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Phytoremediation of Municipal Run-off using *Typha Orientalis* and *Sorghum Arundinaceum* in Sub-Surface Constructed Wetland System

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Abstract— *Constructed wetland is an innovative and emerging ecological technology for wastewater treatment. This study was conducted to investigate the effectiveness of a pilot scale sub-surface flow constructed wetland unit (SSFCW) comprising of 5 cells treatment system of 1800mm x 900 x 900 mm each built within the vicinity of Department of Civil Engineering, Ladoke Akintola University of Technology (LAUTECH) Ogbomoso Nigeria. Three wetland cells were utilized, with two cells planted with two kinds of plants namely; Typha Orientalis and Sorghum Arundinaceum. The unplanted third cell served as control. The wetland cells were fed with municipal runoff wastewater and treated effluents were collected for analyses at 5 day interval for a retention period of 10 days. The results obtained showed that phytoremediation reduced 72% Turbidity, 97% of Nitrate, 86% Phosphate, and 97% of Biochemical Oxygen Demand (BOD). Metal contents in treated wastewaters such as Lead (Pb) and Iron (Fe) were decreased up to 89% and 87% for Sorghum Arundinaceum and 71% and 97% for Typha Orientalis respectively. To conclude, the quality of treated effluent proved that the use of SSFCW, using locally available macrophytes to remove heavy metals, Turbidity, Nitrate, Phosphate and BOD, is an effective technology for municipal runoff wastewater treatment and use for irrigation in rural areas and small communities.*

Keywords— *Constructed Wetland, Municipal runoff, Phytoremediation, Typha Orientalis, Sorghum Arundinaceum.*

I. INTRODUCTION

Wastewater toxicity is generally due to fractions of organic matter, together with detergents, heavy metals, sanitizers, chemicals from boiler and domestic wastes (Victor et. al, 2016; Tripathi et al. 2000). Disposal of poorly treated wastewaters from households and small communities, as well as municipal runoff can lead to hydraulic failure of soil infiltration and pollution of ground and surface waters with consequent risks to human and environmental health (Abou-Elela and Hellal (2012); Tanner et al., 2012).

With rapid urbanization and industrialization, surface water quality of urban watersheds has deteriorated gradually in many cities of the world (Zhang Wei, Li Simin, and Tang Fengbing, 2013). To tackle this problem, much attention has been paid to reducing pollutant loads of point sources. However, the water quality has not been improved obviously (UNEP, 2003). Urban runoff has been considered as one of the primary causes of water quality degradation (Davis and Birch, 2009); (Novotny, 1999). And along with the expansion of point sources control, the contribution of water quality degradation from urban runoff pollution is increasing. Understanding the characteristics of urban runoff pollution is beneficial to develop urban storm water management effectively. Due to the randomicity of natural rainfall and the complexity of urban catchments, urban runoff pollution is characterized by the occurrence of great temporal and spatial variability (Mangani, Berloni, Bellucci, Tat ` ano, and Maione, 2005)

Urban runoff pollutants are divided into six specific groups, such as solids, heavy metals, biodegradable organic matter, organic micro pollutants, pathogenic microorganisms, and nutrients, which are originated mainly from wet and dry deposition, grind tire debris, vegetation (leaves and logs), animals (fecal contributions and dead bodies), fertilizers, and exhaust gas from vehicle, and so forth (Barbosa, Fernandes, and David, 2012 and USEPA, 2004)

In many literatures on urban runoff pollution, the analyses of measurement parameters were usually carried out on whole water samples (Gasperi, Garnaud, Rocher, and Moilleron, 2009); (Li, Yin, He, and Kong, 2007); (Kim, Yur, and Kim, 2007).

Furthermore, some researchers deem that particle substances are the main category of urban runoff pollutants, while particle size distribution on impervious surfaces in urban environments determines the characteristics of urban runoff pollution (Deletic and Orr, 2005); (Bian and Zhu, 2009); (Zhao, Li, Wang, and Tian, 2010).

