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A Sustainable Stormwater Management Model of Vallabh Vidyanagar

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Abstract

Stormwater drainage system is considered as an important infrastructure for any city or town. Extreme precipitations due to climate change and the narrow peak of hydrograph due to uncontrolled urbanization result in unexpected negative impact of stormwater drainage which creates flood like situation and a lot of public outcry. This study is aimed at finding a sustainable solution to the extreme floods occurring in Vallabh Vidyanagar area of Anand, Gujarat, India. The capacity analysis of existing system is performed to identify overflow location and few LID (Low Impact Development) Techniques were incorporated to mitigate the hydrological effects of urbanization in the city using the popular software SWMM (Stormwater Management Model). Various data collected from Vallabh Vidyanagar Municipality and Bhuvan - Geoportal of NRSC/ISRO are used to prepare the schematic view of the study area in SWMM along with ArcGIS tools. SCS Curve Number Method was used to identify the peak runoff volume of the study area from the year 2015-2019. The results unveiled the overflowed links, runoff volume in the links and by applying the salient LID features of SWMM, runoff volume has decreased by 12ML (million liters) in the study area

Keywords: SWMM (Stormwater Management Model), Sustainable stormwater management, LID (Low Impact Development), SCS Curve Number Method.

1. Introduction

Over the past few decades, the effect of urbanization and climate change has caused even the most well-planned drainage systems to be inefficient in fulfilling their functions. The conventional drainage systems focused on removing the excess stormwater from the drainage basin as quickly as possible. However, due to recent changes in climate and an increased requirement of water quantity as a result of population, drainage systems are required such that water can be collected, stored, and used for further purposes with ease. With that in mind, the current drainage system should be analyzed, evaluated by performance during monsoon, and modified with the help of recent technologies, case studies, and software at the most economic cost.

In the district of Anand, ground water surveys have been carried out dating back to the 1960s, in which the technical feasibility and economic viability of optimum utilization of water resources have been found. Further, the Space

Application Centre (SAC) of the Indian Space Research Organisation (ISRO) have used satellite imagery to identify water logged and salinity affected areas in 1981. However, there was no detailed research study to evaluate the effect of population increase on the quantity required for removal of water in the stormwater drainage system.

Due to increased urbanization, the permanent road surfaces, existing buildings and their pavements cause a decrease in percolation of water into the soil. This is due to the fact that pucca road surfaces and other infrastructures will not allow water to enter into its material, hence leading to the requirement of drainage lines on the sides of the road. As the water must be carried by drainage lines, attempts are made to carry large quantity of water out of the streets such that the water does not remain on surfaces for long time to hinder the moving traffic and other daily activities. But the scenario is different in Vallabh Vidyanagar with very few drainage lines and there inefficiency to dispose huge runoff volume. Even though the government officials are trying their best by cleaning the drains before every monsoon, the city dwellers face huge problem during rainfall, with majority of students residing in the area they face difficulty to commute and even their hostels and colleges are flooded with water.

A. Study Area and Data Used

The present study is carried out in Vallabh Vidyanagar (well known as the educational hub of Gujarat) a town and municipality in Anand district in the Indian state of Gujarat. The 2.3 km2 area of Vallabh Vidyanagar town which is 6 km from Anand town is studied in depth and its location map is shown in “Fig.1”. The Geographic location of the study area is

22□33□ N latitude, 72□55□ E longitude. This city has a tropical climate. It receives moderately to heavy rains throughout the rainy season i.e. from June to September. Average rainfall of the town from year 1984-2019 was observed as 720 mm. Stormwater sever of rectangular, closed with perforated concrete slab opening type is provided in the areas which are more prone to water logging within the city.

Data regarding DEM (Digital Elevation Model) map, LULC (Land Use Land Cover) map were extracted from SRTM_GL3 30m DEM obtained from Bhuvan – Geoportal of

NRSC/ISRO. The study area’s map is collected as an

AutoCAD file and drainage details are obtained from Vallabh Vidyanagar Municipal Corporation. Daily Rainfall data from 2015-2019 is collected from GSDMA (Gujarat State Disaster Management Authority).Rainfall data from 1901 to 2014 were collected from SWDC (State Water Data Centre). And the rainfall pattern of the region from 1901 to 2019 is shown in “Fig.2”.

Pre monsoon and Post monsoon Water Depth (“Fig.3”) and Total Dissolved Solids (TDS) (“Fig.4”) data are collected from Gujarat Water Resources Development Corporation (GWRDC), Ahmedabad and graphs are plotted for different years to visualize the pattern prevailing in the study area.

