Assessment of SuDS in an Urban Drainage System of Gurugram city using SWMM

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Abstract: In the recent past, extreme climatic events (i.e. floods, droughts) has been frequently witnessed and significantly impacted on urban flooding. This consequently leads to affect the life of people and property mainly due to water-logging and subsequent health issues. Therefore, the effectiveness of conventional drainage network design has been questioned. Recently, the concepts of Sustainable Urban Drainage System (SuDS) has been developed to minimise the impacts of urban runoff by capturing runoff close to source and then releasing it slowly allowing the stormwater to infiltrate into the ground and subsequently attenuate the peak runoff. Therefore, SuDS as an alternative to conventional approaches is preferred across the world over, however the actual implementation at least in major cities of India is still lacking. Hence, in this paper, a case study to evaluate the effectiveness of implementing SuDS is demonstrated for Gurugram region using Storm Water Management Model (SWMM). The comparative analysis with conventional methods revealed that introducing SuDS has reduced the peak runoff by around 20% on the higher intensity of rainfall and even control the urban flooding by minimising the flooding volume at the junctions by millions of litres and storing it within the catchment area.

Keywords: Sustainable urban drainage system (SuDS); Stormwater modelling; Storm water management model; Urban flooding.

1. Introduction

Urban drainage systems have been facing numerous difficulties during stages of planning and designing. So, management of urban stormwater has become increasingly complex for the past few decades (Cembrano, et al., 2004; Li & Matthew, 1990). Climate change, urban densification and failure of infrastructure had compromised these systems' performance to make it extremely unsatisfactory. This impacted rainfall statistics leading to uncertainty (Ten Veldhuis, 2010; Djordjević, et al., 2011; Fryd, et al., 2012; Willems, et al., 2012; IPCC, 2012; Hammond, et al., 2015). Catastrophic damage of human life and property has been observed due to frequent urban floods (Mugume, et al.,2015; Mugume & Butler, 2017).

These problems have been affecting the human health terribly across the globe by contaminating the food and water, drowning, and also promoting mental and emotional troubles (Ohl & Tapsell, 2000; Huong, & Pathirana, 2013; Shrestha, et al., 2017). Focusing on India, frequency and the magnitude of extreme rain events during the monsoon seasons have increased in the recent past due to global climate change (Da Silva, et al., 2012; Bisht, et al., 2016; Rao, 2019). The stormwater drainage network is too inadequate to serve the disposal of stormwater as only 20% of the road network has been covered with stormwater drains (Indian Council for Research on International Economic Relations, 2011). Especially in Gurugram city of Haryana, the human life is interfered with by endless water logging problems at the time of monsoon rains (Skymet Weather Team, 2017; Bhatt, 2018; The Hindu Team, 2019).

Accompanying to urban floods, depletion of groundwater has also been a problem of disruption in major cities of India (Vaidyanathan, 1996; The Hindu, 2018). Over-exploitation of groundwater has been prelavant over the decades due which there has been a rapid decline in the groundwater table . A total of 750–800 km^3/year of groundwater has already been withdrawn and is escalating rapidly (Shah, et al., 2001; Konikow & Kendy, 2005; Aeschbach-Hertig & Gleeson, 2012). In Gurugram, particularly, there has been a decline of 82% of groundwater during the last decade and the water table has fallen over 20 meters in the past few decades (India Today, 2016; The Times of India, 2018).

Considering the depletion and degradation of urban water resources, sustainable urban drainage system is being advocated which is characterized by implementation of best management practices (BMPs) and advanced management of water pollution (Marsalek, et al., 1993). The adoption of green infrastructure might enhance infiltration and storage volume which ultimately reduce the impacts of urbanization and help to identify flood risk management strategies (Lennon, et al., 2014; Barbedo, et al., 2014; Jato-Espino, et al., 2016).

