Floating Plant Clusters for Urban Runoff Pollution Abatement System (FPC-UROPAS): A Bench Scale Study

Udayashankara T. H	Professor, Department of Environmental Engineering, Sri Jayachamarajendra College of Engineering, Mysuru, Karnataka – 570 006 INDIA
Sadashiva Murthy B. M	Professor, Department of Environmental Engineering, Sri Jayachamarajendra College of Engineering, Mysuru, Karnataka – 570 006 INDIA
Madhukar M	Research Scholar, Department of Environmental Engineering, Sri Jayachamarajendra College of Engineering, Mysuru, Karnataka – 570 006 INDIA

ABSTRACT   *Urban runoff dissolves and uptakes many pollutants from various natural terrain and urban infrastructures. These urban runoffs has the potential to degrade the nearby fresh water sources. Hence, the urban runoff is considered to be significant source of non point pollution of fresh water sources which needs to be addressed to reduce the pollution load on to pond, lake, river etc. Various filtering materials and abatement system have been practiced and experimented for the same, but found not practicable. Researchers have evidently proved that floating wetlands systems can provide reasonable extent of treatment for the runoff waters. The plants root zone play a very important role in reducing organic and inorganic, metal and nonmetal pollutant loads. In the present bench scale study, a fabricated channel (0.25m3), polyurethane sheet (surface area 0.04m2 and thickness of 0.025m) and Eichhornia crassipes, was used for construction of urban storm water pollution abatement system. Urban runoff containing Nitrate, Phosphorus, Lead, Zinc and Cadmium, were synthesized in laboratory. The system bared a promising result of >80% and >85% nutrient and heavy metal removal respectively. Hence, urban storm water collection and conveyance system if planned and managed properly, can be provided with Synthetic floating plant clusters as mesocosm to remove nutrient and heavy metals from the stream.*

Introduction

During storm events, after top soil layers are saturated the water starts flowing down the gradient which is called as storm water runoff. This runoff water eventually reaches nearby water bodies (streams, rivers and ponds) or collects in storm water detention ponds. Quantity of Storm water runoff is more in urbanized locations compared to rural areas. This is due to increase in impervious layers urban infrastructures (residential, commercial and industrial areas, roads, highways, bridges and other impervious layers). Arnold and Gibbons (1996) pictorially presented the effects of Urbanization (pavements and concrete structure) on rate runoff and infiltration (Fig. 1).
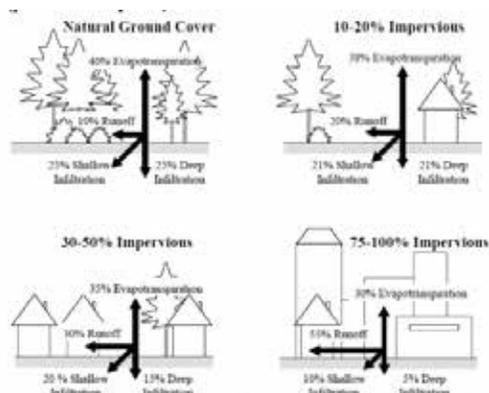
Storm water is considered to be most pure form of water, however, during the course of precipitation the water droplets captures and dissolve the pollutants and reach the ground. Further, when the runoff occurs, a wide range of pollutants such as solids, oxygen demanding substances, Nitrogen and Phosphorous, Pathogens, Petroleum Hydrocarbons, Metals, Synthetic Organics etc., are taken up by the water flow. The pollutants found in the urban runoff are - Eroded Soil (inert particulate), Lawn Chemicals (Fertilizers and Pesticides), Housing Products (paints, thinners, solvents, cleaning agents etc.), oil and grease, Dust (atmospheric deposition and Automobiles), and Septic system discharges. These pollutants are diffuse or nonpoint source in nature. The typical Characteristics of Storm water published by New Jersey Department of Environmental protection (2004) is as furnished in Table 1. However, the characteristics vary depending upon the region, type of land use and land cover, vegetation, atmospheric inputs and source of pollutants (point or nonpoint).

