Purification of urban storm water of curb inlets using biochar embedded bio - geo filter

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Abstract *– Curbs which have immerged with the development of roads have let the collected water of carriage ways to rush off from the road pavement to the line drains and then to the nearest water bodies. The water which flows may contains many pollutants with oil and grease, hydrocarbons mainly such as Cu, Pb, Ni & Zn. Thereby those get mixed with water bodies and. Therefore, this research was aimed to develop a model to purify urban storm water of curb inlets using bio retention filters prior it enters urban water bodies. The prototype was developed by using water from an urban canal hypothesizing that its water accumulated through curbs. A prototype of the bio char embedded bio-geo filter was designed and developed for treating the water varying the loading rate. Accordingly stream water initially was let to flow over biochar embedded grass strips and by changing loading rate, optimum flow velocity was obtained for designing roadside curb inlet and the bank of the urban stream bank. The proposed system successfully removed organic, inorganic, and heavy metals from storm water, which can be applied for purifying storm water of the roadside curb inlets with an appropriate design.*

Keywords*: Bio-Geo filter; Urban storm water; Curb inlets; Heavy metals; Biochar*

1 INTRODUCTION

Recently Sri Lanka has been subjected to industrialization. As a result prevailing high traffic condition has become a serious challenge in transportation sector. Accordingly, the road network has been subjected to expansion for reducing traffic. However, the unnoticeable fact is that many types of pollutants, which originate from variety of sources, accumulate specially over the road surfaces. Due to increase of impervious land area, storm water runoff of urban areas has become a severe threat on the environment and aquatic ecosystems during the rainy season. Therefore, it is essential to introduce a proper way to treat storm water without letting flow into natural surface water bodies directly.

Storm water runoff contains solid wastes, road sweeps, hydrocarbons, sand, silts and other particulate matters which can be chemical, physical or biological (Erickson *et. al*, 2013). Among those, the major influence is the habitat alteration and biological integrity due to loading sediments, chlorides, heavy metals, nutrients, and biological oxygen demanding substances of water.

Roads and highways consist of micro pollutants such as hydrocarbons & heavy metals which combine with sediment particles (Aryal *et. al*., 2005). Usually in storm water runoff contains wide range of organic compounds such as hydrocarbons produced in combustion process (Kennedy *et. al.,* 2016; Huber et al., 2016). Arsenic (AS), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Lead (Pb), Nickel (Ni), Zinc (Zn) were founded as the crucial contaminant metals in the storm waters due to their toxicity, and lack of degradability (Kennedy *et. al.,* 2016). Due to long-time dry periods, accumulation percentage of those pollutants may also increase and with rainfall, those washed out to the water resources while polluting water resources (Wang *et. al*., 2017).

Wetlands are the most important eco-system on the earth due to its unique hydrologic conditions and connection between terrestrial and aquatic systems (Brix, 1994). But in the present days, wetlands are reclaimed to build residents or drained for agricultural purposes. Therefore, the reduction of natural wetland causes to build up artificial bio retention ponds. Retention ponds or wetland concepts have been developed as a sustainable solution for the treatment of the storm water runoff with the ability of flood potential reduction and water quality enhancement. Integration of pollutant absorbents such as vegetative diversity and geo-materials reinforce the water purification process by facilitating the biogeochemical reactions. Bio char is a by-product of thermal decomposition of wood, plant leaves and such organic matters are under a limited substances environment below 700^{0}C. Bio char contains more than 60% of carbon and is used as a soil amendment material (Igalavithana *et. al.,* 2017). It can be used as a microbial inoculants carrier and as a water treating agent (Gwenzi, et al., 2017). Due to its high surface area and oxygen containing surfaces, it can adsorb heavy metals and inorganic compounds such as nitrates and phosphate. The removal of phosphate from water using bio char limits the eutrophication impact on natural water ways. Saw dust bio char has been found to be effective in wastewater improvement (Lou et al., 2016; Kitchener 2017).