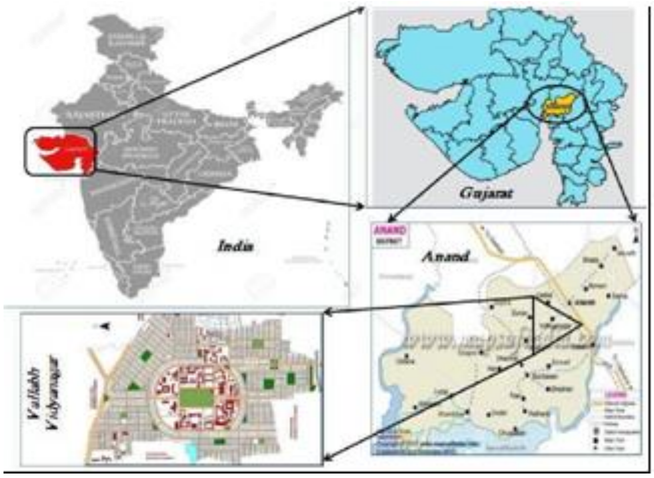


Fig.1 Geographical location of study area

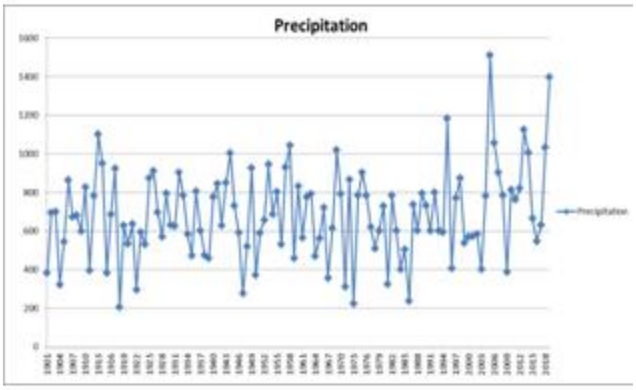


Fig.2 Rainfall pattern of study area from 1901 to 2019

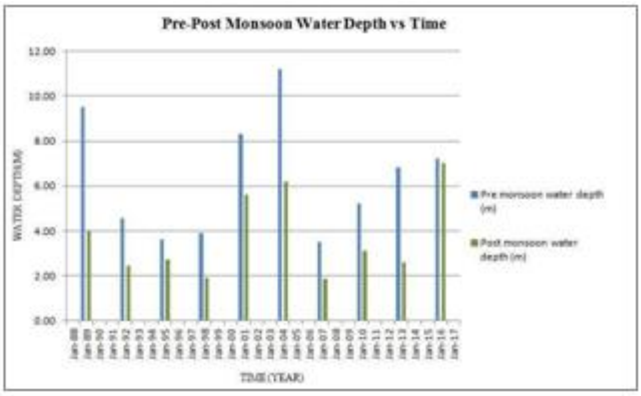


Fig.3 Graph showing Pre-Post monsoon water depth variation

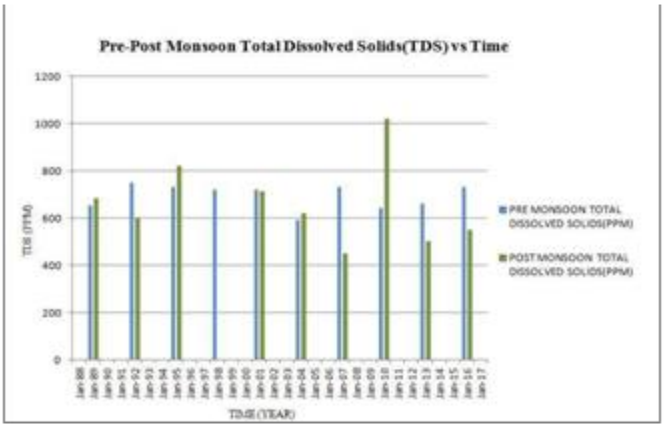


Fig.4 Graph showing Pre-Post monsoon TDS variation

B. Literature Review

Various structural and non-structural Best Management Practices have been studied and successfully implemented in UK, USA, Europe, Canada etc [4],[7],[1]. Landscape based LIDs in the form of green roofs, rainwater harvesting, grass swales and dry swales, bio-retention, permeable pavement, perforated pipe systems, soak ways etc .have been designed and adopted in these countries. Bio-retention or rain-gardens have been adopted as an effective BMP in USA [2]. LID Stormwater management (SWM) guide focuses on a number of lot level and conveyance stormwater management practices that have been used extensively in Europe [1]. EPA carried out 17 detailed studies and concluded that LID practices actually cost less than conventional stormwater management and is environmentally beneficial. The study concluded that significant cost cutting can be achieved through reduced grading, landscaping, paving and other infrastructural costs compared to conventional stormwater management. Studies such as SUDS and LID have not been thoroughly carried out in India, as the current research is a micro-level study in line with structural and waste management practices for urban stormwater management. Sustainable urban drainage system techniques help to reduce stormwater runoff through various processes such as infiltration, filtration, storage, evaporation and detaining stormwater close to the source. Various stormwater approaches such as bio-retention systems, tree filter, porous asphalt parking lot, sand filter and gravel wetland have shown excellent water quality treatment and year round peak flow reduction [7]. Bio-retention is an effective method where the design is made in such a way that all the physical, chemical and biological processes of natural hydrologic system are performed. Bio-retention is used as one of the popular stormwater management practices for addressing urban non-point pollution in New England [3].

C. Relevance of Study

As the monsoon season arrives each year, many streets of Vallabh Vidyanagar become full of water when intensity of rainfall is large, for some temporary amount of time. During that time, traffic nuisance is higher in the streets in which water is not clogged, and as a result, efficiency of the town is slower, as well as there being an increased chance of accidents. The water which is caused leads to other problems on a sanitary level, such as mosquitoes, fly nuisance, and eventually disease. And as the majority of residents being students, they face major problems of commuting even the hostels and colleges are flooded with runoff water in major rainfall events.

Apart from that, the summer season results in decreased flow of water for many house societies, which can be prevented if there is sufficient ground water available for the bore well to pick up. Although many rain water harvesting methods are practiced across the world, there is lack of such methods in the town of Vallabh Vidyanagar.

