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Green Roof Technology in Runoff Mitigation Using SWMM for Developing Sponge Cities

Aruna V[1], Dr. Suja R[2], Rajalakshmi C R[3]

[1]Student, M. Tech Translational Engineering (Interdisciplinary), Government Engineering College, Barton Hill, Thiruvananthapuram, Kerala
[2]Associate Professor (Civil) & Coordinator, Translational Research and Professional Leadership Centre (TPLC), Government Engineering College, Barton Hill, Thiruvananthapuram
[3]Project Associate, Translational Research and Professional Leadership Centre (TPLC), Government Engineering College, Barton Hill, Thiruvananthapuram, Kerala, India

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Abstract - *Urban flooding occurs frequently in many regions in Kerala. The reduction in runoff is a major threat to the authorities in urban areas during the floods; as all the economic activities of the cities are concentrated on the urban areas that its functions will get drastically affected if left improperly managed. The instantaneous floods in cities are mainly caused by the land use types and the percent of imperviousness. In this study the runoff generation for a small catchment is quantified and the effectiveness of low impact development practices (green roofs) in mitigating the runoff at the source itself is analysed and studied using Storm Water Management Model (SWMM). The steady flow model and Hortons's infiltration parameters for the soil type in study area were adopted for the analysis. The results from simulation show that the green roofs are an excellent solution for runoff reduction whatever small its percentage is and the simulation results showed the highest generated runoff depth of 291.31 mm in the base case (without LID) which can be reduced by about 11.41% in case of 100% replacement of existing roof to green roofs and 3.83% in case of 25% replacement of existing roof to green roof. The study reveals the role of low impact development practices in mitigating the runoff by mimicking the pre hydrologic conditions of the landscape and contributes in compensating the pervious surfaces that were altered for the urban development.*

***Key Words*: Storm water management, LID, Green Roofs, Runoff reduction, SWMM**

1.INTRODUCTION

Urban flooding has become a recurrent feature in Indian metros. One of the key reasons why cities are collapsing due to natural calamities is because we have gone against the natural systems. While natural systems retain water, concrete structures tend to waste it. Urbanization results in increase of the impervious surfaces on the landscape, which prevents the infiltration of the precipitation received. This runoff should be properly managed which otherwise leads to eventual flooding. So, during the planning phase itself the developers should concentrate on the imperviousness of landscape and proper runoff control. The urban areas are the centers of all the economic activities and the vital infrastructure has to be protected 24x7 for the proper functioning of the city. We are already in pace with the urbanization that we cannot stop it. Also, we are experiencing climate extremities like draught and flood now a day. Urban development hinders the natural hydrologic cycle thereby we experience the climate extremities. The EPA SWMM software helps in modelling runoff and thus helps in quantifying the runoff so as to devise means to properly manage the storm water.

The sponge city is based on low-impact development and construction model, and is supported by the flood control system, giving full play to the natural accumulation, penetration, purification and relaxation of green space, soil, rivers, and lakes. Sponge city construction should adopt corresponding engineering and non-engineering measures according to the land use of different scales of rainwater (Shuhan et al.,2018). Mariana et al.,2018, states that the low impact development (LID) practices reduced the flood risk in a coastal region of South Brazil that witnessed high rainfall intensities. For this case study the best results were obtained when the combination of LID units namely detention ponds, infiltration trenches, and rain gardens were used. Low impact development (LID) is a landscape planning and implementing strategy for managing storm water at the source with decentralized micro-scale control measures. Since the emergence of LIDs, they are being successfully used to manage storm water runoff, water quality improvement, and for the protection of the environment (Laurent et al.,2012).

Storm water needs to be properly managed as it effects the hydrology of the landscape, the water quality and also the conventional storm water management system. The conventional storm water management system is efficient in removing the water quickly and prevents flooding but it creates a burden to the downstream water bodies as it increases the magnitude and frequency of floods. Also, it changes the physical properties of streams such as its alignment, cross section, bed composition reduces ground water recharge and the availability of drinking water will be very less. The storm water runoff can be effectively managed by reducing the quantity of storm water generated in the first place by maintaining and working with the hydrology of a site and controlling the storm water at the source itself (Minnesota storm water manual, 2006).

LID (Low Impact Development) practice like bio retention cells is effective in retaining large volumes of runoff and contaminants on site, and reduced concentrations of certain pollutants like metals. Porous pavements are effective in allowing storm water runoff through it. Green roofs retain a large percentage of rainfall (63% on average) in a variety of climates. The LID approach results in increased retention of storm water and contaminants on site, and helps recreating the predevelopment hydrologic function of the landscape. (Dietz, 2007).