Actually, runoff pollutants in the environment exist mainly in the form of particulate and dissolved phase, which is one of leading factors on selection of storm water quality control measures (Zgheib, Moilleron, Saad, and Chebbo, 2011); (National Research Council, 2009); (TRCA, 2010)

Phytoremediation, an emerging technology that uses various plants to extract, contain, or immobilize contaminants from soil, has been receiving increasing attention as an innovative, cost-effective alternative method for remediation of contaminated soil (Oh et al., 2015); (UNEP, 2003); (Davis and Birch, 2009). Phytoremediation can remove heavy metals from soil and improve soil quality (Novotny, 1999).

The family Typhaceae consists of a single genus Typha with approximately 10–15 species, that are almost cosmopolitan in distribution. Typha species are typically emergent aquatics of fresh water, have wind dispersed seed, and spread by vigorous rhizome expansion once established in suitable habitats. Many species are significant weeds of irrigation channels, and artificial and altered natural wetlands throughout their natural ranges. Typha orientalis is currently listed as an introduced alien (Keighery and McCabe, 2015)

Sorghum arundinaceum (Desv.) Stapf is a weed from the Poaceae family, originally from Africa, that has been widespread in all regions of Brazil, and is an annual or perennial plant, erect, with 1.5-2.5 m tall. Its propagation occurs through seeds, infesting especially annual and perennial crops, vacant lands and roadsides (Martins et al., 2016)

Wetland treatment systems have been considered as an alternative to conventional treatment methods, especially for small communities (Soukup et al., 1994; Kivaisi, 2001; Solano et al., 2003), because of their low treatment cost and low maintenance, especially in suburban or rural areas without any large-scale sewage treatment facilities. Constructed wetlands can remove most of pollutants like pathogens, nutrients, organic and inorganic contaminants as well as the protection of the public health to prevent transmission of waterborne diseases (Kivaisi, 2001). In the past few decades, constructed wetlands have been applied in treating municipal (Gumbricht, 1992; Kaseva, 2004; Chung et al., 2008), industrial (Mays, 2001; Jacob, 2004; Gottschall et al., 2007), agricultural and livestock wastewater (Comín et al., 1997; Knight et al., 2000). The feasibility of employing constructed wetlands as a secondary treatment system is attractive because it saves land areas; however, the subject still needs more research (Wu et al., 2008).

The aim of this study was to evaluate the performances of a pilot scale sub-surface flow constructed wetland (SSFCW) for the removal of organic compounds, nutrients and pathogenic microorganisms from a real municipal runoff wastewater. In addition, the possibility of using the treated effluent for irrigation purposes was also evaluated.

II. MATERIALS AND METHODS

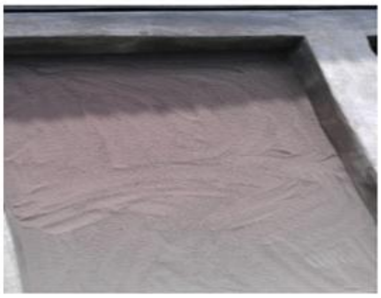
A. Description of the site

A pilot scale sub-surface flow constructed wetland unit (SSFCW) comprising of 5 cells treatment system of 1800mm x 900 x 900 mm each was built within the vicinity of Department of Civil Engineering, Ladoke Akintola University of Technology (LAUTECH) Ogbomoso Nigeria. The wetland cells were fed with municipal runoff wastewater and treated effluents were collected for analyses at 5 day interval for a retention period of 10 days. The flow direction to be achieved is vertical; therefore the substrates to be filled were placed as such. The substrates used were washed granite, washed sand, and humus soil, and were all properly filled in the order which will support vegetation growth as shown in Figure 1. Washed substrates were used so as to remove unwanted materials from the setup. The constructed wetland treatment setup is 900 mm high, and was filled as follows from the bottom to the top; (a) washed granite (12 mm diameter) covered 200 mm; (b) gutter sand covered 400 mm; (c) humus soil covered 150 mm; and (d) freeboard of 150 mm.

The SSFCW was fed with influent runoff wastewater from elevated storage tank and distributed through a network of PVC pipes.