In this context a remedial model to treat the storm water runoff on road pavements was introduced as pollution control systems to enhance water quality of urban drainage canals. Therefore, this research was focused to characterization of curb storm water and to introduce purification system using an urban storm water by using biochar embedded bio-geo filter.

2 METHODOLOGY

2.1 Demarcation of sampling points

Storm water from curb inlets were collected on the road pavement area for characterizing the curb water. Turbidity was measured using HACH 2100P Turbidity meter while pH was measured using JENWAY 3510 pH Meter. Electrical conductivity and temperature were measured using JENWAY 4520 Conductivity Meter while NO_3 and PO_4 were measured using HACH DR 900 Colorimeter. For COD measurements the samples were digested using HACH DRB 200 and then measured using HACH DR 900 Colorimeter. The samples were digested for heavy metal measurements and then measured using ICP-MS.

2.2 Setting up the Experimental model for treating curb storm water

Plywood board of size 2000mm x 500mm was placed forming a gentle gradient of 7:1. Bed of the plywood was fully covered with polythene and a frame was fixed around the plywood of 8cm height.

Biochar was produced by pyrolyzing Gliricidia biomass at <700 ºC in a closed reactor as a by-product of generating energy (Athapattu et al, 2017). Kabook used for this experimental set up was obtained from a demolished house as a waste construction material. Bio char and Kabook was selected 6.35 to 4.76 mm after the sieve analysis and mixed in the volume of 3:1. Mixed bio char and Kabook was layered on the prepared plywood board and sealed them tightly with a use of chemically inactive net. A grass layer was grown over the biochar bed and allowed to grow for few weeks prior to the experiment. Inlet was prepared to shower the water from a higher elevation. A PVC pipe of length 500mm was drilled with hole 1mm diameter with 5mm intervals and fixed horizontally to distribute the water equally along the grass layer. A 500 L tank was setup and flowrate were controlled and fed the system. It was assumed that the urban canals collect road sweeps and storm runoffs during the rainfall and therefore the urban canal water contains considerably higher concentrations of pollutants. The distilled water obtained was used as the datum for inland surface waters.