SWMM, the storm water management model introduced by the EPA, was used for the dynamic rainfall-runoff simulation model for either single events or long-term (continuous) simulation of runoff quantity and quality, mainly from urban areas (Rossman, 2010). Chunlin Li et al.,2016 states that SWMM comprises four components, such as runoff, storage/treatment and transport. In order to achieve the analysis of urban flood disaster, different hydro information of the urban catchment is required in the establishment of SWMM, which are collected, processed and estimated as the model parameters (Nester et al., 2014). Rainfall–runoff (RR) models are used for various hydrological applications like the estimation of catchment runoff to analyzing the effect of change in land use on runoff. The methods of synthesizing the rainfall–runoff process is different for each model; a model classification also exist.

2. METHODOLOGY

The methodology aims at analyzing the runoff generated in the study area by inputting the modelling parameters into the software EPA SWMM Version 5.1.014 and to study the behavior of the study area for various soil types.

2.1 Study Area Description

The college campus of GEC Barton Hill, Trivandrum situated at 8.505157°N and 76.940817°E was taken as the study area because of its terrain and land use characteristics. The college campus is having a highly steep and sloppy terrain so that runoff modelling is needed for the wise use of rain water. The study area includes many buildings, roads, and both light and dense vegetation as shown in figure 1.

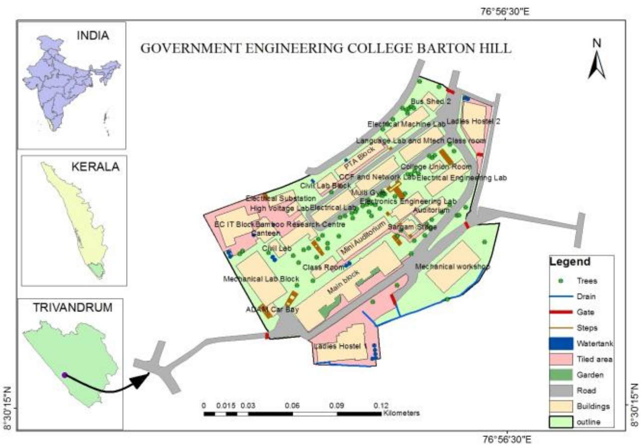

Fig 1: College Campus

2.2 SWMM Modelling

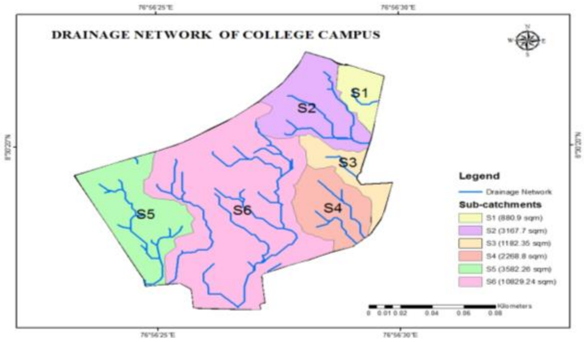

Fig 2. Drainage map of GEC Barton Hill College Campus

The modelling parameters were determined by collecting the data regarding the different land use land cover types in college campus. Topographical data of the GECBH campus was obtained from Total station survey. Also, the hourly rainfall data from the 2005 to 2018 were collected from Indian Meteorological Department. From the elevation data, Digital Elevation Model was prepared in ArcGIS software. Then by using hydrology tool, the sub-catchments and drainage pattern within the study area is delineated and it is shown in figure 2.

There are both physical and hydrological parameters for a sub catchment. Arc GIS was the main tool used for parameter estimation. The physical parameters considered are, area, width and slope of the sub-catchment. The area of each polygon which corresponds to area of the sub catchment is calculated using the geometry tool. Average slope was calculated using zonal statistics tool. The buildings, roads and tiled areas that falls in each catchment were considered as built-up area to calculate the imperviousness. The flow length of each catchment is calculated using stream order tool. The area of the catchment is divided by this flow length to get the width of the catchment.

Impervious and Pervious Manning**'s** coefficient and Impervious and Pervious Depression Storage (D impervious & D pervious) coefficient values were derived from the experimental value of the pervious land cover type and impervious land cover type in the sub catchment. Hortons Infiltration Parameters of the different soil types were taken from Hossain et al., 2019. The elevation of outlets is available from DEM.

