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Application of Green Technologies to Reduce Impacts of Urban Non-Point Sources Pollution

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ABSTRACT-Storm water runoff from different types of urban catchments and discharge from LID system applied in urban catchments were monitored since 2009 to 2017 in Kongju National University. The performance of green technology (GI) system was evaluated to mitigate the problem like pollutant treatment and restore natural hydrological cycle. The result showed that the urban catchments were sources of pollutants like sediments, organics, nutrients and heavy metals. Thus, the concentrations of these pollutants are highly dependent on the antecedent dry days and types of catchments. Since, roads and parking lots observed higher concentration of sediment and organics however heavy metals were highly contributed by the rooftop areas. Moreover, the application of green technologies could be a better solution to mitigate the problems associated with urbanization. Similarly, GI technology were highly significant to reduce runoff generated and can restore natural hydrological cycle. Lastly, the pollutant removal efficiency of different system was significant due to application of different media and plants.

KEYWORDS-Green technologies, Pollutants, Pollutant reduction, Urban catchments, Volume reduction

1. INTRODUCTION

Increase in impervious surface affects the natural hydrology negatively thereby increasing short peak flows, total annual runoff, and decreased infiltration. Hirschman et al., 2008 study observed that the volume of stormwater runoff generated in urban area was directly proportional to the amount of impervious surface in a specific catchment area. Thus, the increment in impervious area also hinders the infiltration, evapotranspiration, bioremediation, and degradation of pollutant through microbial activities in soil. The pollutants deposited during dry days are transported to nearby sources of water during storm events thereby degrading the water quality and affecting aquatic life (Sansalone et al., 1996). An increment in urbanization also increases the surface temperature higher compared to the local surrounding rural area due to impervious areas is known as urban heat island (UHI). Moreover, the UHI directly affects the energy flow mechanism in the environment due to alteration of natural into impervious surfaces while urban air quality, soil properties, and hydrological phenomenon are also affected by the process (Gunawardena et al., 2017; Yang et al., 2016). Some of the studies conducted observed that asphalt concrete used for the road pavements are the major contributor to UHI effect in urban areas (Yang et al., 2016).

However, water sources are usually polluted by the transportation of pollutants from two types of sources namely point and non-point sources. Point sources are defined as pollution originating from single or identifiable point such as pipe or drain. Furthermore, nonpoint source (NPS) pollution are generated from large areas without distinct location which is generated due to storm events in urban areas, agricultural and livestock areas runoff and hydrodynamics alterations (Fang et al., 2005). Since, best management practices (BMPs) like infiltration basin, infiltration chambers, detention and retention basin were under practice since 1970's in order to reduce peak flow, retain and detain the urban stormwater runoff (Gao et al., 2013). Although, green technology has been regarded as a relatively new concept in the field of urban stormwater management and NPS management (US EPA, 2012). Moreover, this system was practiced for the first time in the state of Prince George County, Maryland in the early 1990s and further globalized later on. Best management practices (BMPs) concept called "Low Impact Development" (LID) or Green Infrastructure (GI) was developed to restore the natural hydrologic regime and decrease the runoff volumes and NPS pollution at the downstream area through utilizing sedimentation, evapotranspiration, infiltration, bioremediation, infiltration, filtration, phytoremediation and soil microbial function. On global perspective, LID approach are defined with different terms such as Water sensitive urban design (WSUD) in Australia, Sustainable urban design (SUDs) in United Kingdom, Low impact urban design and development (LIUDD) in New Zealand, Sponge City in China, Low impact development and green infrastructure (LID/GI) in South Korea (Zhu & Chen, 2017; Zimmerman et al., 2010). Thus, current research was focused on quantification of pollutants from urban catchments like road and parking lots, rooftop, and parking lots. Furthermore, the GI system applied in the urban catchments was evaluated for pollutants and volume reduction with long term monitoring data.