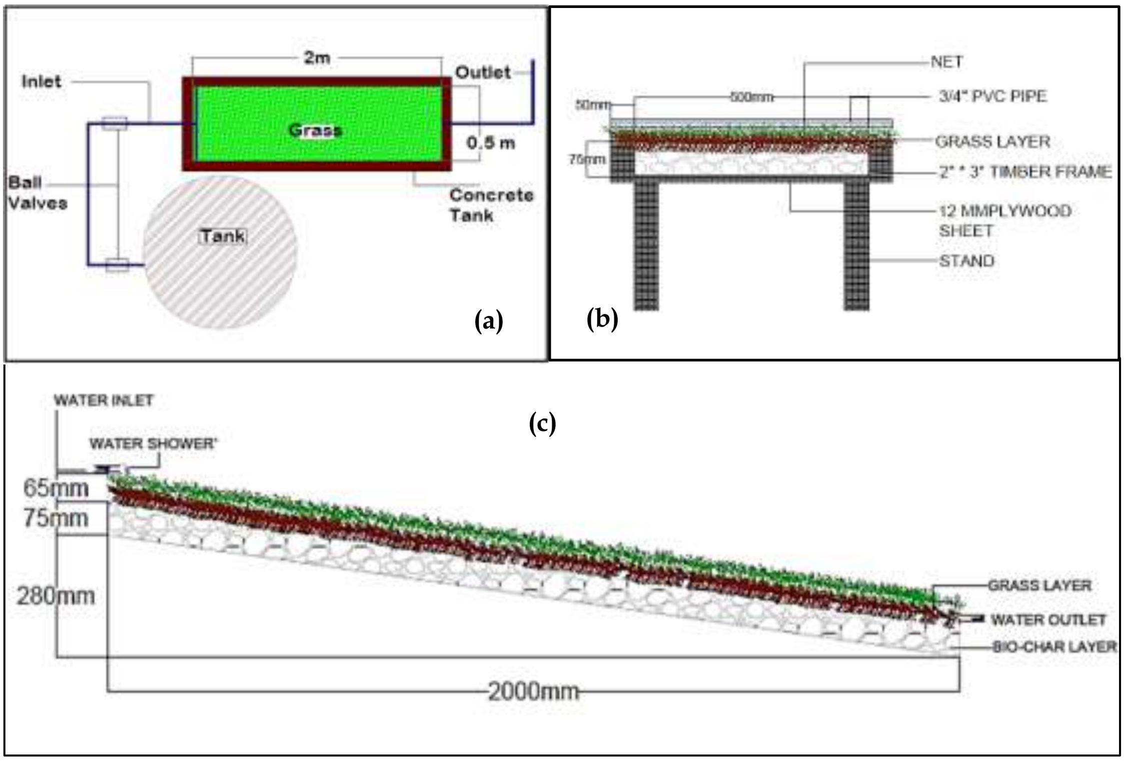


Fig. 1: Details of biochar embedded bio geo filter excremental setup
(a) Plan View (b) Elevation (c) Longitudinal section

The periodically collected samples from inlet and outlet of the experimental setup were measured to estimate the removal efficacies. Fig.1a, 1b and 1c are shown the plan view, elevation, and longitudinal section of the experimental set of biochar embedded bio geo filter, respectively. Fig. 2 shows the pictorial view of model set up at the laboratory. Initially, fresh water was flow over to wash out the system. After cleaning the setup, storm water was filled to the overhead tank and allowed to run with different flow rates such as 10mls^{-1}, 20mls^{-1}, 30mls^{-1}, 50mls^{-1} and 100mls^{-1}. Flow rate was measured while controlling the valve and used to fill a known volume within a known retention time. Drain outs were collected after saturating the bio char and Kabook layers. The drain out samples were tested for turbidity, total suspended solids (TSS), chemical oxygen demand, electrical conductivity, nitrates, phosphates, pH and for selected heavy metals.

2m long, 0.5m wide and 0.075m high grass buffer was prepared for the treatment process. The total volume of the wetland is 0.075m^3. 1/4th total volume was filled with Kabook and ¾ volume was filled with sieved bio char. Water inlet and outlets were made by installing ¾" PVC pipe and placed horizontally to the supply pipe. Assuming the storm water level in the tank is constant the saturation time was calculated and allowed to saturate.

Fig. 2: Pictorial View of Wetland Model

3 RESULTS AND DISCUSSION

Water quality parameters of storm water coming out from the curb inlets are shown in Table 1. The average water quality of storm water was estimated using three different rainfalls obtained monthly for three months. The monthly rainfall of said consecutive months were 50mm, 315mm and 117mm.

Table 1: Characteristics of storm water of curb inlets at Metro city, Sri Lanka

Parameter	value
Temperature °C	30±2
Turbidity (NTU)	28.7±8
Conductivity (µs/cm)	71±24
TSS (mg/L)	11±3
Oil & Grease	0.7±0.3
pH	8.8±0.4
COD	72±35
Nitrate (mg/l)	1.1±0.4
Phosphate (mg/l)	0.35±0.5
Zn (mg/l)	0.369±0.005
Pb (mg/l)	0.042±0.002

It was noted that high turbidity can be observed with the high rainfall intensity. This occurs due to increasing of TSS in the storm water runoff. With the minimum intensity of rainfall, turbidity increases while turbidity decreases during medium rainfall intensity. Total suspended solids (TSS) shows considerable fluctuation while lowest TSS value was recorded as 9 mg/L during the moderate rain.

However, it also varies with the sample time and the location. Usually organic contaminants may increase the amount of TSS along roadsides. Oil and grease content of storm water sample was considerably higher during high rainfall intensity. Storm water run-off was almost alkaline however frequent raining makes it towards acidic.

