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Selection of best stormwater management alternative based on storm control measures (SCM) efficiency indices

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Abstract

Overcoming conventional stormwater management problems and finding appropriate control methods for safely discharging excess runoff from impervious areas is an essential part of any sustainable urban planning. This study aims to analyze the performance of different storm control measures (SCMs) applied to Vellore Institute of Technology (VIT) campus situated in Vellore, Tamil Nadu, which is a highly urbanized catchment. Different SCMs were designed for the VIT campus based on low impact development (LID) options available in stormwater management model (SWMM) software. The most suitable SCM was selected based on its ability to match pre-urbanized hydrographs as close as possible. The SCM location was identified by a localized survey, in such a way that there is least disturbance to the existing storm sewer network. The percentage reduction of peak flow under each proposed SCM were obtained as follows: bio-retention (19.8%), rain garden (18.69%), green roof (49.17%), infiltration trench (20.02%), permeable pavement (22.6%), rain barrel (12.95%), rooftop-disconnection (10.79%) and vegetative swales (17.23%). The results indicated that Option 9 (combination of permeable pavement and bioretention) and Option 10 (permeable pavement and infiltration trench) were better at reducing peak runoff and increasing infiltration. The peak runoff reduction for Options 9 and 10 were observed to be 32.05 and 39.81%, whereas the percentage increase in infiltration was observed to be 25.7 and 29.45% respectively.

Keywords: Storm control measures (SCMs); Stormwater management model (SWMM); Urban stormwater management

Introduction

Stormwater management plays an important role in minimizing the impacts of water logging issues for an urbanized catchment. Much work has been carried out, mostly in developed countries like New Zealand, Australia and USA, in designing a sustainable and efficient urban stormwater control system which meets the desired outcomes of any typical urban stormwater management goals, namely: achieving drainage efficiency, reduction of pollutant load, restoration of pre-urbanized catchment

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characteristics, and minimal impact on receiving streams. Such methods are commonly referred to as LID (low impact development), SUDS (sustainable urban drainage system), WSUD (water sensitive urban design) and LIUDD (low impact urban design and development). These methods have been found to be very effective in managing urban runoff rate and volume, and reducing runoff pollution (Gagrani *et al.*, 2014; Hamel & Fletcher, 2014; Fletcher *et al.*, 2015; Guan *et al.*, 2015; Jato-Espino *et al.*, 2016; Sakshi & Singh, 2016; Mao *et al.*, 2017; Bai *et al.*, 2018; Hoghooghi *et al.*, 2018; Kim & Joo, 2018; Yang & Chui, 2018; Zhang & Chui, 2018; Che & Zhang, 2019; Li *et al.*, 2019). However, as noted by Bhaskar *et al.* (2016), there is still a great deal of scope in urban stormwater management. The application of various types of SCMs presently involves the major objective as reduction in peak runoff volume and maintaining the quality of runoff entering the receiving stream. The water ponded in the SCMs during a rainfall event, after primary treatment, can be either reused to partially meet the increasing water demand in an urbanized catchment or can be allowed to evaporate into the atmosphere or seep through designed aquifers around SCMs and endure primary treatment through a natural aquifer system. The water enters the dynamic groundwater storage and increases the groundwater levels which can be further utilized for meeting commercial/domestic water demand.

Many of the existing SCMs are highly effective in reducing the peak runoff but require greater space for their installation. For highly urbanized catchments, the decentralized stormwater management measures with an optimal design of various point source LIDs are highly recommended. Gogate *et al.* (2017) and Li *et al.* (2019) listed various types of SCMs, their qualities and shortcomings on the basis of performance for a peak storm event and space requirement for the installation, which would be suitable for stormwater management in India. On the basis of the runoff reduction and infiltration volume upsurge, efficiency of each SCM, the capital investment involved, and area requirement for a particular SCM, a suitable stormwater control measure for an urbanized catchment is implemented.

Several SCMs were developed to reduce and reuse the peak runoff generated through the urban catchment (Gogate *et al.*, 2017; Bai *et al.*, 2018; Zhang & Chui, 2018). SCMs are usually multifunctional structures (e.g. infiltration trench, bio-retention and green roofs) that can provide a suitable habitat for species and bring balance to the biodiversity, allow climate regulation by evaporation and adsorption of solar radiation, together with aesthetic/amenity, recreational and educational benefits, and enhancing the urban quality of life and social interaction. The availability of several SCM types offers an opportunity to initiate the selection process at the earliest and streamlines the explicit performance indicators consistent with the usage and nature of catchment. The clear identification and estimation of performance indicators as efficiencies is carried out in Sorup *et al.* (2016) with three scenarios of low, medium and extreme flood events. The indicators are thus formulated for a decentralized approach and then compared with their theoretical values which stipulate the effective usage of SCM for an urbanized catchment. Gogate *et al.* (2017) discuss the advantages and limitations of various SCM techniques for a parcel of urban catchment in India. The decentralized runoff reduction approach for these management techniques by Burns *et al.* (2012) have noted scope for further research in the decentralized runoff reduction approach for the SCM measures with the aim to match the pre-urbanized natural routine of catchment hydrology for varied return periods, without further disturbing the existing urban areas. The major goal of any SCM is to remove the stagnated water from the built-up areas during a peak flood event with minimal damage to the infrastructure.

