species and plants in various parts of the ecological components are shown in Table 2.

Objective of this study

The objectives of this study were two-fold i.e: to determine the water quality of various ecological components of BIOECODS and to determine the function of wetland in improving water quality.

Table 1: Design criteria of the constructed wetland (Zakaria et al., 2003)

Catchment area	1.214 km^2
Design storm (3 month ARI)	22.5 mm/h
Length	155m
Width	60m
Wetland surface area	9,100 m^2
Volume	9,100 m^3
% catchment	0.7
Design inflow rate	0.25 m^3/s
Mean residence time	3 days
Slope of wetland bed	1%
Bed depth	0.6m
Media	peat gravel and soil mixture
Hydraulic conductivity of gravel	10^{-3} m/s to 10^{-2} m/s

Table 2: Weeds and wetland plants found in the ecological component of BIOECODS

Plants and weeds	Drain	Wetpond	Detention pond	Wetland pond	Micro pool	Wading river	Recreational pond
Hydrilla verticilatta	X	X					
Chrisopogon Aciculatus	X	X	X	X	X	X	
Lemna perpusilla	X	X					
Eichornia crassipes		X					X
Pontederia cordata		X					
Saggitaria sagitifolia		X					
Azolla pinnata		X					
Eleocaris dulcis			X	X			X
Aleocaris maxima			X				
Eleocaris variegata				X			
Mimosa pudica			X				
Mimosa invisa			X	X	X		
Mimosa pigra			X				
Palanthus nururi			X				
Scirpus grossus				X	X	X	
Scirpus mucronatus				X		X	X
Phragmatis karka				X			
Typha augustifolia				X			
Hanguana malayana				X			
Pakakania murtika				X			
Lepironia articulata				X			
Nymphae lotus				X			
Molestoma malabathricum							X
Pontederia cordata							X