(a)

(b)



(c)

Fig. 1. Constructed Wetland layers:
(a) granite, (b) gutter sand and (c) humus soil

B. Plantation

Three wetland cells were utilized, with two cells planted with ***Typha Orientalis*** **and** ***Sorghum Arundinaceum***. The unplanted third cell served as control. Typha orientalis and Sorghum arundinaceum were uprooted from nearby fields and transplanted into the treatment set up. The plant rhizomes were planted in February 2015 on moist substrates which had been prepared adequately to receive the rhizome cuttings. It was ensured that the plants were watered daily for 12 weeks (3 months) to make up for the water lost to evaporation from the soil and transpiration from the leaves.

(a)

(b)

(c)

Fig. 2. (a) Pilot scale SSFCW (b) Typha orientalis (c) Sorghum arundinaceum

This was done to ensure the survival of the plants and to guarantee their growth. Figure 2 shows the pilot scale SSFCW and the vegetation growth after two months of study.

C. Sampling

Effluent samples were collected from the outlet zone of the wetland cells at a 5-day interval for a hydraulic retention time (HRT) of 10 days. Physico-chemical analyses were carried out on raw and treated wastewater according to Standard Methods for the Examination of Water and Wastewater. Parameters like Nitrate, Phosphate, Turbidity and Biochemical oxygen demand were determined using standard methods prescribed by the American Public Health Association (APHA, 2005), while others like Calcium, Magnesium, Sodium, Potassium, Manganese, and Iron were all determined by the atomic absorption spectrophotometer.

III. Results and Discussion

A. Physicochemical Characteristics of Wastewater

Before phytoremediation

The concentration values of physicochemical characteristics of untreated run- off wastewater are shown in Table 1. This wastewater is neutral with pH value of 7.2. It has high turbidity value of 13.5 NTU. The concentration of organic loading was indicated by Nitrate, 4.05 mg.L-1 and Biochemical Oxygen Demand (BOD), 185 mg.L-1. The heavy metal present indicate high values of Mn (0.02 mg.L-1), Iron (5.33 mg.L-1) and Pb, 0.63 mg.L-1. Phosphate, 0.17 mg.L-1. In addition, Mg, Na and K has concentrations of 16.85 mg.L-1, 20.1 mg.L-1 and 8.73 mg.L-1, respectively. Ca has the highest concentration of 332.5 mg.L-1 in the cation category.

After phytoremediation

Table I shows the values of different parameters of effluents from the wetland cells (Typha– planted, Sorghum- planted and unplanted- control) during the 10- day HRT, phytoremediation experiments. Effluent of alkaline pH was maintained in the Typha- planted cell during the treatment period. Highest removal efficiency for turbidity was recorded in Typha- planted cell as 89% at day 1; Sorghum- planted 63%, day 1, while least value of 52% was recorded in the unplanted (control) cell (Figure 5). Calcium was not efficiently removed by the wetland cells; typha and sorghum- planted cells, 6% @ day 5 and 11% @ day 10, respectively. The highest was 13% removal @ day 10 from control cell. Magnesium and Potassium were not removed by typha- planted cell. The former was inefficiently removed in sorghum- planted, 14% @ day 5 and 53% removal @ day 10 in the control cell; while the later has 85% removal @ day 1 in sorghum- planted cell. Sodium was maximally removed by typha- planted cell, 70% @ day 10. Nitrate was poorly removed by typha- planted cell, 13% @ day 10, but efficiently removed in sorghum- planted cell, 97% @ day 10 (Figure 1). Eighty- eight percent (88%) removal of Phosphate was recorded by the three cells (Figure 2).

TABLE I. Physico-chemical characteristics of untreated run- off wastewater and effects of plants and hydraulic retention time on removal efficiency during a 10-day HRT phytoremediation treatment.

