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STORM WATER MANAGEMENT OF AN URBAN AREA USING SWM MODEL FOR SUSTAINABILITY

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ABSTRACT

The management of storm water drainage and its aftermath in urban areas has grown increasingly difficult due to the haphazard and rapid growth of urban areas, the loss of vegetation, and the decline in drainage system efficiency. Storm water management in terms of water quantity and quality is one of the difficulties. The storm water management model (SWMM), a dynamic rainfall-runoff simulation model, is used to simulate the quantity and quality of runoff from metropolitan areas over a long period of time, either as a single event or continuously. SWMM has been utilised for the current study's considered study region, which is the prospective Amaravati city of Andhra Pradesh's split new state. The goal of the current study is to assess how well different Low Impact Development (LID) control strategies work in terms of effectively managing storm water runoff from the study area's whole watershed. Each sub-catchment area with several units uses a fraction of its available LID control choices. The surface outflows from each LID control and the subsequent reduction in the overall runoff from each sub-catchment have been used to assess the effectiveness of each LID control for each sub-catchment. Peak runoff is determined by the current analysis for both the entire catchment and each sub-catchment of the planned metropolis of Amaravati. In order for the intended Amaravati city to function as a Water Sensitive City, an evaluation of various LID controls with regard to NO LID control option has also been made in terms of attenuation % in runoff as a parameter to adopt sustainable and/or resilient integrated urban storm water management.

KEYWORDS: Storm water management; SWMM; LID; runoff

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INTRODUCTION

The Indian government has started to build several smart cities around the country. Any existing or planned city that wants to become a smart city must have all the necessary infrastructure in place. In the context of water infrastructure, storm water infrastructure in particular needs to be effective in terms of drainage and management in order to function as a water-sensitive city and be included in smart city initiatives. Every city changes more of its land to be paved during different stages of development, making more of it impervious, which increases runoff, particularly surface runoff. Storm water management in urban areas is therefore getting more difficult these days. More urban areas becoming impermeable would be addressed by storm water management through runoff attenuation. In many nations, different Low Impact Development (LID) strategies, both with and without Best Management Practises (BMPs), are being evaluated as the most effective way to manage storm water effectively for resilient and/or sustainable urban drainage systems. The Andhra Pradesh government regards the proposed city of Amaravati as one of the top smart cities. The proposed Amaravati city is located in a region with a lot of rainfall and is a brand-new smart city that is being created; as a result, it would require efficient storm water management to function as a water-sensitive city for an extended period of time. A research study on an appropriate storm water management system for effective and efficient control and discharge could be conducted for the future city of Amaravati.

The storm water management model (SWMM) of the US EPA [Environmental Protection Agency] has been considered as a tool to model and determination of performance of various LID controls and BMP options for efficient storm water management for the considered Amaravati city of Andhra Pradesh state. This is in order to perform the research study of storm water management system as efficient.

Study Area

The projected Amaravati city in the newly established state of Andhra Pradesh, India has been selected as the study area. In the Guntur district, Amaravati city is situated on the Krishna River's bank. The proposed city of Amaravati is situated at 16.51^0 N latitude and 80.52^0 E longitude, covering an area of 217.50 km^2. The proposed metropolis will consist of agricultural land, 29 existing villages, and a portion of two towns that are part of different mandals in the Andhra Pradesh district of Guntur. The planned metropolis of Amaravati is expected to be the first of India's many smart cities and an effective water-sensitive city for a number of decades.

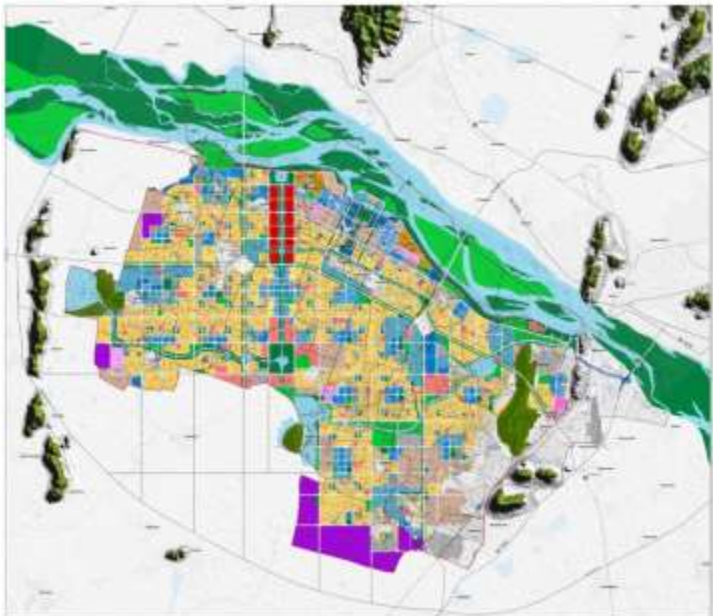

Figure1 Amaravati city.

Data For SWMM Model

The Amaravati SWMM Model was created to assess how well different LID controls and BMP choices work in terms of runoff attenuation for the research area under consideration, which is the proposed Amaravati metropolis, when it comes to effective storm water management. For the Amaravati SWMM Model, the following information is taken into account for every kind of NO LID as well as different LID controls and BMP choices. Version 5.1.014 of the US EPA SWMM software was utilised for SWMM. The simulation ran from January 1, 1992, to July 31, 2021. There are eleven sub-catchments. The Amaravati SWAT model assumes and clearly shows that groundwater flow and any lateral flow have a negligible effect on total runoff.