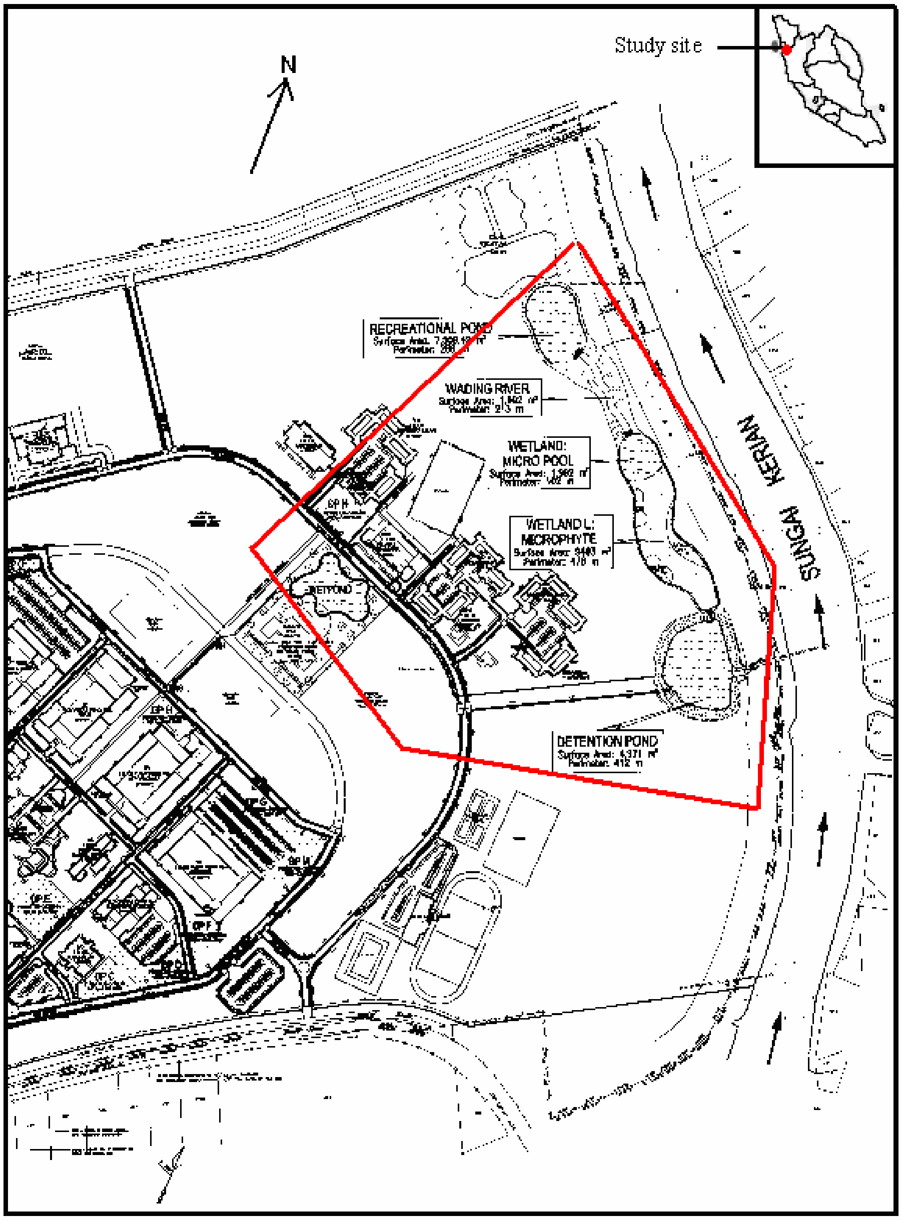

Fig. 1: Study site showing the ecological components of BIOECODS.