2. MATERIALS AND METHODS

2.1 Site location and physical design characteristics

The GI sites were located at Kongju National University, Cheonan City, South Korea. The eight GI sites were designed, developed and constructed to mitigate and treat runoff from the different types of urban catchments. Figure 1 shows the specific site location of all GI facilities. GIs were situated either on a small landscape area near a paved road and building or at the end of a parking lot. The treatment sites were selected for the respective distinct land uses (e.g. paved road, impervious rooftop and parking lot) and design characteristics (e.g. wetland, bio-retention, rain garden and tree box filter with various plant species). Table 1 summarizes the catchment area characteristics (i.e. area, plants and filter media used) of the GI sites.

Figure 1: Site location and physical characteristics of GI

Table 1: Summary on the characteristics of the GI facilities

Characteristic	Unit	Type of LID							
		Small hybrid wetland (SW1)	Small horizontal subsurface wetland (SW2)	Rain garden (RG1)	Raingarden (RG2)	Tree box filter (TBF)	Infiltration/ Planter (IFP)	Bio-retention (BR)	Infiltration trench (Ecobiofilter-EBF)
Year of construction		2010	2010	2011	2014	2010	2013	2013	2009
Actual dimensions (L x W x D) and aspect ratio	m	6.5m x1m x 0.7m (1:0.15:0.1)	7m x 1m x 0.7m (1:0.14:0.1)	3.88m x 1.5m* (1:0.40)	6m x 1.2m x 1.2m (1:0.2:0.2)	1.5m x 1m x 1.3m (1:0.67:0.87)	2m x 1.5m (1:0.18:0.24)	3m x1.3m x1.2m (1:0.43:0.4)	5mx1.2mx1.3m (3.9:0.9:1)
Design total rainfall	mm	5	5	15	25	5	25	-	25
Hydraulic retention time (HRT)	Hrs	1.7	1.4	4.06	-	1.1	-	-	
Storage volume	m^3	1.61	1.56	2.81	2.88	0.56	3.85	2.32	3.54
Types of media	N/A	Sand, gravel, woodchip and geotextile	Sand, gravel, woodchip and geotextile	A mixture of soil and gravel; pebbles; gravel; woodchip	A mixture of soil and gravel; pebbles; gravel; woodchip	Woodchip; sand; gravel	Woodchip; sand; gravel	A mixture of sand, soil, bottom ash and woodchip	A mixture of sand, gravel, woodchip
Types of plants	N/A	Iris	Iris	Satsuki azalea, ground pink, rainbow pink	Bridal wreath blue, star creeper, rainbow pink, marigold	Dawn redwood	Bridal wreath and rainbow pink	Korean fan columbine shrubby cinquefoil, aster	N/A
Catchment types		Road and parking lots	Road and parking lots	Roof	parking lots	parking lots	Roof	Parking lots	Road and parking lots

2.2 Storm events monitoring

2.2.1 Water sampling scheme for GI sites

Manual monitoring was performed to effectively quantify the water quantity and quality of the runoff for every storm event. All of the hydraulic and water quality data considered for the analyses were collected from the respective monitored events. The monitoring of storm events for the systems like SW1, SW2 and TBF was performed from 2010 to 2017. The total number of events monitored since the commencement date for SW1, SW2 and TBF were 38, 32, 48 and 32, respectively. Similarly, EBF system was monitored since 2009 total of 48 rainfall events. However, the monitoring of the RG1 system was conducted from 2013 to 2017 having a total of 28 storm events. In addition, RG2 system monitoring was started in the year 2014 with a total of 23 rainfall events. Lastly, bio-retention and infiltration planter system were monitored from 2013 to 2017 having 19 and 21, respectively rainfall events. The water samples gathered in each monitord events were obtained through manual sampling. Six grab samples were collected during the first hour of runoff having a 0, 5, 10, 15, 30 and 60-minute interval. Another 6 grab samples were collected with a 1-hour interval or until the end of runoff. The mentioned sampling scheme was performed on both inflows, outflow and overflow port of the facility and was based on the typical sampling method used in Korea and first flush concept of monitoring (Choi et al.,2018; Hong & Kim, 2016). Flow rates of inflow and outflow were consistently measured and recorded with a five-minute interval.

2.2.2 Water quality analysis of the runoff samples

Water quality parameters such as organics, nutrients and heavy metals were analyzed based on the Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, & WEF, 2005). However, among the measured water quality parameters, total suspended solids (TSS), Biological oxygen demand (BOD), Total nitrogen (TN) and its constituent, Total phosphorus (TP), Total heavy metals and total soluble metals was considered in this study.