2. Methodology

The Methodology consists of four steps: 1. Collection of various information's from Vidyanagar Municipal Corporation and from public through questionnaire survey to understand about the storm water problems in the region. 2. The surface runoff yield was calculated from rainfall input (daily rainfall data) and other climatic data using the established SCS Curve Number method and the quantity of runoff water was determined 3. Comparison between the capacity of existing drainage system and the runoff yield would be done to find out the excess runoff occurring at various locations through capacity analysis. 4. To manage storm water in a sustainable manner, LID techniques were used and an overall design of storm water drains along with appropriate water retention, water recharging and harvesting plans was proposed by using open source software SWMM.

A. Preliminary Data Collection

As a part of the preliminary data collection, we performed Questionnaire Survey by dividing Vallabh Vidyanagar region into 10 zones and then collected data from random houses in each zone. Some of the questions included in the Survey were: Year of construction of property, Plinth level of the building above ground level, which was the intense flood that you have observed and what was the depth of water around your residence, etc. A total of 60 responses were obtained from different zones. From this Survey we mainly came to know about the critical area, depth of water, direction of flow, etc. "Fig.5" shows critical area of the region, red colour is used for super critical area and blue colour is used for critical area along with water flow direction.

B. SCS Curve Number Method (Determination of Runoff Coefficient)

The Soil Conservation Service Curve Number method was originally developed by SCS (US Department of Agriculture) to predict direct runoff of given rainfall events. Step included are: 1.To collect the daily rainfall data for 2015, 2016, 2017, 2018, 2019 from GSDMA website. 2. Collect Soil type and Land use pattern of VVN from AVKUDA - 2013(latest). 3. Weighted Curve Numbers are obtained. 4. After that table is prepared for consecutive months of rainy season, which consist Columns of date, rainfall (mm), AMC conditions, CN, Maximum Surface retention S(mm), Runoff Volume Q(mm), Runoff Volume Q(m^3) respectively. 5. Percent runoff is carried out by dividing monthly runoff value with Total rainfall during whole month. The SCS-CN method is based on the following basic form calculating runoff from rainfall depth,

$$Q = \{(P - Ia)^2 / (P - Ia + S)\} \qquad \text{for } P > Ia$$

$$Q = 0 \qquad \text{for } P \leq Ia$$

(Where, P is the total rainfall, Ia is the initial abstraction, Q is the direct runoff and S is the potential maximum retention.)

Equations Used: For Weighted Curve numbers, CN II = Weighted CN / % land use pattern CN I = CN II / (2.281 - 0.01281*CN II)

CN III = CN II / (0.427 + 0.00573* CN II)

- Maximum Surface Retention (mm): S = (25400/ CN) – 254
- For Runoff Volume: Q = {(P − Ia)^2 / (P – Ia + S)} for P > Ia

To convert Runoff Volume in m^3 = (Q(mm)/1000)*209.52*10000 (Where, Area in m^2 = 209.52 ha.*10000).