Figure 1. Effects of Urbanization on Runoff and Infiltration [1]

Table 1. Typical Characteristics of Storm water

Parameter	Concen-tration	Parameter	Concen-tration
Total Suspended Solids, mg/L	80	Petroleum Hydrocarbons, mg/L	3.5
Total Phosphorous, mg/L	0.3	Cadmium, µg/L	2
Total Nitrogen, mg/L	2	Copper, µg/L	10
Total Organic Carbon, mg/L	12.7	Lead, µg/L	30
Fecal Coliform, cfu/100mL	10000	Zinc, µg/L	140
E-coli, MPN/100mL	1450	Insecticides, µg/L	0.1-2
Oil and Grease, mg/L	3	Herbicides, µg/L	up to 5

The adverse impacts of these pollutants on the receiving water body can be classified as below

i) Short term changes in water quality during and after storm events along with variation of pollutant concentration and bacteria levels,

ii) Long term water quality impacts caused by the cumulative effects of repeated storm water discharges from various sources and

iii) Physical impacts due to soil erosion and deposition associated with increased frequency and volume of runoff that alters aquatic habitat. Storm water is a useful resource for meeting urban water demand and sustainable development of an urban area.

Hence, the abatement of urban storm water runoff play a vital role, mainly in safeguarding the quality of fresh water resources, to utilize the treated water for various purposes, such as, Domestic and Industrial water needs, gardening, Recharge – Groundwater, lakes and ponds. The storm water collection and conveyance systems plays an important role while managing the urban runoff, by removing the inert grit particles, floating matters and oil and grease. The most imperative parameters which have to be addressed in depolluting the urban storm water runoff is turbidity, oxygen demanding substances, nutrients (nitrate and phosphorous) and heavy metals (Lead, Zinc and Cadmium) which has the potential to degrade the aquatic ecosystem.

The major impacts on public health due to insufficiently managed storm water runoff are: increase in water borne diseases, reduced drinking water quality, load on treatment plants, water logging, soil contamination by sediment transport and increase in vectors [2]. There are various conventional methods such as media based filtration [3-4], Grassed Swales [5], Detention Pond [6-7] and constructed wetland [8] which are being experimented and employed and practiced in some places to address pollutants in storm water runoff. A novel approach of using floating wetlands has been studied for treatment of pond or lakes worldwide for reducing various pollutants [9-10]. Commonly, the system employs conventional or specific aquatic macrophytes. The advantages of using treatment wetlands over other storm water management system are well documented by Southwest Florida Water Management District [11].

Keeping all the above facts in view present study is focused towards using floating plant clusters (FPC) to treat the synthetic runoff water in a bench scale Urban Runoff Pollution Abatement System (UROPAS). The specific objectives is to select the aquatic plant species and build floating plant cluster and employ the same for treating the synthetic storm water (constituting Nitrate, Phosphorus, Lead, Zinc and Cadmium) in a fabricated channel. And carryout the performance of evaluation of the urban storm water depolluting system.

Materials and Methods
Rectangular glass channel of dimensions 1m X 0.5m X 0.5m was fabricated with top open to atmosphere as shown in Figure 2a. Three channels were used in the study. Polyurethane foam sheet was used for anchoring the plant and keeping the plant in floating condition (Figure 2b). The plant is placed in the openings provided in foam such a way that root system is in contact with water and shoots system is in contact with atmosphere. Two foam having surface area of $0.04m^2$ each and thickness 0.025m, where placed in series. The foam sheet was made to be in fixed position by tying it to cleats (4no.) provided in the channel. Eichhornia crassipes obtained from local water body is initially washed with clear water to remove the adhered dirt both on root and shoot system of the plant.

Three rectangular channels 1, 2 and 3 were employed and charged with synthetic storm water at a flow rate of 0.03125, 0.0625, and 0.125L/min i.e. approximately equal to 0.00025, 0.0005 and 0.001m/min respectively. Peristaltic pump was used to regulate the required flow rates. The outflow water was collected and analyzed for the considered parameters (lead, Zinc, Cadmium, Nitrate and Phosphorus) to determine the efficiency of the FPC-UROPAS. In order to maintain the uniformity (to certain extent) with respect to the Eichhornia crassipes, plants having same weight were used in each channel. The weight of each

aquatic plant chosen was 0.25+/-0.05kg. Each plant was weighed after washing with clear water and draining out water completely. Initially, the channel was fed with tap water and the FPC was placed in there for two days.

The stock solutions of lead, zinc, cadmium, nitrate, and phosphate is prepared by dissolving $PbCl_2$, $ZnSO_4$ $7H_2O$, $3CdSO_4$ $8H_2O$, KNO_3, and KH_2PO_4 in de-ionized water, respectively. The stock solutions were used to prepare synthetic storm water. The characteristics of the urban runoff were set based on the literatures (Foroughi, 2013), and drinking water quality and effluent discharge (surface water) IS standard. The concentrations of the synthetic urban runoff used in the present study is furnished Table 2. For oil and grease, used oil procured from a genuine two wheeler servicing centre located in Vishwamanava Double Rd, Saraswathipuram, Mysuru.
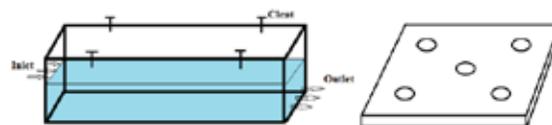