SuDS usually deals in three stages of control: source control, site control and regional control (CPHEEO, 2016). SuDS techniques are used to address water quality, water quantity, amenity and habitat, and hence integrating these multi-disciplinary approaches. Examples of these techniques comprise detention ponds, infiltration trenches, green roofs, filter strips, permeable pavements, wetlands and rain water harvesting systems (Department of Environment, Food and Rural Affairs, 2015). Hence, it's objective is "to minimise the impacts of runoff by keeping it onsite as much as possible and release it slowly" (CPHEEO, 2016). The use of SUDS instead of traditional drainage system tends to mitigate the peak runoff and control water pollution by retention, infiltration and transportation (Hellström, et al., 2000).

The modelling of these drainage systems can be performed manually, using empirical formulae, or with Storm Water Management Model (SWMM) software. This large complex software, developed by EPA (Environmental Protection Agency), can undergo detailed hydrological and hydraulic modelling for stormwater and wastewater catchments to analyse network performance and develop mitigating measures. It is capable of simulating the inflow and outflow of any type of catchment and hence, can be used for economic design of the conduits and various other parts of the drainage system (Lockie, 2009).

Looking to the aforementioned, this study has been planned with the following specific objectives:

2. Objectives

- Modelling of the proposed urban drainage system for a part of Gurugram city, Haryana using the Storm Water Management Model (SWMM).
- Implementing Sustainable Urban Drainage System (SuDS) on the proposed drainage system.
- A comparison between the simulation results of conventional drainage system and SuDS in the SWMM and suggestion for the proposed drainage network.

3. Materials and Methods

3.1.Details of Study Area

The study area has been taken as a part of Gurugram of National Capital Region, mainly **Sector-81 to Sector-98** (Fig. 1). The region lies between $28^0 22'12''$ to $28^0 25'48''$ North latitude and $76^0 52'30''$ to $77^0 59'24''$ East longitude comprising of an area of **41.5** km^2 and average slope of 1.79%. The district comprising the region has hills on the one hand and depressions on the other, forming irregular and diverse nature of topography.