- Percent Runoff = (runoff volume / total rainfall)

C. EPA SWMM Version 5.1 Model Setup

The United States Environmental Protection Agency (EPA) Storm Water Management Model(SWMM) is a dynamic rainfall- runoff- subsurface runoff simulation model used for single event to long term (continuous) simulation of the surface/ subsurface hydrology quantity and quality from primarily urban/suburban areas. The SWMM model was setup using the DEM, LULC map were extracted from SRTM_GL3 30m DEM obtained from Bhuvan – Geoportal of NRSC/ISRO and of drainage details along with AutoCAD file of the study area were obtained from VMC. The total catchment area is divided into sub-basins and watershed delineation map “Fig.6” was created using ArcGIS tools. Runoff volume obtained from SCS Curve Number Method is used for analysis. In this study, the catchment area is divided into 17 sub-catchments, 22 junctions, 2 outfalls and 22 conduits.

D. Capacity Analysis

The SWMM model is developed for the study area as shown in below “Fig.7”. By considering the drainage line in ArcGIS 10.4, the total study area is divided into 17 sub-basins. Area of each sub-basin is calculated and is provided as an input for SWMM Software to define the runoff from each sub catchment (sub-basins are considered as sub catchments in SWMM). Overland flow from each sub-catchment is calculated using SCS Curve Number method and SWMM

3. Results and Discussions

“TABLE I” shows the results for the year 2019. Results of August 2019 are used for computation as it has the peak value among results obtained from 2015-2019.

TABLE I. Runoff Values Of Year 2019

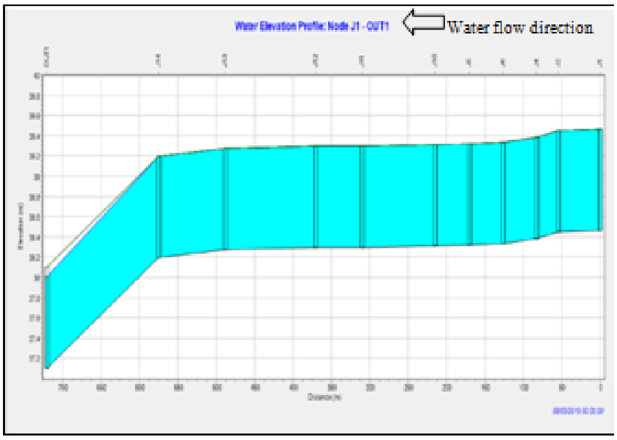
Month	Rainfall Volume	Runoff volume	% Runoff
June	203234.4	34098.475	16.77
July	515419.2	240837.85	46.72
August	1437307.2	1128738.31	78.53
September	773128.8	407917.13	52.76

B. Results after capacity analysis

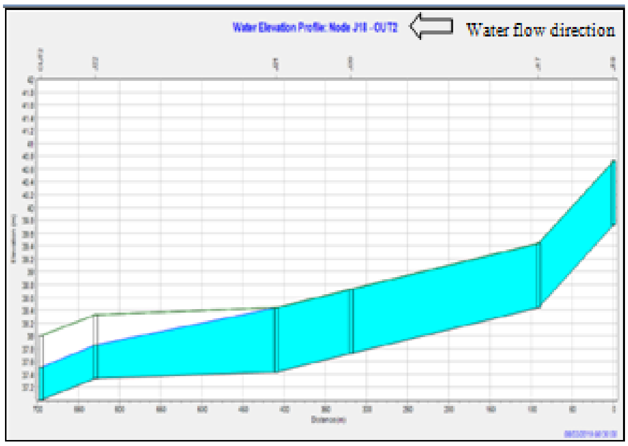
The whole catchment area is divided into 17 sub-catchments, 22 junctions, 2 outfalls and 22 conduits. Among 22 junctions, J-1 to J-6, J-8, J-10, J-11, J-12, J-16, J-17, J-18, J-20 and J-21 were overflowed in a single maximum rainfall event. And among 22 links, 17 links were overflowed in the maximum rainfall event and have attained max/full depth. We have observed from animation of water profiles that after receiving maximum rainfall intensity for 1.5 to 2 hours, all the conduits in the “TABLE II” were overflowed and that caused severe flood like situation for some hours in the catchment area. Flow in the channels is dependent on the roughness and conduit slope and dimensions of channel.