2.2.3 Pollutant concentration analysis

The event means concentration (EMC) is an important factor used to quantify the total concentration of pollutants entering and being discharged by the system. EMC is used to quantify the average pollutant load washed off during a rainfall event and to effectively evaluate the reduction performance of a system (Maniquiz et al., 2010). It is a flow-weighted average shown in Equation 1 (Bertrand-Krajewski et al., 1998). The EMC was calculated using:

$$EMC\left(\frac{mg}{L}\right) = \frac{M}{V} = \frac{\int_0^T C(t) \times q_{run}(t)dt}{\int_0^T q_{run}(t)dt} \approx \frac{\sum_0^{t=T} C(t) \times q_{run}(t)}{\sum_0^{t=T} q_{run}(t)}$$

Equation 1

Where, M (g) = total mass of a pollutant transported during a storm event; V (m3) = total volume of runoff; C(t) (mg/L) = concentration at time t; qrun(t) = runoff flow rate discharged at time t. The limits of integration t = 0 and t = T refer to the time associated with the start and end of runoff, respectively. By calculating the inflow and outflow pollutant load, the removal efficiency of the system in treating the certain contaminant could be quantified by utilizing the Equation 2.

$$Load\ removal\ efficiency\ (\%) = \frac{Inflow\ load - Outflow\ load}{Inflow\ load} \times 100 \qquad (2)$$

The volume reduction efficiency of the system is calculated using Equation 3.

$$Runoff\ reduction = \frac{I-O}{I} x100 \qquad (3)$$

Where, I = Total inflow volume, O = Total outflow volume

3. RESULTS AND DISCUSSIONS

3.1 Urban pollutants

Box plot analysis for TSS, organics, nutrients, particulate and dissolved heavy metals from urban catchment were presented as shown in Figure 2. TSS was major pollutants from the urban catchments and pollutants like heavy metals, nutrients are highly correlated thereby contributing particulate bound pollutants (Bertrand-Krajewski et al., 1998). Similarly, current results also observed the higher concentration of TSS from urban catchments in descending order of parking lots and road> parking lots >rooftop. Moreover, the road and parking catchments observed TSS ranging from 1.56 to 2133 mg/l; parking lots observed TSS ranging 3.11 to 468.22 mg/l and rooftop observed 1.95 to 129.01 mg/l. The observed TSS concentration in rooftop catchment was 17 to 21 times less than parking lots and road. Conversely, heavy metal EMC from urban catchments were in descending order of rooftop > parking lots and road > parking lots. It can be clearly observed that heavy metal deposited on rooftop catchment was bounded with a lower concentration of TSS. Gunawardena et al., 2013 studied the heavy metal concentration due to atmospheric deposition reported that Cr and Zn metals in an urban area were extremely contributed dry deposition contributed by air from the urban environment. In addition, Zn deposition in the urban atmosphere was highly contributed by the tire wear from vehicles. Moreover, the heavy metal EMC inflow from parking lots observed 16 to 62 times less concentration of heavy metal compared to parking lots and road catchment during different storm events. The result shows a higher concentration of Cr from the parking lots followed by Zn, Ni, Cd, and Pb. This means total heavy metal EMC from parking lots and road were observed in descending order of Zn> Cr> Ni> Cd> Pb. Helmreich et al., 2010 conducted a study to characterize the road runoff concluded that the total heavy metals were in the descending order of Zn, Cu, Pb, Ni and Cd. Several other studies conducted to characterize the heavy metal concentration in the urban area observed a similar trend (Charters et al.,2016; Davis et al.,2001; B. Davis & Birch, 2010).Thus, it can be concluded that heavy metal in urban rooftop area are highly contributed by wet and dry air deposition and runoff from rooftop catchments needs higher care and treatment before the application like rain water harvesting and discharged to the nearby water sources.