Parameters (mg/l except pH & Turbidity)	Before Phytoremediation (Raw Samples)	Typha- planted wetland cell			After Phytoremediation Sorghum- planted wetland cell			Unplanted (control) cell		
		Day 1	Day 5	Day 10	Day 1	Day 5	Day 10	Day 1	Day 5	Day 10
pH	7.2	7.4	7.5	7.3	7.3	7.2	6.9	7.1	7.2	6.9
Turbidity	13.5	1.5 (89)	5.5	3.8	5.0 (63)	6.6	5.0	6.5(52)	11.0	11.5
Ca	332.5	439.5	311.5(6)	339.5	343.5	308.5	296.5(11)	378.0	293.0	288.5(13)
Mg	16.85	26.1	27.3	31.7	33.75	14.5(14)	14.6	36.5	19.0	7.97 (53)
K	20.1	25.3	27.3	31.7	3.1 (85)	14.5	14.6	9.93	10.18	7.97 (60)
Na	8.73	2.81	2.9	2.64(70)	4.1	3.95	3.82 (56)	3.58	3.1	2.95 (66)
Mn	0.02	0.01 (50)	1.0	10.2	0.98	15.1	4.79	15.64	18.2	18.3
Fe	5.33	0.02(99.6)	0.2	0.17	1.43	8.81	0.71 (97)	5.63	29.2	4.22 (21)
NO_3^-	4.05	3.69	3.63	3.54(13)	0.23	0.58	0.12 (97)	1.33	0.96	0.58 (86)
P_2O_5	0.17	0.08	0.02(88)	0.02	0.02(88)	0.02	0.06	0.16	0.03	0.02 (88)
Pb	0.63	0.66	0.06(91)	0.19	0.74	0.46	0.07 (89)	0.71	0.19	0.15 (76)
BOD	185.0	4.0 (98)	6.2	5.0	4.14(98)	8.5	7.7	45 (76)	63.5	58

Note: Values in bracket are highest percentage removal (%) by the plants against the retention day.

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Manganese was removed by typha- planted cell only, 50% @day 1, afterward, there were increase in Manganese values as HRT increase. Iron was effectively removed by the two planted cells. Typha- planted, 99.6% @ day 1 and sorghum-planted, 97% @ day 10. The unplanted cell (control) has a poor removal value of 21% @ day 10 (Figure 4). Ninety- one percent (91%) @ day 5, 89% @ day 10 and 76% @ day 10 of Lead were efficiently removed by typha- planted, sorghum-planted and unplanted cells, respectively (Figure 3). Typha-planted and Sorghum- planted cells removed 98% @ day1 of BOD, while 58% @ day 10 was recorded in control cell (Figure 6).

From the experiment, Typha orientalis effectively remediated turbidity, sodium, iron and lead, while Sorghum arundinaceum accumulated high concentrations of potassium, and nitrate. The two plants were removed phosphate and BOD even at day one retention (Figure 7). The high metal concentration in the plant roots is found to be similar with the results of previous studies (Lu et al. 2004; Hassan, Talat and Rai, 2007). In general, most studies reported that higher levels of metals were accumulated more in roots compared to leaves. One of the reasons for higher accumulation factor in the plant roots may be due to of their absorption to the surface of root tissue (Mohamad and Puziah, 2010).

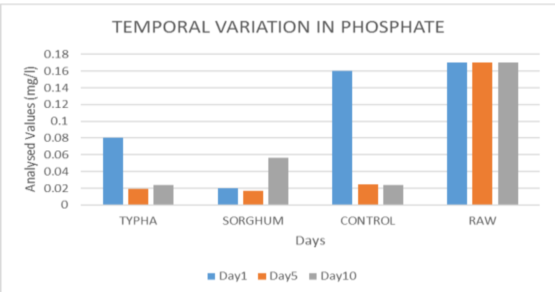


Fig. 1. Nitrate concentration against retention days.

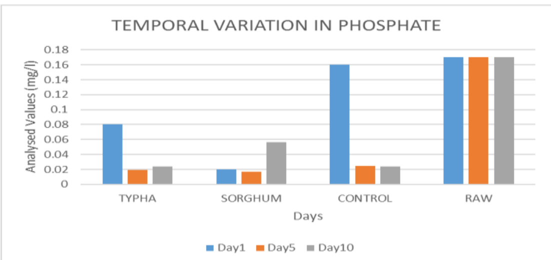


Fig. 2. Phosphate concentration against retention days.