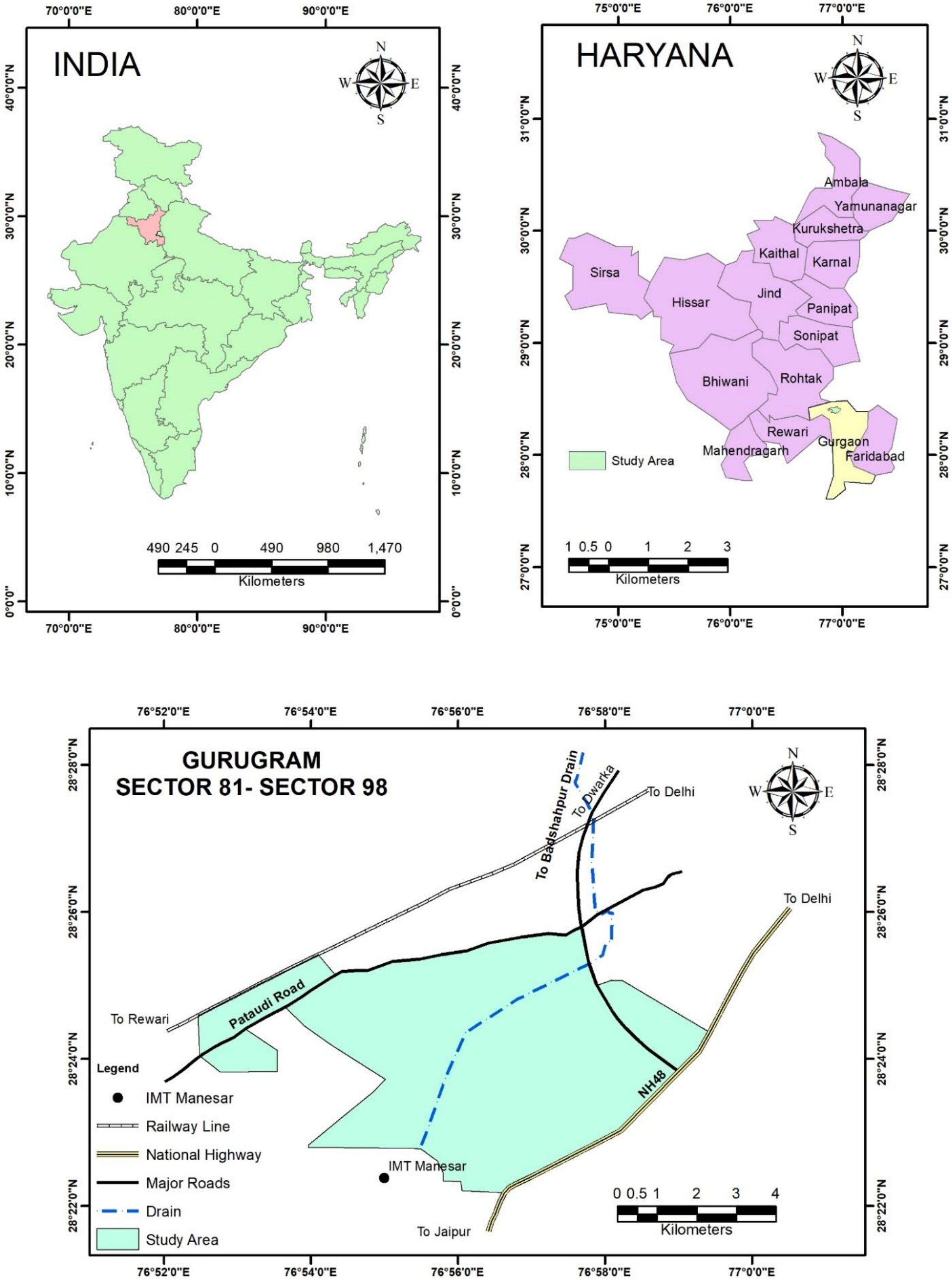

Fig. 1. Location of study area

The average annual precipitation of the area is approximately 714 mm and most of the rainfall occurs in the monsoon season.
The main drain of the area which carries entire runoff connects to Badshahpur drain which ultimately disposes of in Najafgarh Jheel (Lake), which is around 10 kilometres from the study area. Presently, the built-up area is around 53% with mainly high raised building with patches of single or two-storeyed, the farmlands are about 46% and the remaining areas with grass or barren lands.

3.2.Details of Hydrological and Catchment Data

Hydrological analysis, simulation and modelling plays a vital role in providing flood risk management measures and hence, to evaluate the urban runoff and mitigate urban floods (Guo, et al., 2010). Particularly, the precipitation analysis of the catchments becomes fundamental identifying the most effective strategies for green infrastructure.
The factor which affects the runoff most is the local precipitation. Hourly rainfall data of Palam (New Delhi, India) Station has been analysed for the years 1991 to 2014. Different storm data was noted down which occurred in short span with high intensity. The intensities were used for hydraulic simulations.
The drainage map (proposed master plan) obtained from the municipality technical office provides technical details of the sewer network system. It contained length and cross sectional details of the conduits along with formation and bed levels of its starting and end junctions.
Catchment details are also critical part of the runoff analysis to which depends on the volume and depth of discharge occurring in a particular time. Land use/ land cover, slope map and soil map are various data required to enumerate the sub catchment details. Land use was analysed from 30×30m resolution Landsat 8 data (Jia, et al., 2014) and modified with the help of Geographic Information System and Google satellite images.
The soil map was obtained from the Survey of India illustrating variety of soils classifying each type very specifically according to their drainage capability, constituents, salinity, erodibility, sodic conditions, etc. This soil map was used to identify the region’s soil type (Group A, B, C & D). Accordingly, the curve number to be used in the SCS-CN system to assess infiltration has been allocated.
The vertex data of the Alaska Satellite Facility with a resolution of 12.5 ×12.5 m can be used to deduce slope map of different catchments using ArcGIS from the Digital Elevation Model (DEM) of the appropriate area. This map was used to derive the mean slope and to locate the outlet of different sub catchments.
The length of the overland flow can be estimated from the point of departure. The width of the catchment has been shown by dividing the area with the longest overland flow length.