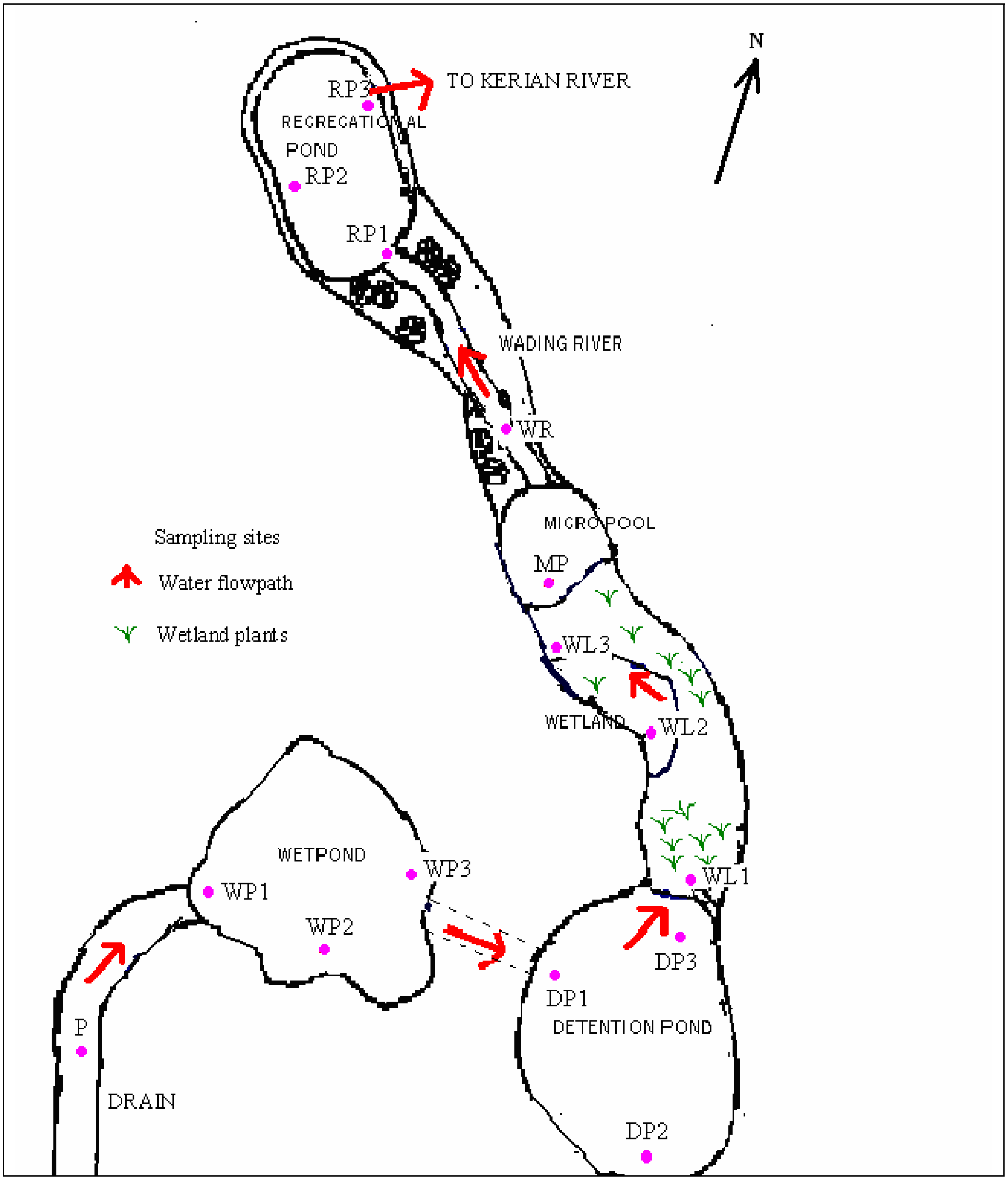

Fig. 2: Sampling sites

MATERIAL AND METHODS

Water sampling strategies include monitoring water quality parameters of water bodies at several locations from the inlet to the outlet in the ecological components of the BIOECODS (Fig. 1). Sampling was carried out from April 2003 - September 2003 every fortnight. In situ parameters such as dissolved oxygen were measured using a YSI 58 meter. pH, temperature were measured using a portable Eutech pH meter, conductivity and total dissolved solids were measured using Hach meter. Analyses for suspended materials, and nutrients were completed in a lab. Turbidity was measured with a Hach DR2000 Turbidimeter. TSS were determined by filtration method using Whatman GF/C filter paper with pore size of 0.45 µm, and drying at 105°C (24 hours) (Gordon et al., 1992). Nutrient analyses were performed using the cadmium reduction method (APHA, 1989) for nitrate; diazotizing method (APHA, 1989) for nitrite; phenol hypochlorite methods (Wetzel and Likens, 1995) for ammonia, and the colorimetric method (Murphy and Riley, 1962) for orthophosphate. Statistical and data analyses were conducted in Microsoft Excel and SPSS.

RESULTS

Results suggested that most of the water quality parameters improved from wet pond through detention pond towards recreational pond after flowing through the constructed wetlands ponds.

a) Water Temperature (^{o}C)

Water temperature were observed to be almost constant with a mean average of 30^{o}C with very little fluctuation except for Wl1 and Wl2 (Fig. 3a).

b) pH

pH increase from drain P, into wet pond (WP), drop a little in detention pond (DP) and after that stay almost constant with median pH at 7.4 in wetland, micropool, wading river and recreational pond (Fig. 3b).

c) Dissolved oxygen (mg/l)

Dissolved oxygen were low with all station recorded below 4 mg/l. DO increase from drain (p) into wet pond and drop a little in the detention pond and wetland before increasing again in micro pool, wading river and recreational pond (Fig. 3c).

d) Conductivity and total dissolved solids (TDS)

Conductivity were higher in drain and Wp1 and Wp2 but drop a little at Wp3 before increasing again in detention pond. It drops again in wetland, micro pool and recreational pond. Conductivity was observed to decreases from a range of 140-200 μS/cm to a range of 100-180 μS/cm. Similar behaviour was observed for TDS (Fig. 4).

e) Turbidity and TSS

There is a strong correlation between turbidity and TSS. Turbidity was higher in the drain, wet pond and detention pond (ranging from 10-30 FTU) and lower in wetland, micro pool and recreational pond (ranging from 5-11 FTU). Turbidity declined from about 15-25 FTU in detention ponds to between 5-10 FTU downstream of wetlands.

Similarly, the mean suspended sediment concentration declined from about 20 to 25 mg/l in drain and WP1, to below 10 mg/l at Wp2 and Wp3. The sediment concentration in detention pond we also higher at Dp 1 and Dp2 (ranging from a mean concentrations of 20-35 mg/l). The sediment concentrations in wading river and recreational pond were lower ranging from about a 5-10 mg/l. A significant fluctuation in concentration were observed at Dp1 and Dp2 shown by high standard deviation values ranging from 20 to 25 mg/l). This could be associated with heavy rainfall events responsible for higher sediment discharge and resuspension of bed sediment. Fluctuations in sediment concentrations were observed at the drain, Wl1 and micropool shown by higher standard deviation.