The maximum electric conductivity was recorded as 114.5µs/cm. However, electric conductivity of fresh water fluctuates from 15 – 30 µs/cm. with moderate and lower conditions of raining it may deviate a little. Chemical Oxygen Demand also varies with the rainfall intensity. It fluctuates from 46mg/l to 91mg/L. during the period of concern. However, it was observed that, the minimum of COD of storm water was considerably higher than freshwater COD (10 mg/l). Further, 1.5 mg/l of nitrates was observed while lowest nitrate, 0.8 mg/l was observed during mild rainfall. Hence the heavy rain conditions, nitrate may dilute with runoff. In fresh water it was recorded as 0.08 mg/l of nitrates.

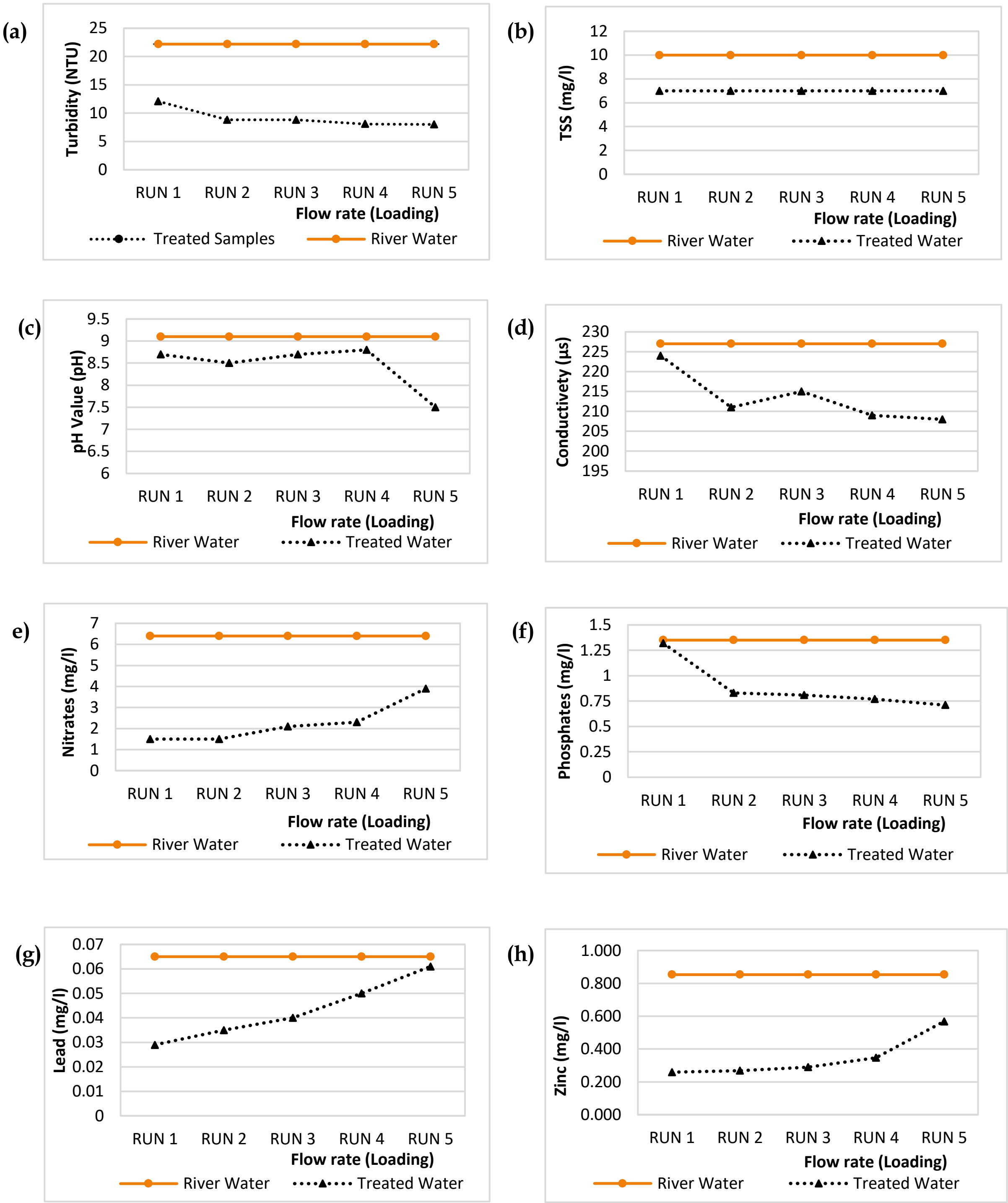
Phosphates showed the similar variation as nitrates. Minimum value of 0.28 mg/l is seen in high rainfall intensity due to the dilution of contaminants. However, in freshwater phosphate concentration was nearly 0.07 mg/l. Usually of 0.002 mg/l of zinc recorded in fresh water while the storm water showed considerably higher value. In addition, lead concentration of fresh water (<0.001 mg/l), while the storm water Pb value deviate considerably probably due to vehicle emissions.