Similarly, nutrients and organics from the urban catchments are secondary pollutants needs to considered after TSS which can fuel the growth of bacteria and viruses thereby degrading quality of nearby streams (Opher & Friedler, 2010). TN EMC from road and parking lots, rooftop and parking lots catchments ranges from 0.10 to 21.16 mg/l, 0.92 to 18.03 mg/l and 0.58 to 107.24 mg/l, respectively. Corresponding, TP concentration ranges from 0.04 to 6.59 mg/l, 0.03 to 5.01 mg/l and 0.03 to 1.94 mg/l. Generally, organics and nutrients in urban catchments are highly contributed by the animals wastes, pest, plant litter and leaves (Gurung et al., 2018)

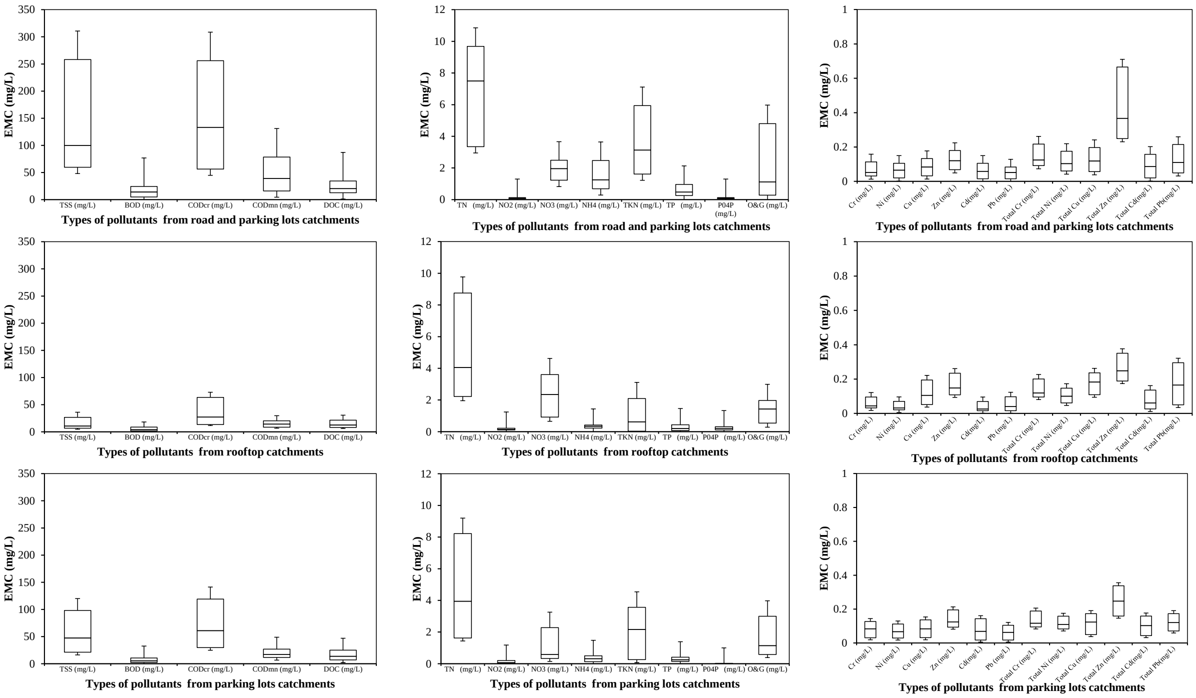

Figure 2: Pollutants transported from the different urban catchments

3.2 Impacts of green technology

3.2.1 Volume reduction

The volume reduction efficiency of GI system was evaluated to restore the natural hydrological cycle thereby increasing infiltration, evapotranspiration due to application of system in urban areas. The total volume, average and peak flow rate reduction efficiency of GI system for varying rainfall depths were monitored and evaluated. The total runoff, average and peak flow rate reduction of GI system was presented in Figure 3. From the results, it can be observed the total volume reduction efficiency of SW1, SW2, RG1, RG2, IFP, BR and TBF and EBF was 34.7%, 26.5%, 94.8%, 98.9%, 94.14%, 86.8%, 62.6% and 56.8%, respectively. However, total runoff reduction efficiency of the SW1 system ranges from 12 to 49.07% although average and peak flow rate reduction range from 18.07 to 84.2% and 4.24 to 59.2%, respectively. The peak flow rate reduction efficiency of SW1 for rainfall depth less than 5 mm was least. The systems like wetlands, total volume reduction efficiency recorded to be low compared to other system like bio-retention and raingarden due to lack of infiltration function. However, these systems were statistically significant ($p<0.05$) to reduce peak flow rate even with bigger rainfall depth. The reason behind, that was due to early arrival of runoff during bigger rainfall depth compared to smaller one which takes longer times to reduce runoff due to saturated condition of media layer thereby affecting the efficiency of wetland system (Williams et al.,2012). Similarly, the total runoff, average and peak flow rate reduction efficiency of the SW2 system ranges from 15.2 to 45.8%, 9.8 to 38.9% and 5.51 to 64.9%, respectively. SW2 system was statistically significantly ($p<0.05$) to reduce the total volume generated due to rainfall depth less than 5 mm. The average runoff reduction efficiency of the SW2 system was 26.5% which is least among all the system considered for the evaluation. Generally, wetland systems are designed to detain runoff and pollutant treatment thereby by sedimentation mechanism (Debo & Reese, 2003). Hirschman et al., 2008 study suggested that the wetland systems are generally good for the pollutants treatment rather than the runoff reduction mechanisms.