2.3 Preparation of design storms

The hourly rainfall data for the year 2005 to 2018 were available from IMD. From the 14 years of rainfall data, the intensities for different durations have been worked out. From the maximum intensities and the durations, the Intensity Duration Frequency Curves or IDF curves are generated using Gumbel's Type I distribution and shown in chart 1

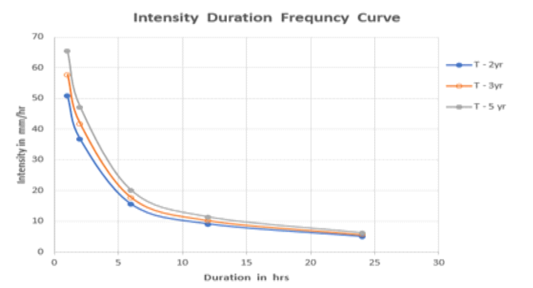

Chart 1 - Intensity Duration Frequency Curve

By Gumbel's Type I distribution,

$X_T = X_{mean} + K_T S$

Where, XT is the value of the random variable associated with a given return period, Xmean is the mean of the observations and S is the standard deviation of the observations.

The frequency factor associated with return period T, KT, is given by

$$KT = -\sqrt{6}/\pi\ [0.5772 + \ln(\ln(T/T-1))]$$

Design storms in mm/hr for the Return Period 2-year was derived from IDF curves.

2.4 SWMM Modelling

SWMM uses a Rainfall/Runoff process model and the routing model adopted is steady flow. The infiltration method used is Horton's method as it was treated as the best method for infiltration as per literature. Assuming the evaporation loss to be zero and assuming that the study area is having a uniform composition of soil the modelling was done. The study area was divided into 6 sub catchments and all the flow from each sub catchment is being routed to one outfall.

The inputs include the estimated physiographic, hydrologic parameters of the sub catchment and the rainfall intensities of the 2yr design storm. The program was run to model the runoff generated in each sub catchment due to the 2yr design storm. An LID module was implemented with the green roofs as the LID and the runoff generated in each sub catchments is thoroughly analyzed to study the effectiveness of the LID in reducing the runoff generated by comparing the characteristics of the sub catchments with and without LID to the design storms.

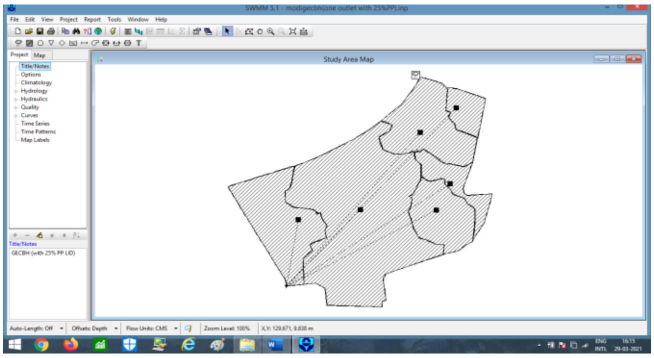

Fig 3: Study Area Map developed in SWMM

In this study green roof were selected as the LID as all the sub catchments have a fixed percentage of roof area that can be transformed to green roofs. The SWMM routing with green roof as LID was done by replacing the existing roof area by 100%, 75%, 50% and 25% and the selection of best case is done for the study area. The 2yr design storm and the soil type loamy soil (pertaining to study area) is considered for the simulations of the LIDs to represent an average site. The input parameters for LIDs were both assumed and adopted from the various literature (Yiran et.al). The input parameters of LID were adopted as in Table 2. The cross section of green roofs is shown in figure 4 below.

Table 2

Input parameters for LIDs

Input parameters for LID (green roofs)			
Layer	Parameters	Unit	Green Roofs
Surface	Berm Height	mm	50
	Vegetation Volume Fraction		0.2
	Surface's roughness		0.13
	Surface slope	%	1
Soil	Thickness	mm	200

	Porosity		0.5
	Field Capacity	mm/hr	0.3
	Wilting Point		0.1
	Conductivity	mm/hr	700
Drainage Mat	Thickness	mm	100
	Void Ratio		0.43
	Seepage Rate		0.03