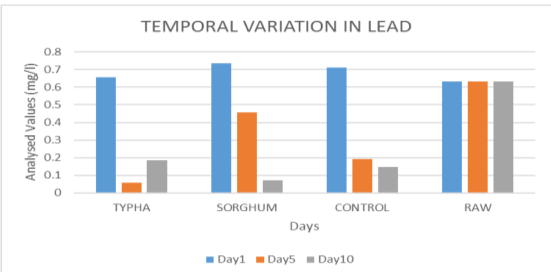


Fig. 3. Lead concentration against retention days.

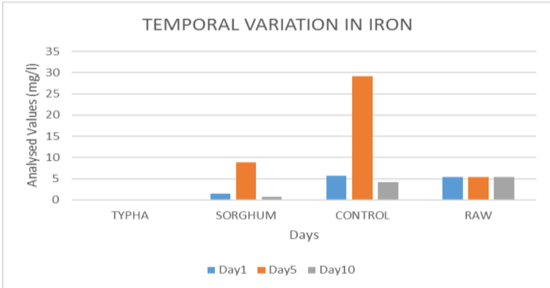


Fig. 4. Iron concentration against retention days.

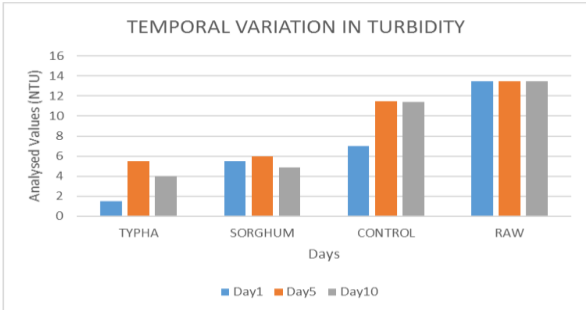


Fig. 5. Turbidity values against retention days.

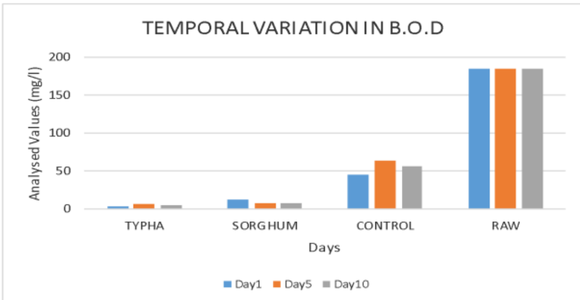
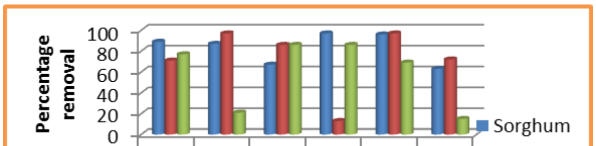


Fig. 6. B.O.D values against retention days.



	Lead	Iron	Phosphate	Nitrate	BOD	Turbidity
Sorghum	89	87	67	97	96	63
Typha	71	97	86	13	97	72
Control	77	21	86	86	69	15

Fig. 7. Percentage removal of contaminants.

IV. CONCLUSION

From the 10-day retention wastewater treatment study, it is clear that the sub-surface flow constructed wetland unit (SSFCW) with Typha Orientalis and Sorghum Arundinaceum, in independent wetland cells is effective in removing turbidity, sodium, iron and lead, potassium, and nitrate, phosphate and BOD from runoff wastewater. The treated effluents, in terms of all forms of nitrogen and inorganic phosphate, were able to meet the effluent discharge standards for inland waters set by the Drinking and Irrigation Water Quality Standards (2008). The planted wetland cells had higher treatment efficiency than the unplanted one. The present research demonstrates the feasibility of using constructed wetlands planted with Typha Orientalis and Sorghum Arundinaceum and shows that they could be employed as the secondary treatment process for municipal wastewater.elaborate on the importance of the work or suggest applications and extensions.

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