Raingarden system received runoff from parking lots and urban rooftop catchments. RG1 and RG2 system observed total runoff, average and peak runoff rate reduction greater than 90%. RG1 system significantly ($p<0.05$) reduced the total runoff, average and peak runoff rate. Raingarden systems are usually provided with infiltration function which significantly helps to reduce the runoff received by the system. Hirschman et al.,2008 study observed that the system with infiltration function can achieve almost 50 - 90% of runoff reduction. Two bio-retention systems runoff reduction efficiency was studied for different rainfall depth. Total runoff reduction efficiency of the IFP system was 70.7 to 100%, peak runoff rate reduction efficiency was observed 65.8 to 100% and average runoff rate reduction ranges from 58.7 to 100%. The inflow received by the system from urban rooftop catchment was significantly ($p<0.05$) reduced. Similarly, the BR system also observed total runoff reduction of 67.3 to 97.9%. Moreover, peak and average flow rate reduction were observed in the range of 75.9 to 98.9% and 56.8 to 97%. The overall runoff reduction efficiency of the system like IFP was 93% while BR system observed 83.4% decline. Shafique, 2016 observed that the bio-retention system can control rainfall and runoff behavior which can be applied as the sustainable urban runoff management tools. Bio-retention systems are usually designed for bio-filtration process and observe runoff reduction ranging from 40 to 80% (Hirschman et al., 2008).

The TBF LID system observed runoff reduction of greater than 70% up to rainfall depth of 10 mm. However, total runoff, peak and average runoff reduction percentage was decreased less than 50% for rainfall depth greater than 10 mm. The average runoff reduction efficiency of TBF was 55.5%. Besides, runoff reductions by using evapotranspiration, infiltration function of TBF facility usually intercept precipitation due to the bigger canopy of trees (Rossman, 2013). The removal efficiency of LID/GI system was highly affected by the rainfall depth and rainfall intensity thereby affecting the retention of water and outflow from the system. Furthermore, EBF system observed total volume reduction efficiency ranging from

48.8% to 80.5% depending on rainfall depth. However, EBF system are usually applied on roadside to restore the natural hydrological state and pollutant treatment transported from the highways and roadsides and urban catchments (Eureka et al., 2015)