Major factors influencing the design of any SCM depends on its spatial and temporal variation with respect to the catchment flow characteristics. As per McGrane (2016), Sorup *et al.* (2016) and Li *et al.* (2019), the typical objectives considered in the design of any SCM are: (1) maximizing the surface runoff volume harvested; (2) minimizing the total cost; (3) maximizing the treatment efficiency of SCM (either attained by means of treating the stormwater in a distributed manner or using a combined sewer network); (4) maximizing the social and behavioral benefits of the user (behavioral benefits include psychological improvements and social benefits including public comfort and relaxation activities); and (5) ecosystem improvement (obtained by attenuating the peak flow to bring back pre-urbanized hydrological characteristics for an urbanized catchment). Preliminary analysis for any stormwater control structure is to categorize the location in such a way that the setting up of any control structure does not disturb the densely built-up zone. The temporal and spatial location of SCM in an urbanized catchment varies on the basis of land-use characteristics, connectivity within catchments, runoff generated and level of treatment. The selection of explicit location for the installation of SCM further requires systematic study to handle the peak runoff generated through the urbanized catchment. To achieve the effective runoff reduction efficiency, McGrane (2016) suggested that the optimal location of SCM in an impervious area should stand along the natural flow regime of the channels and be installed at the lowermost position.

In order to identify the type of SCM for a particular area, the stormwater management goals work on the subsequent profile requirements. First, the vital need for any SCM (storage and infiltration) in an urbanized catchment is adequate surface area with the purpose of effectually permeating the surface runoff generated through the catchment. Hamel & Fletcher (2014) conducted studies on the effectiveness of decentralized stormwater control measures in different urbanized regions of Australia and commented that a combination of feasibility-sized tanks and raingardens is likely to restore the baseflow regime to a greater extent. A similar approach can be adopted with modification in the effectiveness of various SCM measures to reduce the peak flow. The varied rainfall analysis of existing sewer networks and suggestive measures to improve or replace with alternate SCMs like grass swales, unlined canals, infiltration trenches, retention ponds (Sin *et al.*, 2014; Luan *et al.*, 2017; Song *et al.*, 2018; Yang & Chui, 2018; Li *et al.*, 2019) etc., will be analyzed with their relevance to recharge the groundwater or reuse in the adjoining urban catchment. In other words, the focus of the study will be to develop a stormwater management strategy which will maintain an ecological balance and mimic the hydrology of pre-urbanized catchment (Burns *et al.*, 2012). A few of the shortcomings mentioned above in the literature are addressed in this study and the objectives are to: (a) improve the runoff hydrograph to mimic the pre-urbanized scenario for varied rainfall events; (b) identify the best SCM (Storage or directing type) solution amongst the seven available SCMs in SWMM software; (c) propose the SCM combination using SWMM to maximize the infiltration capacity emulating pre-urbanized runoff hydrograph.

In the present study, the SCM types were categorized into three groups, namely: storage type SCM, by-pass type SCM and a combination of storage and by-pass type SCM. A storage type SCM stores the water for a duration (typically about 48 hours) and then the excess volume of water is allowed to flow freely to the next system component (Chow, 1965; Pazwash, 2016). Some of the examples for storage type SCM are: infiltration trenches, bio-retention tanks, and rain gardens. The by-pass type SCM refers to the systems where water is simply diverted from impervious areas to other SCMs. For example: roof top disconnection and permeable pavements. A combination SCM refers to the one where both storage and by-pass of water is accomplished. Examples include: green roofs, rain barrels, and vegetative swales.