e) Nutrients

The longitudinal distributions of nitrogen were in declining trend from inlet to the outlet (Fig. 5). All nitrogen components decline after flowing through wetlands. Nitrite decline from 0.035 mg/L to 0.028 mg/L; nitrate from nitrate from 0.13 – 0.28 mg/L to about 0.09 – 0.18 mg/L, and ammonia decline from 0.12 to 0.06 mg/L. The lowest value of nitrite was at Wl1, located at the orifice inlet of wetland pond, with a mean concentration of less than 0.01 mg/l. The lowest value for ammonia was observed at Wp3. Orthophosphate, on the other hand, increasing slightly in longitudinal trend from 0.08-0.2 mg/L to 0.15–0.23 mg/L.

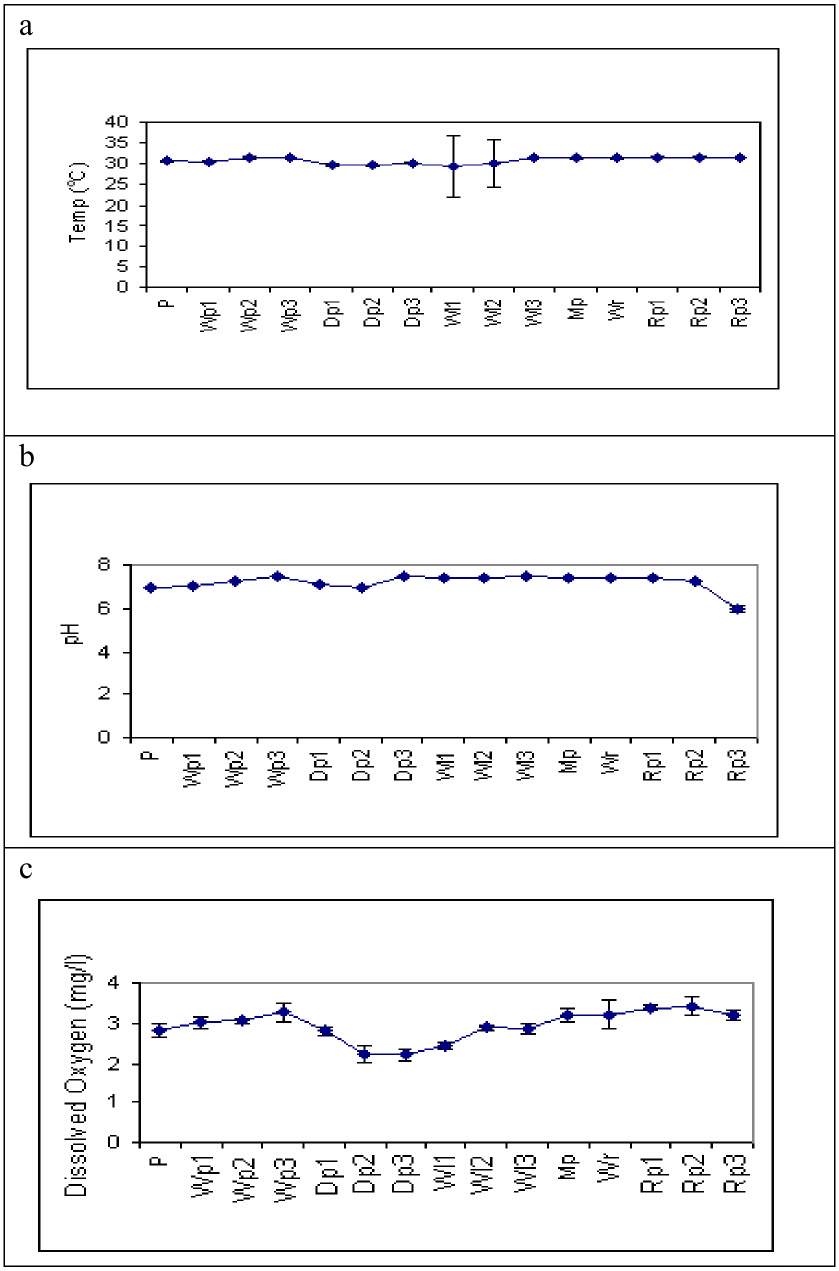

Fig. 3: In situ parameters (a) Temperature, (b) pH and (c) Dissolved oxygen

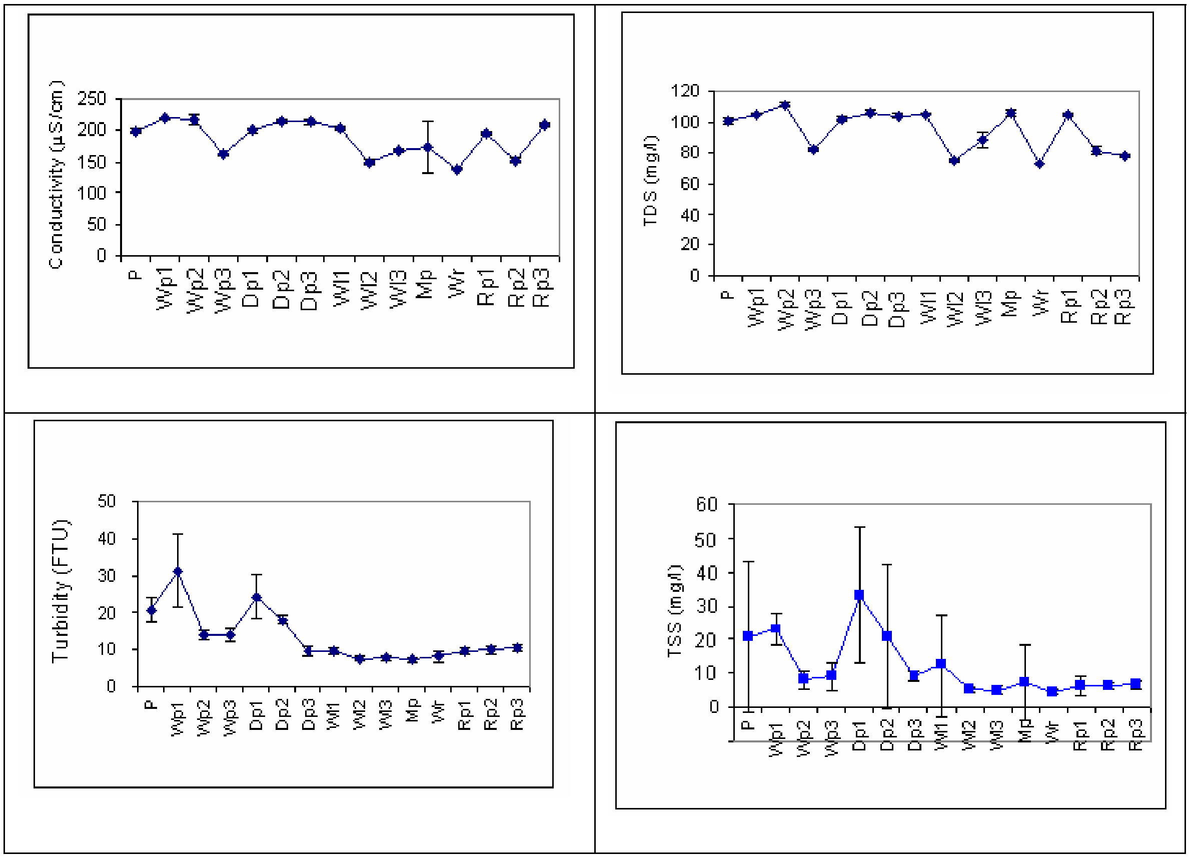

Figure 4: Relationship between conductivity and TDS (above), and between Turbidity and TSS (bottom).