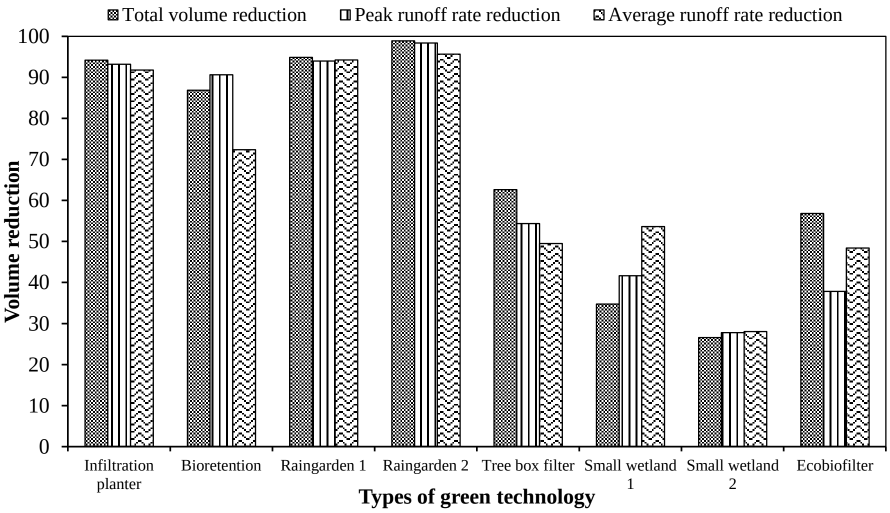

Figure 3: Volume reduction efficiency of different types of green technology

3.3 Pollutants reduction

Besides, volume reduction to restore the natural hydrological state GI facilities are also efficient to treat pollutants transported from urban catchments as shown in Table 2 and Table 3. It can be observed from the table, that TSS reduction of GI system ranges from 50.5% to 98.01%. Similarly, heavy metals transported from urban catchment removal efficiency ranges from 28% to 100% where total % removal was maximum and dissolved % was minimum among different types of heavy metals considered for the study. The systems with detention function are significantly effective for TSS and particulate heavy metal removal, however, nutrients removal moderately efficient. The other factors affecting the pollutant removal was due to sedimentation tank provided in the system which helps to remove the bigger particle, leaf and litter transported from the catchments. The pollutants like litter, leaves and bigger sediments are collected in the sedimentation tank thereby affecting the removal efficiency even without significant volume reduction in the system. The provided pre-treatment tank usually retained the runoff and decreases the velocity thereby enhancing the sedimentation mechanism in GI system (Lee et al., 2014).

The bio-retention systems like infiltration planter, TBF and RG were highly efficient in heavy metal removal compared to the wetland system. The reason was due to plantation of different types of well-maintained plant, which can sustain and treat the heavy metal up to 90% (Glass & Bissouma, 2005). Furthermore, different components like plants like roots, plant stems, leaves and filter media applied in GI are effective in removal of heavy metal (Sultana et al.,2014; Yadav et al., 2010). Walker & Hurl, 2002 investigated the sediment entrapped in stormwater wetland concluded that metals like Pb and Zn were efficiently removed by the sedimentation mechanism. Thus, application of different varieties of plant in GI system enhanced the heavy metal removal greater than 90%. Some of the rainfall events observed leaching of heavy metals due to effect of several factors such as like higher rainfall intensity, rainfall volume and concentration transported to the system with respect to designed parameter

(Herngren et al.,2005). Generally, metals like Cr and Cd EMC were observed highly in dissolved form. Thus, in order to enhance dissolved heavy metal removal, the application of different plants and media layer are highly recommended. The application of pre-treatment tank in the system also further helped to remove the particulate bound metal efficiently in that way increasing removal efficiency.

Meanwhile, the organics reduction from GI system ranges from 33.37 to 96.3%. Similarly, TN and TP removal ranges from 42.7 to 98.4% and 33.9 to 98.03%, respectively. From the results it can be observed that bio-retention, raingarden system highly efficient for organics and treatment. In addition, some of the study revealed that the GI systems like dry ponds, vegetation swales and buffer are moderately efficient for nutrient treatment, however, a system with retention function is usually effective to for nutrient removal due to efficient control of NO_3-N (Jiang, Yuan, & Piza, 2015). Conversely, some of the study finding suggested that field scale study of bio-retention system for TP removal ranges from 77-79% (Davis et al., 2009). Similarly, other study revealed that bio-retention systems can ensure minimum nitrogen, phosphorus and zinc removal up to 70% as well as a reduction in peak discharge rate, increase concentration time and protect channels (Gao et al.,2013).