Study area

Vellore Institute of Technology (VIT) is an educational institute situated in the town of Vellore, Tamil Nadu, established in 1984. Being an educational institution, it shows many features of typical urban land use. The area of the campus is about 372 ha and about 52% of the total area (which is equivalent to 193.4 ha) is covered by buildings and roads. There is a lake in the campus which has a surface area of about 4 ha, and it is primarily utilized for discharging treated wastewater and stormwater runoff. The campus has a well laid out open rectangular storm sewer network, the runoff from which is finally discharged into the lake. Most of the existing storm sewer network was constructed in 1995, and only a few additions have been carried out in subsequent years. However, much development in the way of construction of new roads and buildings has taken place in the preceding years, such that the stormwater runoff has frequently exceeded the carrying capacity of the storm sewer. Apart from this, the campus has also experienced severe water scarcity in the past few years, especially during the summer season. To overcome the problem of water scarcity, the VIT management has come up with some temporary solutions, such as rain water harvesting (RWH), rooftop disconnection (only for one building), using treated wastewater for gardening, etc. However, as VIT is planning to increase the intake of undergraduate students, it is possible that the water scarcity issue may become even more severe and the existing water harvesting systems may not be sufficient to meet the increased demand. Hence the objective of this study is to identify a suitable SCM which will satisfy the twin objectives of partially meeting the pre-urbanized runoff hydrograph characteristics of the catchment and increase the runoff capture efficiency. The pre-urbanized scenario for the campus was selected as land use characteristics corresponding to the year 1995 (shown in Figure 1(b)), whereas the post-urbanized scenario was considered for land use corresponding to the year 2017 (shown in Figure 1(a)). In the pre-urbanized scenario, percentage imperviousness was about 23%, whereas in 2017 (post-urbanization scenario), the imperviousness increased to 52%. The predominant soil type in the campus is sandy loam (which falls under hydrologic soil group C), with a hydraulic conductivity of 1.1 cm/h and porosity of 43%. The methodology for selecting the most suitable SCM for the study area is discussed in the next section.

Methodology

The suitable SCM for the case study area was determined using SWMM 5.1 software. The development of SWMM as a modelling tool began with its application on the design of engineered waste water pipes. The hydrodynamic rainfall-runoff and urban drainage simulation model SWMM (Storm Water Management Model) is a state-of-the-art software tool applied in research and practice (Jang *et al.*, 2007; Niaizi *et al.*, 2017). SWMM is a freely available software from USEPA which is used for various hydrological applications in urban hydrology and water-quality models such as design analysis and planning of sanitary and storm sewer networks, urban flood analysis and green infrastructure studies in urban catchments. Hydrological modelling in complex urbanized areas for runoff transport requires high computation speed for interconnected hydraulic and hydrologic features. Kinematic wave routing procedure in SWMM closely captures the peak urban runoff which can be used to compare the performance of different types of SCMs, flow regulators, and bypass devices (Liang & Melching, 2015; Ferrer *et al.*, 2018). The SWMM user interface characterizes the connection between sub-catchments, hydraulic nodes and conduits, SCMs, and other conveyance systems in a simplistic view which helps to make parameterization and calibration feasible and reduce the risk of mismanagement of runoff flow. This advantage of SWMM models facilitated policy makers, designers, and planning agencies to resolve various urban watershed problems. The homogeneous classification of the catchment makes it easier for the

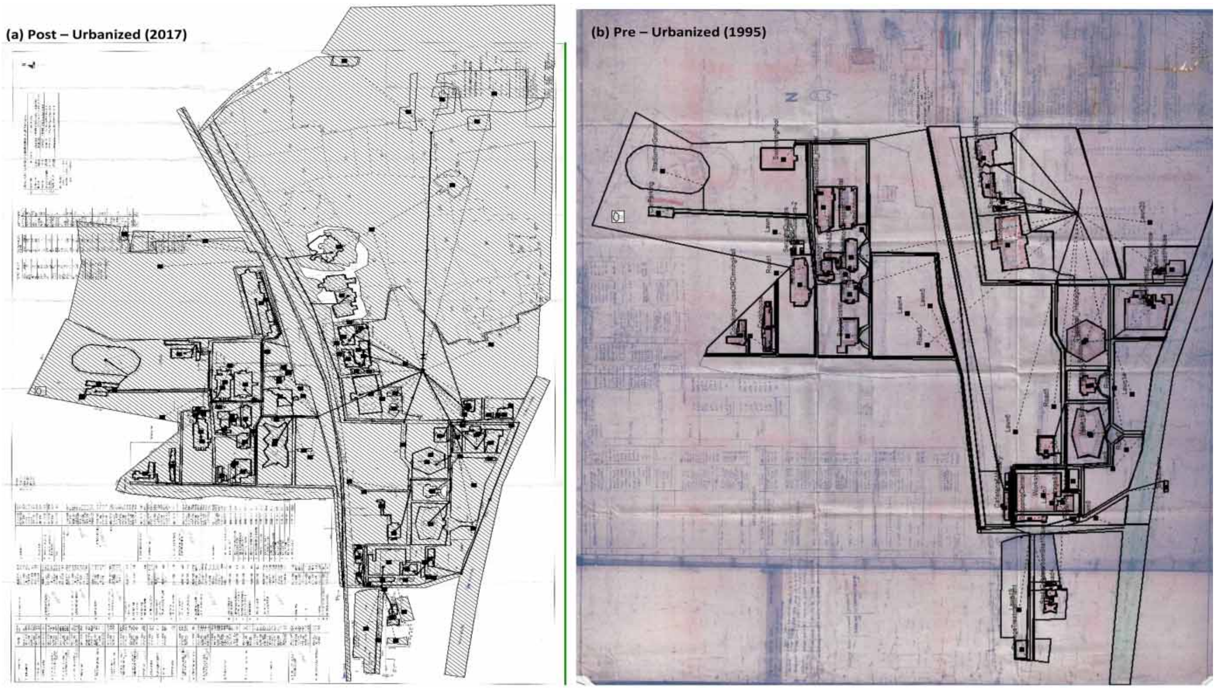

Fig. 1. Thematic maps of study area: VIT campus with adjoining regions (a) post-urbanized (year 2017) with 52% urbanization; (b) pre-urbanized (year 1995) with 23% urbanization.