Fig 2. a) Glass Channel and b) Polyurethane Foam

The heavy metals were analyzed using inductively coupled plasma mass spectroscopy, Nitrate (Phenol Di-Sulfonic Acid Method), and Phosphorous (Stannous Chloride Method). Oil and Grease is measured as per Standard methods [12]. The effect of flow rate on removal of pollutants is determined by varying flow rates and drawing samples from the reactor to analyze the concentration remaining in the treated water. The samples are drawn at time interval of 0.25h up to 6h.

Table 2. The Characteristics of Synthetic Urban Storm water Runoff

Parameter	Concentration	Parameter	Concentration
Nitrate	45 mg/L	Zinc	6 mg/L
Phosphorous	10 mg/L	Cadmium	2.5 mg/L
Lead	2.4 mg/L	Oil and Grease	12 mg/L

Results and Discussion
The outflow water from UROPAS was collected at regular time intervals of 0.25h (up to 6h) and analyzed parameters listed in Table 2. The removal efficiency of the pollutant by the FPC-UROPAS was determined with respect to each parameter using the simple efficiency equation 1.

$$\text{Removal Efficiency, } \% = \frac{\text{Initial Concentration} - \text{Final Concentration}}{\text{Initial Concentration}} \times 100 \quad (1)$$

The nitrate concentration was found to be significantly reduced in the outflow when compared with the inflow concentration (Figure 3). The average removal of nitrate in the FPC-UROPAS was 78%, 81% and 86% in Channel 1, 2 and 3 respectively. The reduction in concentration of nitrate is may be due to bio-sorption of nitrate by the roots system of plants. The nitrate is an essential constituent for plants growth and production of seeds. It is easily absorbed by root zone and converted to NH_4. The ammonia is further converted to amino acids and proteins. The Nitrate absorbed by root may diffuse directly to shoot system or may be converted to ammonia initially and then transferred to shoot system. Further, Nitrate removal occurs by biologically, by the action of denitrifying bacteria which are commonly present in the root system of aquatic plants.

Phosphorus (P) is considered to be a pivotal nutrient for all the living cells. When the phosphorous present in the water is in organic form, first it has to be hydrolyzed for easy up take by the plant roots. Commonly, the process of hydrolysis is taken care by root system and microorganisms (rhizomes). In the present case

phosphate source is derived from mono-potassium phosphate in which potassium is also an essential element for the cellular processes in plants, including turgor regulation, charge balance, movement, and protein synthesis. Hence, the rate of uptake of Phosphorus is high compared to nitrate. The total average phosphorous removal in the UROPAS was greater than 80%, 84% and 90% by Channel 1, 2 and 3 respectively (referring to Fig. 4).
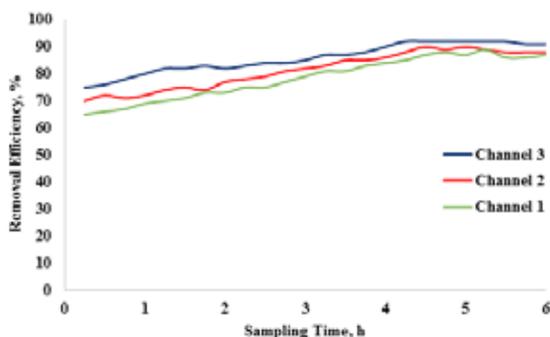

Figure 3. Nitrate Removal by FPC-UROPAS

Zinc and cadmium removal from FPC-UROPAS was promising. The removal efficiency varied from 86% 97% in case of Zinc and 88% to maximum of 98% in case of Cadmium. Zinc is an essential micronutrient for activating the plant enzymes. And also the sulfate ion is an essential secondary Nutrient required for the plant growths which are added as Zinc sulfate and Cadmium sulfate during the preparation of synthetic water. Sulfate ions are used for synthesis of amino acids which are utilized for protein synthesis and also for production of chlorophyll, utilization of phosphorus and other essential nutrients. Sulfate is commonly considered to equal the rank of nitrogen for optimum crop yield and quality. Hence, the uptake of zinc and cadmium in the present bench scale study was found to be significantly high. The lead uptake was also found to range from 90% to 95% in the FPC-UROPAS.
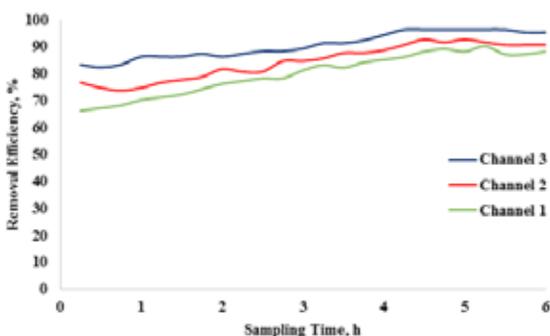