Table 2: TSS, organics and nutrients reduction efficiency of LID facilities

LID Types	Turbidity (NTU)	TSS (mg/L)	BOD (mg/L)	CODcr (mg/L)	CODmn (mg/L)	DOC (mg/L)	O&G (mg/L)	TN (mg/L)	NO2 (mg/L)	NO3 (mg/L)	NH4 (mg/L)	TKN (mg/L)	TP (mg/L)	PO4P (mg/L)
Infiltration planter	95.81	98.01	96.30	98.31	99.98	98.60	97.71	98.37	99.41	98.78	99.60	98.98	98.03	99.76
Bioretention	59.68	50.55	90.69	88.08	98.94	94.49	92.60	89.32	87.26	92.09	97.63	93.41	95.76	98.83
Raingarden 1	53.38	81.41	96.88	96.68	95.88	96.79	98.88	93.08	100.00	95.74	93.62	93.34	84.21	89.66
Raingarden 2	99.23	99.64	99.40	99.32	99.25	98.76	99.30	99.35	97.76	98.84	99.36	98.84	99.04	99.17
Tree box filter	61.66	87.55	37.90	61.05	51.39	26.68	62.63	62.08	69.30	38.25	74.34	58.28	59.20	59.87
Small wetland 1	66.47	75.93	33.37	55.17	52.78	27.15	63.54	42.72	30.73	50.15	67.63	68.16	33.97	74.40
Small wetland 2	66.36	75.97	40.02	58.00	53.58	39.95	74.04	47.70	56.52	62.47	58.39	51.88	53.62	48.99
Ecobiofilter	74.71	75.77	58.76	74.23	77.93	67.31	33.18	62.92	77.54	46.66	65.09	76.31	66.86	12.33

Table 3: Dissolved and total heavy metal removal efficiency of LID facilities

LID Types	Cr (mg/L)	Ni (mg/L)	Cu (mg/L)	Zn (mg/L)	Cd(mg/L)	Pb (mg/L)	Total Cr (mg/L)	Total Ni (mg/L)	Total Cu (mg/L)	Total Zn (mg/L)	Total Cd(mg/L)	Total Pb(mg/L)	As (mg/L)	Total As (mg/L)
Infiltration planter	98.99	98.14	98.93	98.26	98.16	98.71	98.86	98.11	98.72	98.32	98.21	98.62	100.00	100.00
Bioretention	92.43	92.74	94.58	96.18	93.22	94.02	88.99	92.29	92.20	95.05	92.78	94.40	95.27	92.13
Raingarden 1	93.58	96.16	97.65	96.92	94.13	97.53	96.05	96.56	96.71	95.80	96.28	97.08	94.43	93.14
Raingarden 2	98.97	98.99	98.94	98.67	98.98	98.56	98.91	98.95	98.97	99.04	98.97	98.91	99.38	99.30
Tree box filter	53.99	52.60	58.44	49.38	52.27	50.45	54.23	58.57	57.80	68.32	53.32	56.64	32.51	36.67
Small wetland 1	41.55	49.04	53.35	49.71	42.31	37.76	44.76	48.01	53.07	56.12	40.92	53.12	80.53	70.09
Small wetland 2	28.63	38.12	39.80	47.21	35.56	35.17	37.58	37.02	38.39	57.37	35.55	34.34	51.35	51.48
Ecobiofilter	52.91	52.86	57.95	53.64	54.16	49.29	57.94	59.98	54.67	68.32	56.33	49.31	-	-

4. CONCLUSION

Green technologies are simple, cost effective, decentralized system which can ensure to reduce the impacts of urbanization due increment in impervious areas. Unlike, its application in developed countries these technologies could be valuable tools for the developing countries to mitigate the impacts of non- point sources and haphazard urbanization. From the results and discussion presented above, following findings are concluded.

1. Urban catchments are major sources of different types of pollutants like organics, total suspended solids, nutrients and heavy metals which can be transported to the nearby water sources thereby degrading water quality and affecting aquatic life.
2. Green technologies (GI) were statistically significant to reduce the runoff generated from urban catchments to restore the natural state of hydrological cycle in urban areas thereby increasing the infiltration,

transpiration, evaporation and interception function.

3. Lastly, Green technologies were also statistically significant to reduce and treat the pollutants transported from urban catchments which can help to improve the quality of nearby water bodies.

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