C. Results after application of LID

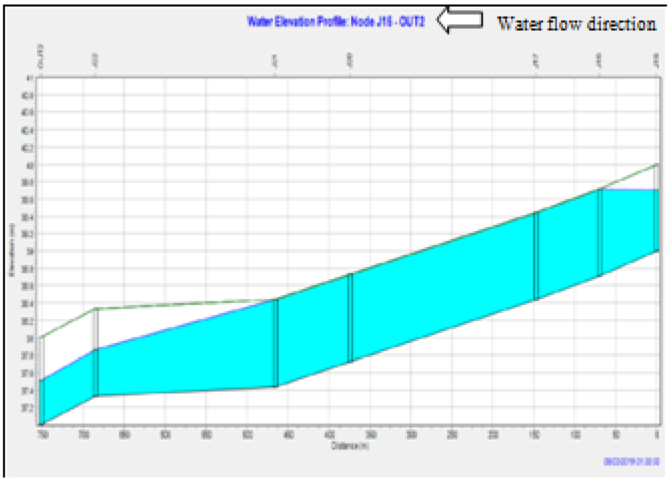
Due to continuous development of residential, commercial buildings in town, permeable land is reducing progressively. By integrating few LID (Low Impact Development) techniques in SWMM software like rain garden and rain barrel to the sub-catchments which are more prone to water logging, considerable reduction of 12ML of runoff is observed, (as seen in “TABLE III”) which is aiming at sustainable solution to the flood problems faced in the study area. This reduction in runoff shows the potential applicability of LID Techniques for urban areas and their sustainable nature leads to an environment friendly town.



(a)



(b)



(c)

Fig.8 Water surface profile at different junction point

TABLE II Summary Of Overflowed Links

Node	**Hours Flooded**	**Maximum Rate CMS**	**Hour Of Maximum Flooding**	**Total Volume Of Flooding 10^6 liters**
J1	0.98	0.179	1:00	0.506
J2	0.95	0.199	0:04	0.276
J3	1.03	0.2	0:04	0.168
J4	1.98	0.479	1:01	2.776
J5	1.95	0.435	0:04	0.535
J6	3.81	0.59	0:07	4.544
J7	2.17	0.394	0:04	0.95
J8	3.91	0.197	0:13	2.009
J9	0.01	0.117	0:04	0.001
J10	4.17	1.94	1:00	14.267
J11	4.18	1.288	1:00	10.242
J12	3.99	2.56	1:00	16.789
J13	2.89	0.758	1:00	4.195
J16	4.14	6.714	0:44	43.318
J17	4.43	1.943	0:09	17.787
J18	0.88	0.638	1:00	1.891
J19	5.52	5.234	1:00	35.787
J20	5.15	1.688	1:00	14.685
J21	7.53	3.059	1:00	29.362

TABLE III Summary of Lid Application

Subcatchment	LID Control	Total Inflow mm	Evapo Loss mm	Infil Loss mm	Surface Outflow mm	Drain Outflow mm	Initial Storage mm	Final Storage mm	Continuity Error %
S2	Rain garden	1283.54	0	56.49	941.33	0	100	385.74	0
S7	Rain garden	4002.73	0	27.62	3763.88	0	100	317.98	-0.16
S8	Rain garden	2906.9	0	66.01	2537.19	0	100	403.72	0
S10	Rain garden	1781.13	0	65.1	1412.03	0	100	404.02	0
S11	Rainbarrel	727.21	0	0	0	387.46	0	339.75	0
S11	Rain garden	1376.05	0	64.93	1006.04	0	100	405.1	0
S13	Rainbarrel	3006.82	0	0	1343.26	721.16	0	942.4	0
S13	Rain garden	6290.98	0	82.61	5878.19	0	100	430.2	0
S14	Rain garden	3099.02	0	75.51	2705.2	0	100	418.32	0

S16	Rainbarrel	1604	0	0	130.75	632.4	0	840.85	0
S16	Rain garden	3490	0	76.85	3092.63	0	100	420.53	0

4. Conclusions

From the results of the research, it can be concluded that

- It is observed that the existing drainage channels of Vallabh Vidyanagar area are insufficient to accommodate the peak runoff volume, analyzed using SWMM software.
- Among 22 links and 22 junctions, 17 links and 15 junctions are getting submerged during the peak rainfall events.
- By incorporating certain Low Impact Development techniques like Rain Garden and Rain Barrel in the SWMM model along the sub-catchments prone to water logging, runoff volume is reduced by 12ML

(million liters) in the study area.

- For efficiently managing the stormwater, LID

Techniques should be placed at the source or upstream portion of the study area and further research in this regard is needed.

- Along with LID Techniques by increasing dimension of the drainage system, water surcharge condition at the junctions can be reduced.
- LID will help to discharge stormwater as close to the source itself and to improve water quality when it infiltrates through the soil media. Bio-retention methods such as Rain Garden and Rain Barrel will add landscape features and the ambiance of the City. This will help to consider stormwater as a resource rather than a nuisance.

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