3.3.Modelling in SWMM

US EPA SWMM allows us to model and display the runoff volumes, storage volumes, infiltration volumes, or depths, etc. of any type of catchment very effortlessly compared to manual process. It estimates the quantity of runoff generating from each sub catchment, its discharge, flow depth, and also quality of water in each conduit during a certain simulation period with multiple time steps (Rossman, 2010).

The results of both before and after implementing SuDS on the proposed drainage network will be obtained and compared when modelled out in SWMM. The simulation has been performed using different intensity and duration of rainfall. The SWMM uses the hyetograph of rainfall as an input to stimulate the catchment area runoff. So, higher intensity storm data were considered for simulation which are shown in the table 1.

Table 1. Storm data used for simulation

Hourly Intensities (mm/hr) Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	Total Depth (mm)
30/8/1995	0.7	0.1	0	0	4.5	10.5	19.5	60.7	1.5	0	1.8	0.6	0	0.2	100.1
17/7/2014	0	0	0	0	0	0	0	23	24	18	22	5	4	4	100

The manning's roughness coefficient for the conduits are assumed to be 0.013 as all the pipes and channels are built up of concrete lining. The manning's roughness coefficient of the sub catchment represents the resistance experienced on overland flows as it runs off over the surface (Rossman, 2015). The values were assumed for pervious (0.13 $s/m^{1/3}$) as most of the pervious regions are farmlands and impervious (0.013 $s/m^{1/3}$) for all the sub-catchments. Depth of depression storage is the volume that is filled within before the starting of runoff from the sub-catchments (Rossman, 2015) which were considered 2mm (impervious region) and 6mm (pervious region) for all the sub-catchments. These values were referred from the tables of SWMM's User Manual.

The Curve Number Infiltration model was used for evaluation of infiltration through the pervious portion of catchments as it is the most commonly used method because of the known standard values of curve number (CN). The values required were CN and drying time within which the soil will be dried after getting saturated which is usually 2-14 days (Rossman, 2015). CN values assigned are as shown in Table 2. which are referred to SWMM's User Manual assuming antecedent moisture condition II. Accordingly, the value of CN differed in sub-catchments as per the land use of the sub-catchments. The drying time was considered 5 days, the soil being sandy loam and falling in Group A.

Table 2. CN values for different type of Land Use

Land Type	**CN**
Built-up Area	77
Farmlands	72
Barren Land	68
Grass	49

Kinematic Wave Routing uses the continuity equation with a simplified form of the momentum equation in each link whereas Dynamic Wave Routing uses the complete 1D Saint-Venant flow equations. These equations consist of both the continuity and momentum equations for links and a volume continuity equation at nodes (Gironás, et al., 2010). So, not to complicate the modelling much Kinematic Wave Routing was preferred while stimulating.
SWMM provides option for internal routing of runoff from pervious to impervious sub- areas or vice-versa. But the during this simulation routing to the outlet was considered for all the sub-catchments. Considering ideal situation, 100% routing was assumed for all the sub-catchments which indicates that all the rainfall which has not infiltrated or stored has been routed to the outlet.
The study area has been divided in various sub-catchments. The details of which are provided in table 3.

Table 3. Details of sub-catchments

Sub-catchments	**Area (ha)**	**% Slope**	**%imperviousness**	**CN**
Sector 94	59	1.77	59.66	75.01
Sector 96	180	1.75	14.59	72.74
Sector 97	144.7	1.91	15.93	72.75
Sector 81A	335	1.97	62.75	74.88
ABAD SHI	238.8	1.98	51.38	74.47
Sector 98	174	1.64	27.17	73.35
Sector 95	192	1.85	47.29	74.23
Sector 89	237.2	1.74	42.07	73.96
Sector 88	182	2.05	34.37	73.73
Sector 84	180.4	1.75	71.00	75.48
Sector 85	145	1.77	73.37	75.69
Sector 93	147.3	1.52	52.17	74.59
Sector 92	275.51	1.75	50.83	74.34
Sector 91	182.5	1.59	39.23	73.67
Sector 90	135.57	1.59	40.96	73.94
Sector 87	231.5	1.64	49.26	74.46
Sector 86	229	1.65	69.68	75.39
Sector 81	183.85	1.70	49.18	74.46
Sector 82	124.2	1.62	94.05	76.69
Sector 82A	110	1.91	51.41	74.60
Sector 83	234.85	1.78	87.23	76.38