decision makers to identify the critical points for overflow and install a specific SCM in order to mitigate the surface runoff. However, this strength can also be considered a limitation depending on the modeling goal. Options for users to represent urban drainage features with a higher degree of process-level detail are called for but for model refinement to be justified it needs to be supported by field data and adequate scientific understanding. The SWMM interface provides an option to analyze different types of SCMs in an urbanized area To determine a suitable SCM using SWMM, the input parameters required are: various topographical characteristics of the catchment such as curve number, Manning's roughness coefficient, percentage imperviousness, SCM types and sizes (Table 1), and climatic data (daily rainfall and temperature). The hydrologic performance of the study area was checked for different options of SCMs. The options were as follows:

Option 1: Bio-retention tanks
Option 2: Rain garden
Option 3: Green roof
Option 4: Infiltration trench
Option 5: Permeable pavement
Option 6: Rain barrel
Option 7: Rooftop disconnection
Option 8: Vegetative swales
Option 9: Combination of bio-retention tanks and permeable pavements
Option 10: Combination of infiltration trench and permeable pavements

Table 1. SCMs input parameters for SWMM model.

SCM parameters		Units % area	Option 1 6.54	Option 2 5.32	Option 3 39.44	Option 4 7.78	Option 5 20.72	Option 6 4.57	Option 7 7.23	Option 8 32.395	Option 9 31.74	Option 10 30.29
Surface	Berm height	mm	400	150	30	150	20	800	500	200	920	670
	Vegetation Volume fraction	–	0.1	0.1	0.1	–	–	–	–	0.9	0.1	–
	Surface Roughness	–	0.12	0.12	0.13	0.24	0.014	–	0.014	0.12	0.148	0.268
	Surface slope	%	0.1	0.3	1	0.1	1	–	1	0.8	2.1	2.1
Soil	Thickness	mm	500	500	100	–	150	–	–	–	650	150
	Porosity	–	0.5	0.3	0.5	–	0.5	–	–	–	1	0.5
	Field capacity	–	0.35	0.2	0.2	–	0.1	–	–	–	0.45	0.1
	Wilting point	–	0.187	0.1	0.024	–	0.024	–	–	–	0.211	0.024
	Conductivity	mm/h	10	500	30	–	100	–	–	–	110	100
	Suction head	mm	210	3.5	60	–	3.5	–	–	–	213.5	3.5
Storage	Thickness	mm	150	0	–	600	150	–	–	–	300	750
	Void ratio	–	0.5	0.75	–	0.75	0.4	–	–	–	0.9	1.15
	Seepage rate	mm/h	12	200	–	24	1.2	–	–	–	13.2	25.2
	Clogging factor	–	–	0	–	0	–	–	–	–	–	–
Drain	Flow coefficient	–	–	–	–	0.69	–	0.68	–	–	–	0.69
	Flow exponent	–	0.5	–	–	0.5	0.5	0.5	–	–	1	1
	Offset height	mm	6	–	–	6	6	125	–	–	12	12
Pavement	Thickness	mm	–	–	–	–	100	–	–	–	100	100
	Void ratio	–	–	–	–	–	0.25	–	–	–	0.25	0.25
	Impervious Surface fraction	–	–	–	–	–	–	–	–	–	–	–
	Permeability	mm/h	–	–	–	–	250	–	–	–	250	250

The optimal design dimensions of each SCM were determined in SWMM for a design rainfall of a five-year return period as determined by the IDF (intensity duration frequency curves) Equation (1):

$$i = \frac{6.1T^{0.2}}{(t+0.5)^{0.8}} \tag{1}$$

where i is the rainfall intensity in cm/hr; T is the return period in years; and t is the rainfall duration in hours. Once the optimal dimensions were obtained, the performance of each option was determined using the efficiency measures as defined by Sorup *et al*. (2016). The efficiency measures are as follows:

1. Volumetric efficiency (E_{fp}): the ratio of annual volume of water contained by the SCMs (V_{managed}) to the total annual inflow to the SCMs from impervious areas ($V_{\mathrm{Annual\ inflow}}$). Mathematically, this is expressed as:

$$E_{f_p} = \frac{V_{managed}}{V_{Annual\ inflow}} \tag{2}$$

2. Runoff efficiency: the recurrence interval for the peak storm event for any SCM plays an important role in identifying the type of SCM adopted in an urbanized or non-urbanized catchment. The runoff efficiency indirectly relates to the performance of SCMs in reducing the peak runoff from the catchment. Mathematically, it is expressed as:

$$E_{rr} = \frac{V_{Runoff\ reduced}}{V_{Annual\ inflow}} \tag{3}$$

   where $V_{\mathrm{runoff\ reduced}}$ is the excess runoff volume from a SCM.
3. Storage efficiency: the prime objective of SCM in an urbanized area is to manage the peak runoff by accommodating managed water in the form of infiltration or storage tanks. Storage efficiency helps to identify the amount of water that is stored by a particular SCM ($V_{\mathrm{water\ storage}}$) with respect to the total annual inflow to the SCM. Mathematically, this can be expressed as:

$$E_{storage} = \frac{V_{water\ storage}}{V_{Annual\ inflow}} \tag{4}$$

The options which give a higher value for all the efficiencies can be considered as the most suitable SCM for the study area. The steps involved in the design and analysis of different SCM options is shown in a detailed flow chart in Figure 2.

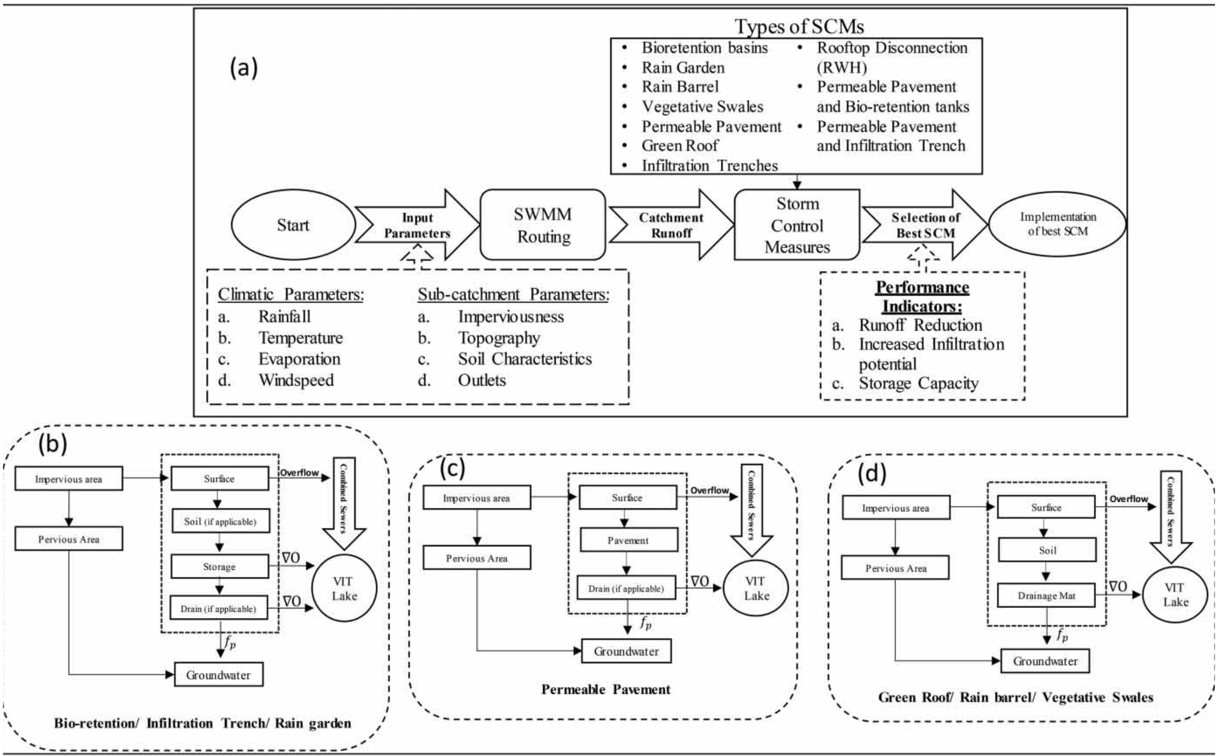

Fig. 2. (a) Detailed methodology flowchart; (b) storage type SCMs; (c) bypass type SCMs and (d) combination of by-pass and storage type SCMs.