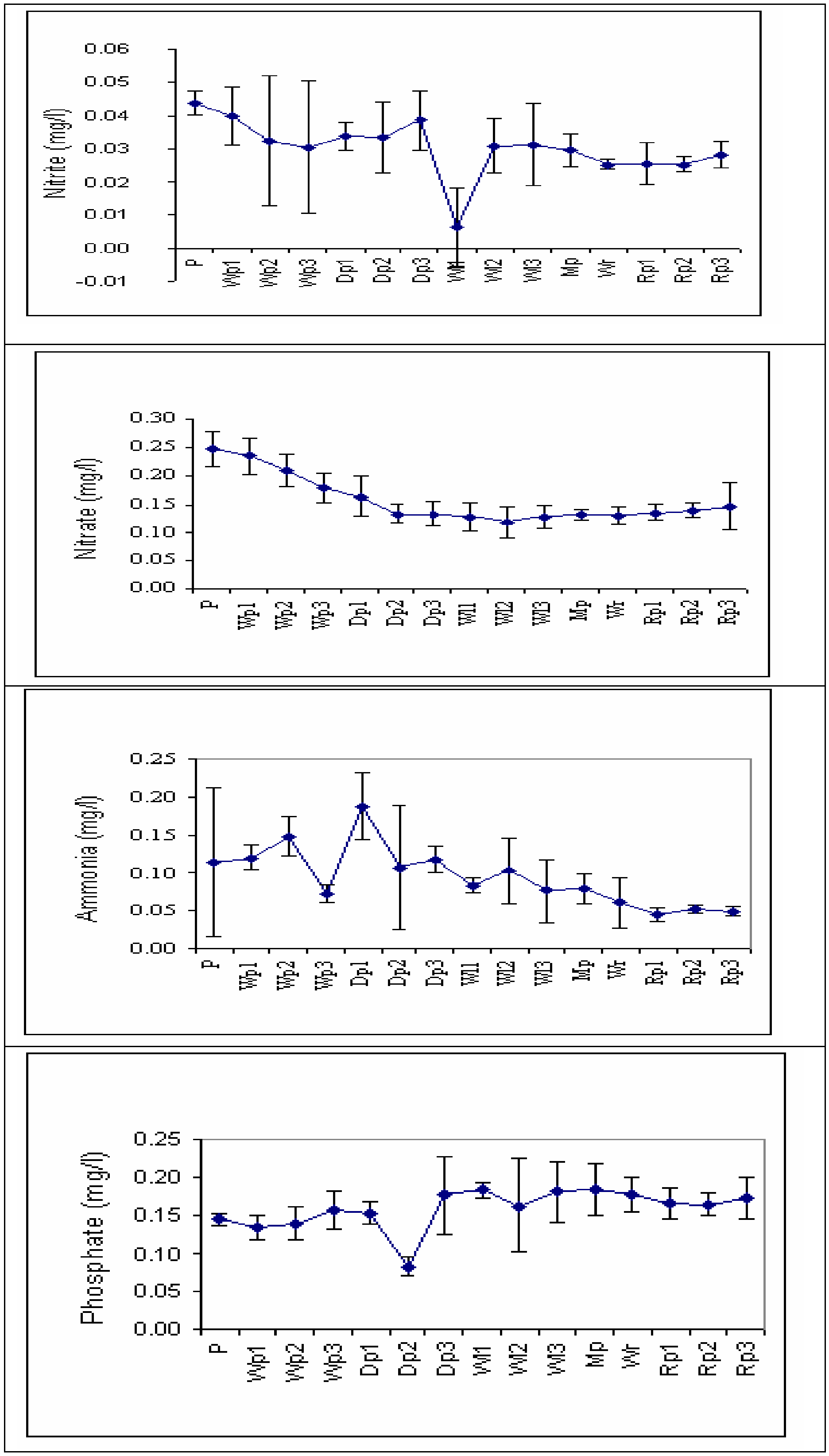

Fig. 5: Longitudinal variations of mean nutrients concentrations

DISCUSSIONS

BIOECODS is design to provide time for the natural processes of sedimentation, filtration and biodegradation to occur (Zakaria et al., 2003). Sedimentation and aquatic plants in the wet pond and detention pond were able to reduce nutrient and some portion of the before it goes through the wetland cells. Constructed wetlands were initially developed about 40 years ago in Europe and North America to exploit and improve the biodegradation ability of plants. The advantages of these systems include low construction and operating costs and they are appropriate both for small communities and as a final stage treatment in large municipal systems (Cooper et al., 1996). A disadvantage of the systems is their relatively slow rate of operation in comparison to conventional wastewater treatment technology (Shutes, 2001).

Wetlands often function as sinks for nutrients in high concentrations (Nixon and Lee, 1986). Wetlands are considered to be a low-cost alternative for treating municipal, industrial and agricultural wastewater (Karathanasis et al., 2003; Mitsch and Wise, 1998; Reddy and Angelo, 1997).Wetlands could also be used as tertiary wastewater treatment, especially using the root-zone method; the efficiencies to remove nitrogen and phosphorus were high (Gumbricht, 1992). Greenway (2005) reported that constructed wetlands can be designed to maximize the removal of nutrients by enhancing macrophyte diversity through the incorporation of lagoons, shallow-water wetlands and subsurface-flow wetlands into the treatment train.