The study area was accommodated with 26 junction nodes, physically represented as manholes in sewer system or pipe connection fittings, and these nodes were connected with 26 links which represented conduits or channels. These hydraulic elements made up the whole proposed network of drainage system with water flowing from one node to another passing through the conduits or channels (Rossman, 2015). A flowchart in Fig. 2. Shows the data required and the methodology to use those in SWMM.

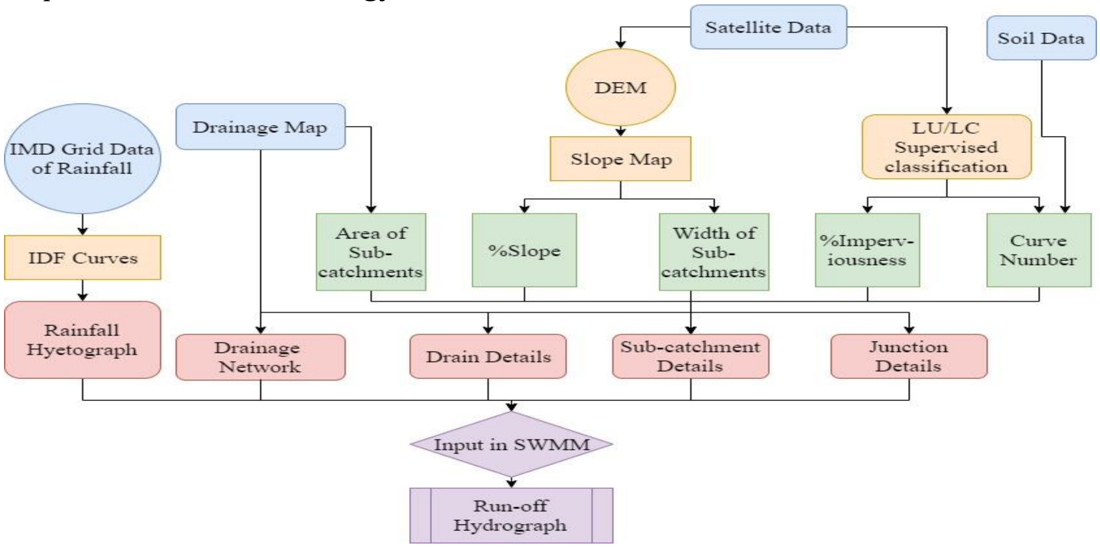

Fig. 2. Steps to follow in SWMM

3.4.Implementation of SuDS

SuDS components such as filter strips, infiltration trenches, bio-retention units, detention ponds, etc. have the ability to store or infiltrate the storm water allowing it to slowdown and delay the peak of the runoff. SWMM has the capability to accommodate these abilities of SuDS components as the features of a sub-catchment. The software has the potential to explicitly model SuDS components of green roofs, infiltration trenches, detention ponds, etc. (Gironás, et al., 2010).

In this study, two of the components are chosen to implement in the proposed conventional drainage system which are infiltration trenches and detention ponds. Both the component chosen has the ability to control the runoff as close to the source as defined by the primary objective of SuDS. Combining these systems can be said a whole sustainable urban drainage system as these components can control the pollution generated in the runoff to some extent. The runoff, when slowed down, can leave behind the harmful constituents by the process of sedimentation. Infiltration trenches, in turn, can let the stormwater undergo the filtration process.

The infiltration trenches were added to all the subcatchments along the width of it; in a way that entire runoff from the sub-catchment first reaches the trenches and then allowed to enter the drainage network (Gironás, et al., 2010). The properties of trenches used are provided in table 4.

Table 4. Details of Infiltration Trenches.