Results and discussion

The various SCM options for the VIT campus were designed for a five-year return period storm, using SWMM software. The performance efficiency of each SCM option was tested based on the efficiency measures described in the methodology section. A daily annual rainfall data of the latest available year (2017) was used to check the performance of each option in replicating pre-urbanized flows. The procedure of iterating for all the measures in the catchment allows the user to effectively implement the specific control measure. Bhaskar *et al*. (2016) reflects on the study of hydro-ecological model variation in the catchment with time and the impact of SCM construction on the hydrology of the system. The design dimensions for each SCM option are shown in Table 1. After fixing the design dimensions for each option, the runoff hydrograph and infiltration graph for annual daily rainfall data were derived, which are shown in Figures 3 and 4, respectively. The runoff hydrograph for each SCM option was plotted against a pre-urbanized (land use corresponding to 1995) runoff hydrograph. Figure 3(a) shows the runoff hydrograph for storage type SCMs, Figure 3(b) bypass type SCMs and Figure 3(c) is for the combination of by-pass and storage type SCMs. From Figure 3(a)–3(c) it can be inferred that the runoff hydrographs resulting for Options 2, 10 and 3 are closer to the pre-urbanized hydrograph, which implies that the aforementioned SCM options are relatively better at replicating pre-urbanized runoff for the catchment. The monthly infiltration depth from the SCMs in comparison to monthly

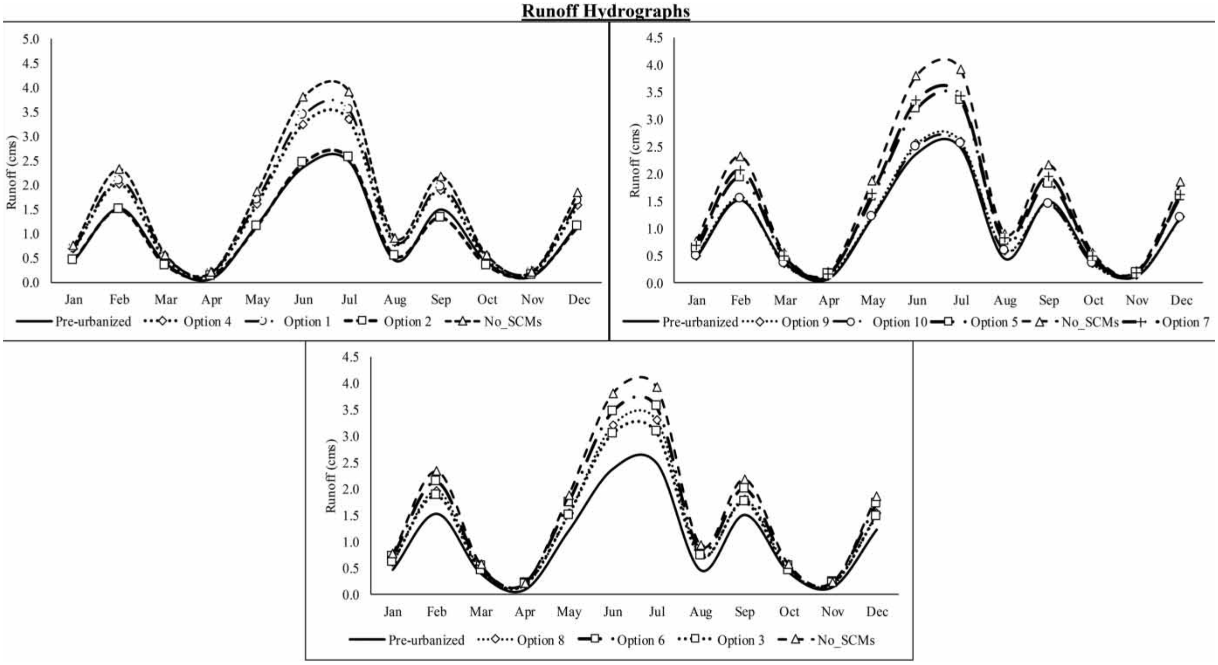

Fig. 3. Monthly runoff generated from VIT catchment after implementation of various SCMs.