This study manage to show that the wetland component were able to improve water quality and reduce nutrient input from wet pond and detention pond. The turbidity declined from about 15-25 FTU in detention ponds to between 5-10 FTU downstream of wetlands. This is almost 16-24% reduction. In a study by Nairn and Mitsch (1999) they found that wetland decreased turbidity from 62-27 NTU which a reduction of about 56%. Our small reduction is because the wetlands are still in its infancy when we carried out our study.

Wetlands also act as sink for suspended sediment. TSS declined from about 20 to 25 mg/l in drain and WP1, to 5-10 mg/l in wading river and recreational pond. Brix (1997) described that the higher TSS removal performances in planted filter systems are attributed to larger surface areas, reduced water velocities and reinforced settling and filtration by the root network.

In our study we also found that DO increased from detention pond 2 to 3.3 mg/l. Nairn and Mitsch (1999) also found that dissolved oxygen increase from 9 to 11 mg/l in created wetland ponds receiving river overflow.

Nitrogen components decline in concentrations after flowing through the ecological system. Nitrite decline from 0.035 mg/L to 0.028 mg/L which was accounted for 20% reduction; nitrate from 0.13 – 0.28 mg/L to about 0.09 – 0.18 mg/L (31-36%), and ammonia decline from 0.12 to 0.06 mg/L (50%). This is in agreement with other studies where Spieles and Mitsch (1999) found that nitrate decreased by 74%. Nitrate removal by mass range from 29% in wastewater wetland to 37–40% in the riverine wetlands (Spieles and Mitsch, 1999), although differences in retention varied widely by season and were not statistically significant among the wetlands. Lee and Scholz (2007) also found that ammonia-nitrogen reduction efficiencies were always higher for constructed wetland filters planted with *Phragmites australis* compared to unplanted filters. Furthermore, nitrate-nitrogen reduction efficiencies for planted filters were much higher than those for unplanted filters.

Phosphate were also normally reduced after flowing through wetlands. Average P concentration decreased 64-92% in a low flow wetland in a study by Mitsch et al (1995) in Des Plaines Wetlands in Chicago, Illinois, USA. Fink and Mitsch (2001), for example, show that annual orthophosphate and total phosphate (TP) are reduced by 46% and 31%, respectively. A greater attenuation TP occurred in the emergent marsh section of the wetland than the open water section (Fink and Mitsch, 2001). Comparing planted and natural wetlands, Nairn and Mitsch (1999) found that inflow dissolved reactive phosphorus (DRP) and total phosphorus (TP) concentrations (17±3 and 169±11 μg P l^{-1}) were significantly higher ($P<0.05$) than outflow concentrations (DRP: 5±1 and 6±1 μg P l^{-1}; TP: 69±8 and 74±9 μg P l^{-1}) for planted and unplanted wetlands, respectively. Phosphorus removal was related to decreases in turbidity and the level of biological activity (Nairn and Mitsch, 1999). However, our study indicate some slight increase in the phosphate concentrations from 0.08-0.2 mg/L in DP to 0.15–0.23 mg/L after flowing through wetland. A number of studies supported this argument where phosphorus could increase due to the influence of the chemical composition of parents soils in wetland. for the retention of phosphorus (Reddy and Angelo, 1994). In general, wetlands are able to reduce P by 60% and nitrate by 40%.

CONCLUSIONS

This study presented a significant contribution to the emerging research on the usage of wetland in water quality improvement. Wetland systems play an important role in controlling and maintaining a good water quality of the runoff water. The whole Bio-Ecological Drainage System (BIOECODS) is an effective way to treat runoff from urban areas before discharging to the river, thus help maintain the health of natural environment. Constructed wetlands are very effective to remove excess nutrients and other pollutants where sewage treatment plants are not feasible due to high cost of construction and maintenance. Results from this study, although it was in the early stage of implementation, are comparable to observations found elsewhere.

Acknowledgements

This study was undertaken using the USM Short term grant. We appreciate the help of Salleh Bakar, Saranisa Abdul Rahman, Masnira Mohamad Yusoff and Aziani Awang during field sampling.

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