3.1 Removal of pollutants through the system

The experimental setup was initially fed with fresh water for 24 hrs to saturate the system. Thereby runs were repeated with different loading rates and water quality parameters were measured with respect to the initial sample parameter. The Table 2 shows the pollutant removal efficiency when passing through the biochar embedded bio geo filter system.

Table 2: Pollutant removal efficiency of stormwater using purification system

Experiment Series	**Influent Loading Rate**	**Percentage removal**								
		Turbidity (%)	**TSS (%)**	**pH (%)**	**COD (%)**	**Electrical Conductivity (%)**	**Nitrate (%)**	**Phosphate (%)**	**Zn (%)**	**Pb(%)**
Run 1	10 ml/s	45.50	30.00	4.40	43.24	1.32	76.56	2.22	69.64	55.38
Run 2	20 ml/s	60.27	30.00	6.59	45.95	7.05	76.56	38.52	68.58	46.15
Run 3	30 ml/s	60.32	30.00	4.40	40.54	5.29	67.19	40.00	66.00	38.46
Run 4	50 ml/s	63.60	30.00	3.30	35.14	7.93	64.06	42.96	59.44	23.08
Run 5	100 ml/s	63.92	30.00	17.58	0.00	8.37	39.06	47.41	33.41	6.15



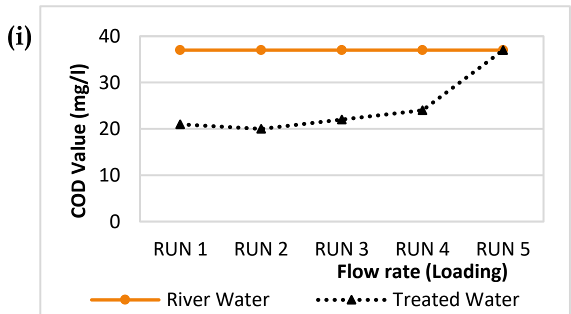


Fig. 3: Variation of water quality parameters of treated water with respect to the urban river water
(a)Turbidity; (b) TSS; (c) pH;
(d) Conductivity (e) Nitrate; (f) Phosphate;
(g) Lead; (h) Zinc; (i) COD

Fig. 3 shows the removal of respective contaminants when passing through the experimental biochar embedded bio geo filter. A reduction of turbidity is clearly seen with respect to the initial turbidity. COD was varied with the initial value in every run. Minimum COD value was observed in RUN 2 and maximum value was observed in RUN 5. But the Electric conductivity is gradually decreased with the increase of flow rate. Minimum obtained value is 208 µs/cm. Total suspended solids were constant (7mg/l) in every run and it was minimized from the original value. The treatment of nitrogen has been decreased with the higher loading rates. Maximum treatment was occurred at the RUN 1 and minimum Treatment was occurred at RUN 5.