Property	Value used
Width	3 m
%Slope	0.001
%imperviousness	0
Manning's coefficient (Pervious)	0.24 s/m$^{1/3}$

Depth of depression storage (Pervious)	300 mm
CN	39

Trapezoidal detention ponds were introduced in the drainage network using the option of storage units in SWMM. These were designed overseeing the availability of area in a particular sub-catchment and had been provided a side slope of 3H: 1V, ensuring the stability of the soil. To consider seepage losses through the detention ponds following data from SWMM's Reference Manual (Rossman, 2016) were assumed: suction head (4.33mm); saturated hydraulic conductivity (0.43 mm/hr); and initial deficit which is the difference between porosity and initial moisture content (0.33). The different sizes of detention ponds used are shown in Table 5.

Table 5. Details of detention ponds

Detention Ponds	Area on ground (m^2)	Depth (m)	Total Volume (m^3)
DP1	10,000	3	23,736
DP2, DP3	15,000	3	38,061
DP4	20,000	3	52,386
DP5, DP6	10,000	3	25,086
DP7, DP8	4,000	3	8,976

A tool had been identified by Pappalardo, et al., 2017, to compare the peak of the pre and post implementation of SuDS in the conventional drainage system. The tool was named indicator of peak flow ratio (I_f) in percentage:

$$I_f = [(Q^I - Q^{II})/Q^I] \times 100$$

where, Q^I is the peak flow of the catchment modelled before the implementation of SuDS and Q^{II} is the peak flow of the catchment modelled after the implementation of SuDS.

4. Results and Discussions

The proposed urban drainage system of the study area had been modelled in SWMM as shown in Fig. 3. It has 21 sub-catchments, 26 junctions and 26 conduits. The conduits are both circular and box type having sizes varying from 64 inches in diameter to 12.00m x 2.43m rectangular box. The details of which are given in table 6.

Table 6. Details of conduits between different junctions

Conduit	Number	Cross-section	Size
C1	2	Circular	64”
C2	5	Circular	72”
C3	6	Rectangular Box	(2.43 x 1.82) m^2
C4	6	Rectangular Box	(3.04 x 1.82) m^2
C5	1	Rectangular Box	(3.04 x 2.43) m^2
C6	1	Rectangular Box	(4.00 x 2.43) m^2
C7	2	Rectangular Box	(4.50 x 2.43) m^2
C8	1	Rectangular Box	(5.50 x 2.43) m^2
C9	1	Rectangular Box	(8.50 x 2.43) m^2

C10	1	Rectangular Box	(12.0 x 2.43) m^2

The land use land cover (LU/LC) classification showed that the area has 53% of built-up area including roads, high raised buildings, housing societies, etc., 46% of farmlands mostly cultivated with wheat. The rest of the area were with grass of around 0.3% and barren land being 0.7%. The accuracy assessment performed to the LU/LC image gave an Overall Classification Accuracy of 70.10% and Overall Kappa Statistics as 0.5998 which are not good results as these have to be above 80% and 0.8 respectively.