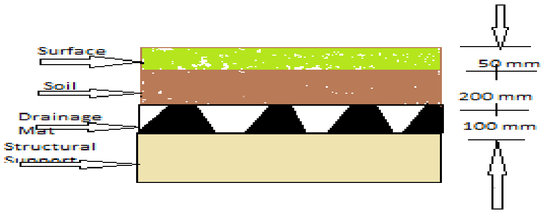

Fig 4: Cross section of green roofs

3. Results & Discussion

This study deals with the behavior of sub catchments in generating runoff for the design storm of 2yr. So, this case study deals with 5 scenarios such as the performance of 6 sub catchments for a 2yr design storm. Finally, the performance of the study area in generating runoff with and without LID is compared for evaluating the effectiveness of the LID in runoff reduction. The sub catchment S1 with highest percent of imperviousness generated the highest runoff depth of about 291.31 mm in the base case which can be reduced by about 11.41% in case of 100% replacement of existing roof area to green roof and 25% replacement of existing roof area to green roof resulted in 3.83% runoff reduction. Similarly for all other sub catchments the higher the percent of imperviousness higher the runoff depth and the reduction potential is higher in case of 100% replacement of existing roof to green roof which accounts to about 2-11% in case of all sub catchments and lowest in case of 25% replacement of existing roof area to green roof the runoff reduction potential is about 0.8-3.83%.

It can be seen that in all the sub catchments the placement of LID reduced the total runoff depth than the without LID case. Out of the four LID cases the 100% replacement showed higher reduction in runoff and the reduction is less for 25% replacement. In all the four LID scenarios the percentage of runoff reduction is higher for the sub catchment S1 of about 11.41% which is a 100% replacement and 9.536%, 7.023% and 3.838% for 75%, 50% and 25% respectively for replacement of roof area. Also, the sub catchment S3 performed the least in reducing the runoff as the roof area existing is very less compared to other sub catchments and it is 2.97% in case of 100% replacement and 0.896% in case of 25% replacement.

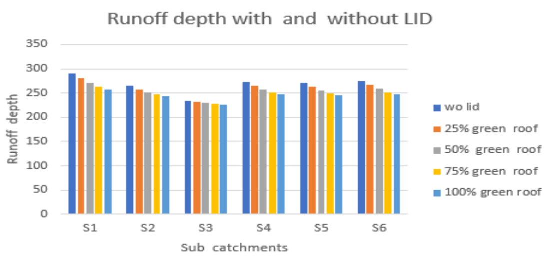

Fig 5: Total runoff depth (with & without LID)

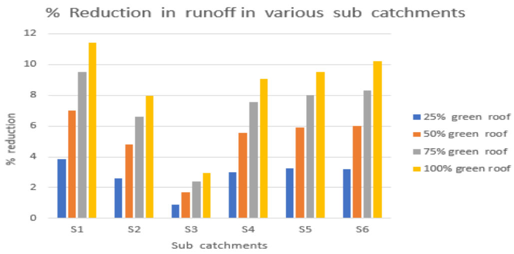

Fig 5: % runoff reduction in various sub catchments

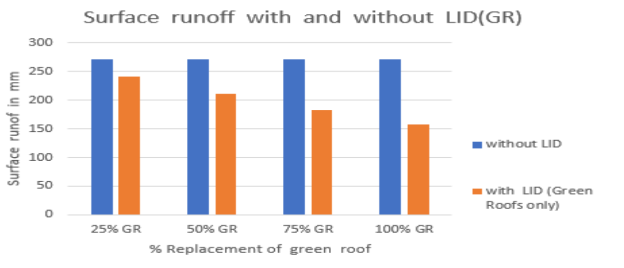

Fig 7: Surface Runoff generated in 4 scenarios with and without LID

4. CONCLUSION

From the results, it can be stated that higher the percentage replacement of roof area higher the runoff reduction. It can also be inferred that implementing the 100% replacement of roof area will result in 11.41% runoff reduction in sub catchment S1 and 3.83% reduction in case of 25% replacement. The sub catchment S3 is having the least runoff reduction of 0.896% in case of 25% replacement of roof area and 2.97% in case of 100% replacement. The reduction potential ranges from 2-11%, 2-9%, 1-7%, 0.83 -3.83% in case of 100%, 75%, 50% and 25% replacement. The LID input parameters can be subjected to field study and can be calibrated for more reliable results. The unavailability of gauged data also might have resulted in inaccurate results. Besides these limitations SWMM software is a reliable tool in quantifying the runoff and thus to analyse the pre urbanised condition of a landscape that retains the pre development hydrologic cycle.

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BIOGRAPHIES

Mrs.Aruna V
Student, M. Tech Translational Engineering (Interdisciplinary), Government Engineering College, Barton Hill, Thiruvananthapuram, Kerala

Dr.Suja R
Associate Professor (Civil) & Coordinator, Translational Research and Professional Leadership Centre (TPLC), Government Engineering College, Barton Hill, Thiruvananthapuram, Kerala

Mrs.Rajalakshmi C R
Project Associate, Translational Research and Professional Leadership Centre (TPLC), Government Engineering College, Barton Hill, Thiruvananthapuram, Kerala, India.