Phosphate removal was enhanced by the system however regular increment can be seen. Minimum treatment was occurred in the RUN 1 while maximum treatment had occurred in Run 5. When consider the removal efficiencies of heavy metals; Pb and Zn showed considerable removal efficiency however the Zn removal efficiency is considerably higher than the Pb. With the increment of the water flow rate, the treatment percentage decreased gradually. With respect to the above percentages, the treatment process on the RUN 2 had the highest treatment efficiency of 42 % total.

3.2 Application of the curb water purification system

The elevational heights of the roadside or any topographical changes of the area can consider for this application. Fig. 4 is shown a proposed application with relevant elevations of the ground and a water flowing structure. Accordingly, the existing slope should be gentle slope for better filtration process. The grass buffer with bio char is to be applied with a gradient of 1:7 towards a horizontal distance of 3.0 m. At the end, a concrete drain of 600 mm x 500mm of gradient 1:100 is to be constructed to transfer the treated water to a retention pond through the grass buffer. The retention pond shall construct with integration of bio geo-materials.

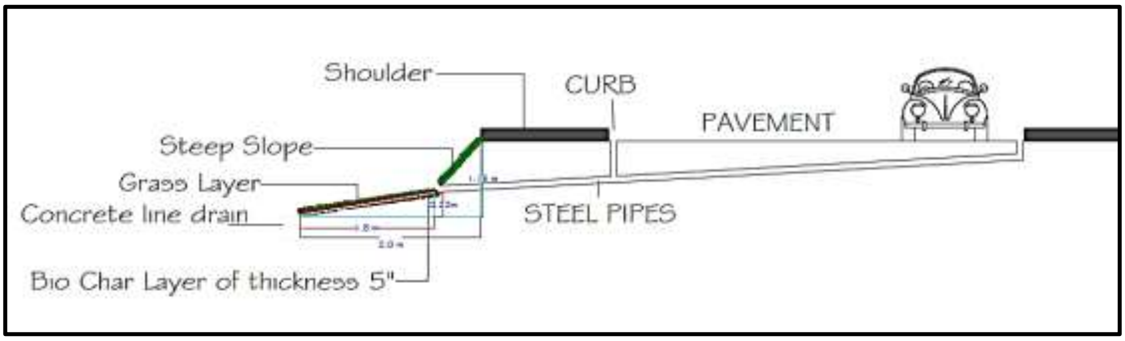


Fig. 4: Illustration of setting out stormwater treatment system at the curb inlet

4 CONCLUSION

This study was conducted for the storm water to clarify the impurities associated. Several parameters, Zn, Pb, NO_3^-, PO_4^{-2}, oil and grease, suspended solids, turbidity, COD, pH, electric conductivity were checked by changing loading rate. The flow measurements were taken from the inlet and the outlet of the bio char embedded bio-geo filter while increasing the loading rate from 10ml/s to 100ml/s. The concentrations of effluents were measured to investigate the removal efficiency of the system which simulates the roadside curb inlets.

According to the removal efficiency, a maximum efficiency was shown in 20 mls^{-1} loading rates. Minimum was obtained with maximum flow rate of 100mls^{-1} proving the heavy rainfall intensities will drastically impact on road sweeps to the nearby water ways. In this experiment, it was used only a 75mm bio char layer and it was treated using a fixed gradient of 1:7. This can be varied according to the topography of the available land. As 20mls^{-1} have shown good removal efficiency and it deviates with the gradient, application length and thickness to the bio char layer the practical application can be adjusted accordingly to obtain the better removal rate.

Though the maximum efficiency of the bio char layer for flowing water is 42%, if it be retained, the efficiency is much more than the above. Therefore, bio char can be used as a treatment agent for storm water enhancing and it can be easily applicable to the roadside curb inlets with a greening strip before flowing into the nearby urban canals. Such green application will bring the sustainable built environment to harmonize with the urbanized activ*iti*es.

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