Figure 4. Phosphorus Removal by FPC-UROPAS

About 90% of the oil and grease were found floating on the surface of the water at the outlet end and remaining was found on channel and polyurethane foam surfaces. Hence, the oil and grease trap and skimming becomes as vital component while addressing to storm water treatment. Further, from the study, it is evident that, the flow rate affects the efficiency of continuous flow phytoremediation. From figure 3 and 4, it can be observed that when flow rate was decreased the removal efficiency of nitrate and phosphorous from depolluting system increased. Similar trend is observed with respect to Zinc, Cadmium and Lead. The interaction between ions and roots will be maximum at low flow rate hence removal efficiency is high. The Root Zone provided in the UROPAS is found to be sufficient enough to remove the pollutants from the synthetic urban runoff.

Conclusion

From the present study, it can be concluded that, the root zone provided in the UROPAS was sufficient enough to remove >80% of both nitrate and phosphorous even at maximum flow rate considered in the present study. In continuous flow phytoremediation the efficiency of the system is affected by flow rate i.e. as the flow rate increases efficiency decreases. The heavy metal uptake was effective in the present simple urban runoff pollution abatement system. The average removal of heavy metals (zinc, cadmium and lead) is found to be >85%, which is a significant value in phytoremediation. The designed reactor channel performance is found to be promising for depolluting urban runoff. Therefore, providing FPC to storm water channels/detention ponds can be recommended to reduce the pollution load on receiving water body. Further study is recommended to understand the effect of shock load on the performance of the FPC-UROPAS.

REFERENCE

1. Arnold, C. L., and Gibbons, C. J. 1996. Impervious surface coverage: the emergence of a key environmental indicator. Journal of American planning association, 62(2), 243-258. | 2. Gaffield, S. J., Goo, R. L., Richards, L. A., and Jackson, R. J. 2003. Public Health Effects of Inadequately Managed Storm water Runoff. American Journal of Public Health, Vol 93, No. 9, 1527-1533. | 3. Khiadani (Hajian), M., Zarrabi, M., and Foroughi, M. 2013. Urban runoff treatment using Nano-sized iron oxide coated sand with and without magnetic field applying, Journal of Environmental Health Sciences & Engineering, 11:43, 1-8. | 4. Foroughi, M., Khiadani (Hajian), M., Amin, M. M., Pourzamani, H. R., and Dastjerdi, M. V. 2013. Treatment of synthetic urban runoff using manganese oxide coated sand in the presence of magnetic field, International Journal of Environmental Health Engineering, 2(2), 1-5. | 5. Backstrom, M. 2003. Grassed swales for storm water pollution control during rain and snowmelt. Water. Sci. Technol. 48, 123–134. | 6. Shammaa, Y., Zhu, D. Z., Gyurek, L. L., and Labatiuk, C. W. 2002. Effectiveness of dry ponds for storm water total suspended solids removal. Can. J. Civil. Eng. 29, 316–324. | 7. Mallin, M. A., Ensign, S. H., Wheeler, T. L., and Mayes, D. B. 2002. Pollutant removal efficacy of three wet retention ponds. J. Environ. Qual. 31, 654–660. | 8. Sahu, O. 2014. Reduction of Heavy Metals from Wastewater by Wetland, International Letters of Natural Sciences, Vol. 12, 35-43. | 9. Headley, T. R., and Tanner, C. C. 2008. Floating Treatment Wetlands: an Innovative Option for Storm water Quality Applications, 11th International Conference on Wetland Systems for Water Pollution Control, Indore, India, November 1-7, 1101-1106. | 10. Kirim, B., Coban, D., and Guler, M. Floating Aquatic Plants and Their Impact on Wetlands in Turkey, 2nd International Conference - Water resources and wetlands. 11-13 September, 2014 Tulcea (Romania); ISSN: 2285-7923; Pages: 102-109 Available online at http://www.limnology.ro/water2014/proceedings.html. | 11. http://www.swfwmd.state.fl.us/publications/files/stormwater_systems.pdf. | 12. Standard Methods for the Examination of Water and Wastewater, APHA, AWWA and WEF, 21st Edition, 2005. | |