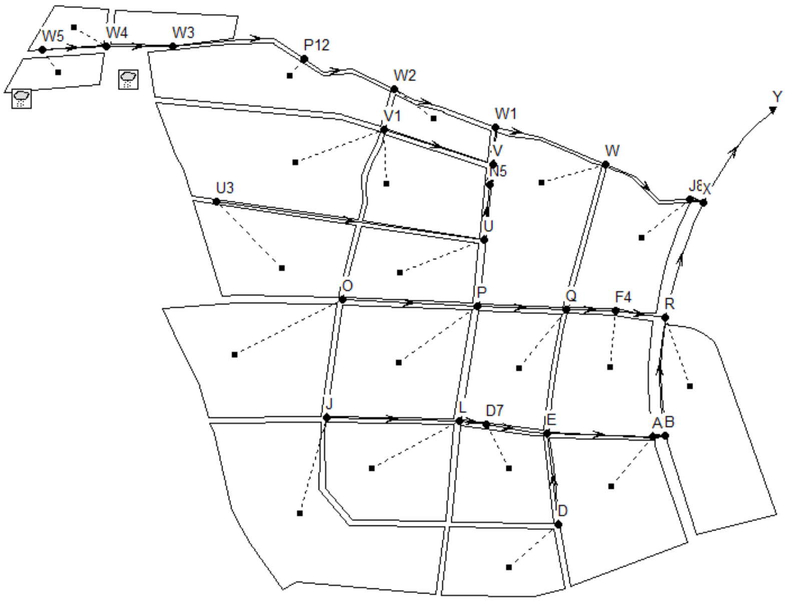

Fig. 3. Layout of drainage system in SWMM.

Results of the simulation before the implementation of SuDS in the proposed conventional drainage system are as shown in Table 7.

Table 7. Modelling results obtained in SWMM before SuDS

Storm dated	*Surface Runoff depth (mm)*	*Flooding Vol. (*10^6 Lit.)*	*Peak Flow at outlet junction (m^3/s)*	*Time Lag (hrs.)*	*Storage Vol. (*10^6 Lit.)*	*Junction flooded (n)*
30/8/1991	73.757	1276.5	102.72	8	0.855	20
17/7/2014	69.583	1029.2	75.57	4	0.122	14

The proposed drainage system turned to be inadequate for these sequences of rainfall as major flooding losses are seen to occur. This may cause frequent flooding problems at almost all the junctions, during times the depth of rainfall is above the stimulated sequence (100mm). To overcome this situation either the network must be redesigned or SuDS can be adopted which can reduce the flooding to a very large extent. In this paper infiltration trenches and detention ponds are used to convert the convention drainage system to SuDS.
The infiltration trenches were installed in every sub-catchment in a way that entire water enters the trenches from the sub-catchment and then discharges to junctions of the drainage

network. Detention ponds are installed as per the area availability and necessity. The installation of both the components is shown in Fig. 4.