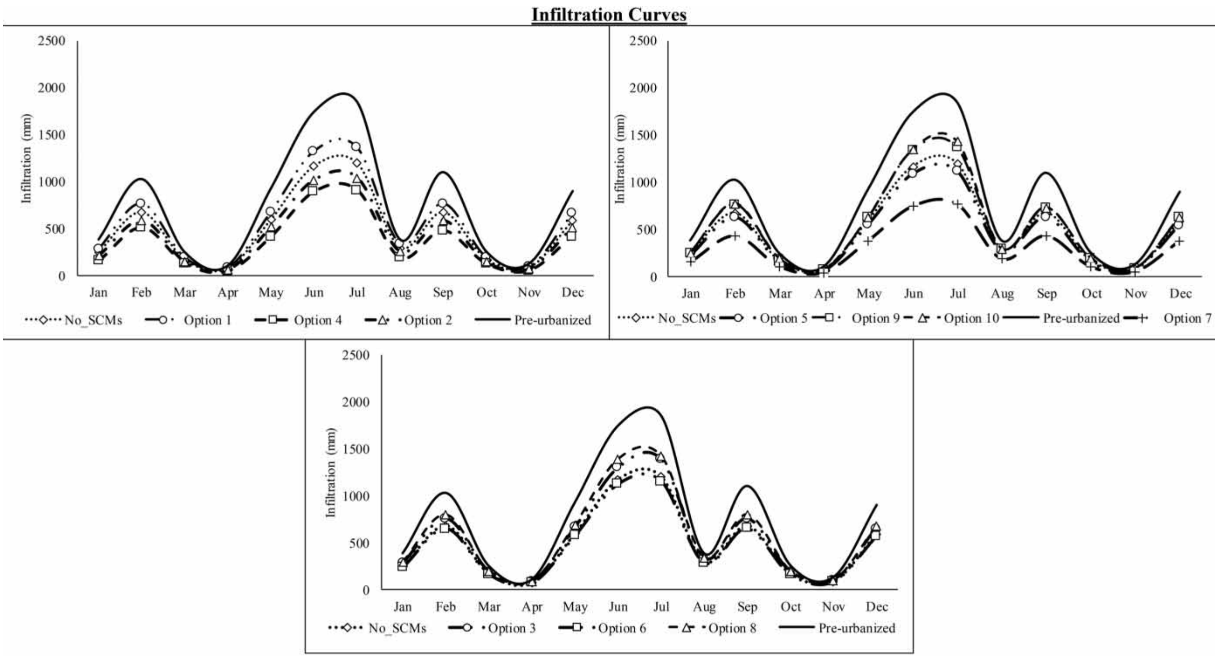

Fig. 4. Infiltration depth (in mm) obtained after implementation of SCM options on VIT catchment.

infiltration depth during pre-urbanized scenario are shown in Figure 4(a)–4(c). From these figures it can be surmised that Options 4, 10 and 8 are better at restoring pre-urbanized infiltration depths for the catchment. Also, the hydrologic efficiencies for all the considered SCM options are shown in Table 2.

SCMs were evaluated to estimate the amount of water stored during the rainfall event in assorted layers which can be used or supplied through drains. The water stored in SCMs can be pumped to the adjoining structure for reuse or is supplied to the sewage treatment plant in VIT precincts for daily use. The reduction in surface runoff with respect to the percentage imperviousness for this study is comparable to other studies in the urban watersheds (Fry & Maxwell 2017; Hoghooghi *et al.*, 2018). For a catchment consisting mostly of a built-up area like VIT, it is advisable to carry out a detailed manual survey for all topographical parameters such as the rooftop shape, type of storm sewer, soil type, depression storages etc. to simplify the calibration process (Niaizi *et al.*, 2017). The findings by Martin *et al.* (2017) illustrate the advantages and influence of SCMs in an urbanized catchment.

From the results shown in Table 2 it can be surmised that among the selected SCMs, green roofs (Option 3) are being implemented on one of the buildings, The Technological Tower, with the vegetation growth adopted across the open spaces in window terraces. If implemented on other buildings, green roofs can be most effective to reduce the runoff by approximately 50% of the total annual runoff from the catchment. However, one of the primary limitations of green roofs if implemented on any rooftop is the increase in weight and the large initial cost incurred for its installation (Guan *et al.*, 2015; Li *et al.*, 2015; Yang & Chui, 2018). Moreover, it restricts the further development and, for an educational institute, it is not advisable to restrict the expansion either vertically or horizontally.

Option 7 (rooftop disconnection) can be considered as the least preferable SCM as its performance in all the three-efficiency measures (in Table 2) is the lowest when compared to the other SCMs. It is only slightly better in percentage area occupied. When it comes to Option 1 (bio-retention tank) and Option 2 (rain gardens), percentage area occupancy is relatively less and storage efficiency is high when compared to other SCM options. Comparing Options 1 and 2, we can say that Option 2 is better in three performance metrics (% area occupied, E_{fp}, and E_{storage}) and hence can be considered as more preferable among the two SCMs. Option 4 (infiltration tank) performs well in runoff reduction and increasing infiltration potential, however the percentage water in storage is considerably less (0.18%). The percentage area occupied is, however, not very large (7.78%).

Option 5 (permeable pavements) shows good measure in runoff reduction and improving infiltration potential, although the percentage occupied is quite high (about 20.72%). Although permeable pavements can be considered as a good option for SCM, due consideration should be given to the cost involved in retrofitting the existing parking lots or walkways into permeable pavements. Also, the availability of relevant technology and locally available skilled labor for its operation and maintenance should be ensured.

Option 6 (rain barrels) can be considered as the most preferable option when the area available for constructing or expanding a new SCM is very limited. The overall percentage area under rain barrels for the present study area is approximately 4.57% (Table 2). However, it has considerably less storage efficiency (0.08%, which is only slightly better when compared to Option 7, for which it is 0.06%). Option 6 also has very low performance efficiency in controlling runoff volume (12.95%) and increasing infiltration potential (10.32%).