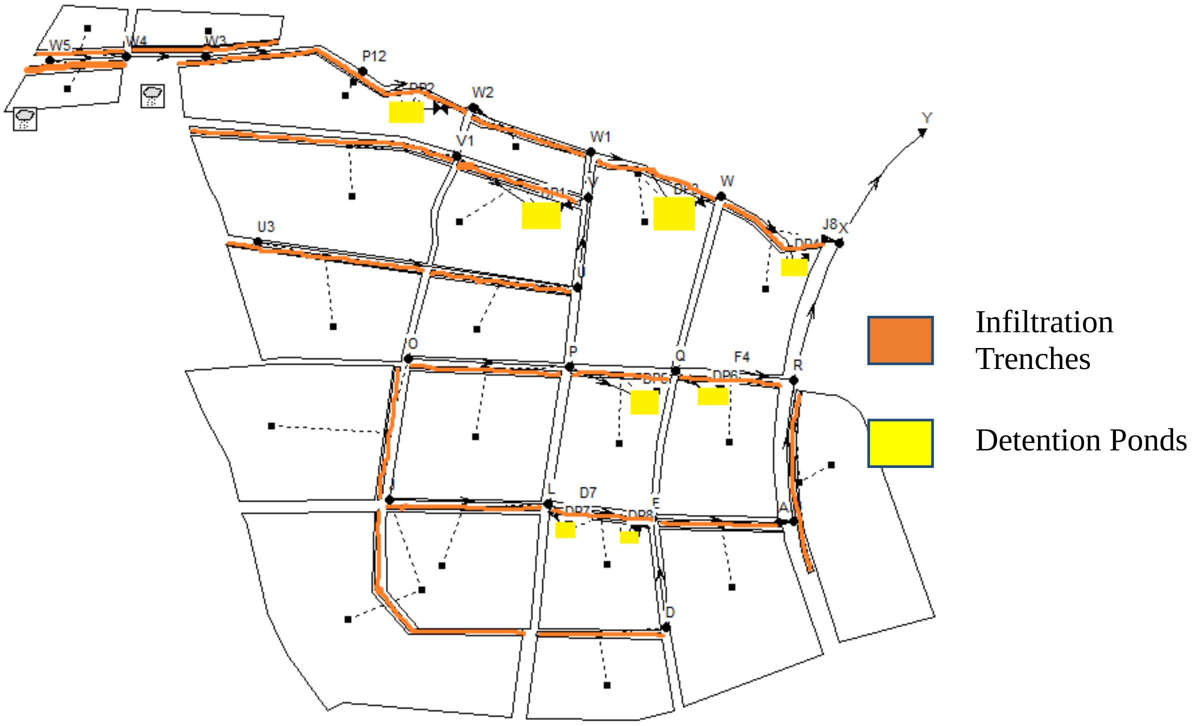

Fig. 4. Layout of SuDS in SWMM

Simulation of the above model in SWMM gave results as mentioned in Table 8.

Table 8. Modelling results obtained in SWMM after SuDS

Storm dated	***Surface Runoff depth (mm)***	***Flooding Vol. (*10^6 Lit.)***	***Peak Flow at outlet junction (m^3/s)***	***Time Lag (hrs.)***	***Storage Vol. (*10^6 Lit.)***	***Junction flooded (n)***
30/8/1991	72	29.2	80.57	10	136.4	4
17/7/2014	67.4	0.00	68.11	5.5	135	0

I_f at outlet for storm dated 30/8/1991 has been evaluated as 21.56%, whereas for the storm on 17/7/2014, it was 9.87%. This result shows SuDS can be more effective during higher intensity of rainfall.

Implementation of SuDS in conventional drainage system proved to be effective in reduce the flooding to a very large extent as the number of junctions flooded and the volume flooded have been reduced considerably. The peak flowrate has not only attenuated but also has been delayed by hours which provides the time for taking mitigation measures during flooded situation. There is also greater storage of stormwater which can be put to use in future drought conditions or can be allowed to percolate into the ground for recharging groundwater.

The infiltration trenches have the ability to filter the water and detention ponds can undergo sedimentation process which combines to replicate a whole water or sewage treatment plant to treat the surface runoff and control the pollution entering groundwater or any other water sources.

The SuDS components have not been quantitatively analysed instead it only has been qualitatively proven that implementation of SuDS can reduce the peak runoff and control the flooding effectively. The sensitivity analysis of different SuDS components should be performed in order to categorise or show the effect of each component more constructively.

These limitations on assessing of SuDS call due to the unavailability of field data. All the input data and other parameters were taken on the reliable results of researchers. More reliable results must have been obtained for the field observation or data would have been available. For the validation of model input parameters and to interpret results support of hydraulic engineers is still required (McCutcheon & Wride, 2013).

As in the present scenario, the study area has only 53% of built up area, there is scope for the implementation of SuDS. The area required for introducing the SuDS components can be spared from the open spaces needed for a building or housing complex as per the National Building Code.

5. Conclusions

This study was to assess the effectiveness of SuDS on a conventional drainage system of an urban catchment using US EPA SWMM. The reason behind the requirement of SuDS instead of simple drainage system is to prevent frequent urban flooding to a large extent in an effectual manner. Simultaneously, reducing and delaying the peak of surface runoff by keeping the runoff as close to source as possible. Besides this, SuDS also has the ability to control the pollution of water sources caused by urban runoff (Department of Environment, Food and Rural Affairs, 2015).

The simulation was performed in SWMM for a proposed drainage network of a part of Gurugram city, Haryana in India. The results of the simulation proved the need for improvement in the drainage network as flooding was observed during the analysis. The redesign can be made either by changing the conduits' cross sectional area, or introducing SuDS components and converting it to sustainable urban drainage system.

The results show that the application of SuDS has been proved to be an effective means to reduce the peak rate of runoff i.e., up to 20% and flooding to a large extent. Thus, it contributes sustainably to sustainable urban ecosystem growth. The sensitivity and feasibility analysis of the SuDS components would show more appropriate results but the qualitative analysis of the infiltration trenches and detention ponds also demonstrated enough to be implemented on the field.

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