Option 8 (vegetative swales) performs best in improving infiltration potential (about 34.87%) among all the options. This is expected, since one of the primary functions of vegetative swales is to infiltrate the runoff water. However, the area required for constructing vegetative swales is quite high, which can be a limiting factor for highly developed areas. Also, the runoff reduction efficiency does not reach an appreciable level (about 17.23%). Apart from area limitation, another difficulty with vegetative swales is lack of proper design standards, especially for a developing country such as India; and difficulty in replacing it with conventional storm sewer networks. Through Options 1–8, only single SCMs for the entire study area are considered. However, it is possible to implement more than one SCM option for the entire area. In the present study Options 9 and 10 consider a combination of SCMs. Option 9 is a combination of permeable pavements and bio-retention tank, whereas Option 10 is a combination of permeable pavements and infiltration trenches. The reason for selecting permeable pavements as a common option for both cases is that it can be replaced with existing walkways or parking lots with minimal effort; and also, the runoff control efficiency and infiltration efficiency for permeable pavements is considerably higher. Similarly, it is easier to place/implement bio-retention tanks and infiltration trenches in the selected case study area, without causing greater disturbance to the existing storm sewer system. Of the two options, i.e. Options 9 and 10, it can be stated from the tabulated results of Table 2 that Option 10 on all the metrics is more preferable to Option 9. Finally, it can be concluded that if a combination of SCMs is to be implemented then Option 10, which is a combination of permeable pavements and infiltration trenches, is the most preferable SCM; on the other hand if only a single SCM is required to be implemented throughout the area then Option 4 (infiltration trenches) can be considered as the most preferable option.

Conclusions

The main objective of the paper is to identify the most suitable SCM for an urbanized catchment, such as the VIT campus, using SWMM software that can satisfy the typical objectives of a SCM which are: restoring pre-urbanized runoff hydrograph and increasing infiltration potential of the area. A total of approximately ten SCM options were tested for the study area and the most suitable SCM was selected based on the efficiency measures defined by Sorup *et al.* (2016). The natural drainage lines for the study area were obtained by studying drainage maps available for the VIT campus and delineated maps generated through DEM. The design dimensions for each SCM were finalized based on a five-year return period storm. The efficiency measure for each SCM was determined based on daily rainfall data for

Table 2. Hydrologic efficiencies for different SCMs in comparison to the existing scenario.

SCM type	Area occupied (%)	E_{rr} (%)	E_{f_p} (%)	$E_{storage}$ (%)
Option 1	6.54	19.8	6.15	3.21
Option 2	5.32	18.69	9.61	3.52
Option 3	39.44	49.17	18.15	1.25
Option 4	7.78	20.02	29.53	0.18
Option 5	20.72	22.6	27.04	1.01
Option 6	4.57	12.95	10.32	0.08
Option 7	7.23	10.79	3.56	0.06
Option 8	32.39	17.23	34.87	0.12
Option 9	31.74	32.05	21.7	1.6
Option 10	30.29	39.81	29.45	7.7

the most recently available (2017) rainfall data. From the results it can be concluded that when area is a limiting factor for SCM, Option 2 (rain garden) and Option 6 (rain barrel) are more suitable as they cover a much smaller area, 5.32 and 4.57% of the overall campus area, respectively. However, their performance in reducing peak runoff is comparatively less at 18.7 and 13% respectively. Also, the infiltration potential for Options 2 and 6 is also relatively low (9.61 and 10.32% respectively). If runoff peak reduction is the primary criteria for selecting the SCM, then Option 3 (green roof) and Option 10 (combination of permeable pavements and infiltration trench) give relatively better efficiency values at 49.17 and 39.81% respectively. If increasing infiltration from the catchment is the major goal of SCM, then Option 4 (infiltration trench), Option 8 (vegetative swales) and Option 10 are more suitable with efficiency values of 29.53, 34.87, and 29.45% respectively. Hence the order of preference based on the efficiency measures given in Table 2 for the best three SCMs that can be implemented for the campus is as follows:

Order 1: When area is limiting: Option 6 > Option 2 > Option 1
Order 2: When peak runoff reduction is the primary objective: Option 3 > Option 10 > Option 9
Order 3: For improving infiltration potential: Option 8 > Option 4 > Option 10
Order 4: Storage for reuse: Option 10 > Option 2 > Option 1

Since for any SCM the primary objectives are peak runoff reduction and increasing infiltration potential, Option 10, which is a combination of permeable pavements and infiltration trenches, is the best option that can be implemented for the VIT campus. Also, Option 7 (roof to disconnection) can be considered as the least preferable option as it gives relatively less efficiency values in all criteria. Finally, it can be stated that SWMM is a very handy tool in identifying and designing the most suitable SCM for an urbanized area. The study can be further extended by adopting a more comprehensive multi-criteria decision-making tool for selecting the best SCM among the various options.

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