Climatology data

Data about precipitation is sourced from the SWAT TAMU web portal's data sets.
The two sources of evaporation data are (i) monthly averages and (ii) temperature data.
Temperature information from the POWER LARC NASA online portal is taken into consideration for the Tulluru village region at Latitude 16.53^0 N , Longitude 80.47^0 E. Monthly averages of data sets from the SWAT TAMU web portal are used to calculate wind data.
The SWAT TAMU web portal's data sets are where precipitation data is found.
Data on evaporation is derived from temperature data (i) and monthly averages (ii).
We use temperature data from the POWER LARC NASA online portal for the Tulluru village region, located at Latitude 16.53^0 N and Longitude 80.47^0 E.
The wind data on the SWAT TAMU online portal is regarded as monthly averages of data sets.

Sub-catchment data

The ground slope percentage is supposed to be 0.1 or 1 in 1000, meaning that there should be a 1 m ground drop for every 1000 m on the ground. Manning's N for pervious area is 0.03 [for winding, sluggish ground with grass and some weeds], and 0.013 [for concrete with float finish surface] for impermeable areas. Both pervious and impermeable areas do not take depression storage into account. The infiltration process is evaluated using the CURVE NUMBER approach.

LID data

Examined, Each LID unit has an area of 2 acres, or 8093.7 m^2.
500 m is the surface breadth per unit.
Initially saturated percentage = 0. 95% of the non-LID impervious area is treated.
95% of the non-LID treated previous area percentage
Every output from every LID will be taken into account and restored to the non-LID pervious area.
When developing the SWMM model, the proposed Amaravati city's detailed master plan sketch is taken into account. The SWAT model is used to identify the catchment area for the main outlet position under consideration and to further divide the entire catchment into a number of sub-catchments and their areas.

METHODOLOGY

The EPA The Storm Water Management Model, or SWMM, is a dynamic rainfall-runoff simulation model that may be used to simulate runoff quantity and quality from mostly metropolitan areas over a long period of time, either as a single event or continuously. A group of sub-catchment areas that receive precipitation and produce runoff and pollutant loads are the focus of the runoff component of SWMM. This runoff is transported by the routing component of SWMM via a network of channels, pipes, pumps, regulators, storage/treatment equipment, and gadgets. During a simulation period made up of several time steps, SWMM monitors the amount and quality of runoff created inside each sub-catchment, as well as the flow rate, flow depth, and water quality in each pipe and channel.

Since its first development in 1971, SWMM has undergone a number of significant improvements and alterations. Worldwide, storm water runoff, combined sewers, and other urban drainage system planning, analysis, and design continue to be heavily reliant on SWMM. The Amaravati SWMM model's section 4 above describes the number of trials or iterations that are carried out for the specified data and conditions. The best runoff attenuation outcomes are achieved by multiple trials with different impervious and pervious area proportions. For total peak runoff from the entire watershed, the best outcomes of different LID control techniques are compared to the NO LID option. Additionally, the best outcomes are confirmed by comparing the same and other locations for impervious

Additionally, an analysis of the sensitivity of taking into account evaporation based on temperatures and monthly averages revealed minimal variance in evaporation and peak runoff from each sub-catchment. Furthermore, the sensitivity of each sub-catchment's peak runoff magnitude variation to percentage ground slope, Manning's N for pervious and impervious areas, depth of depression in the impervious area, and depth of zero depression in the impervious area has been analysed. It is discovered that while these parameters influence the total runoff from both pervious and impervious areas, the variation in peak runoff is minimal.

Table 1 Impervious area as a percentage of land use [Source: Storm Water Management Model Reference Manual Volume I – Hydrology (Revised)]

Land Use	Percentage Impervious Area
Commercial	56
Industrial	76
High density residential	51
Medium density residential	38
Low density residential	19
Institutional	34
Agricultural	2
Forest	1.9
Open Urban Land	11

Table 2 Amaravati City land use/ land cover types and percentage of each land use / land cover area.

Land Use / Land Cover Type	Percentage Area
Agriculture	59.89
Water	1.64
Pasture	10.64
Built-Up	12.66
Forest	15.16

The comparable imperious area as per the SWMM handbook is obtained as mentioned below, which is 9.52%, from the above tables reference on (i). SWMM criteria on impervious area as a percentage of each land use, and (ii). Amaravati land use / land cover kinds and their proportions.

Areas that are immune to depression and those that have zero depression are both said to have no depth of depression. For the specified ground slope percentage, Manning's N for pervious and impervious areas is used to compare results with different LID control options that occupy different portions of each sub catchment. Starting with the above 9.52% impervious and no zero depression impervious area, the remaining portion is considered pervious, and evaporation is considered as the monthly average option.
Using the same set of data as previously stated, the model considers evaporation from temperature as the next NO LID option, with 9.52% impermeable and no zero depression impervious area, and the rest area as pervious area.
100% impermeable and 100% zero depression impervious area is another NO LID option that was taken into consideration for modelling. Runoff results are found by taking into account bio-retention cells as a LID control option for a portion of each sub catchment area with multiple units. By adjusting the bio-retention cell's occupied area, the best outcomes with the LID option are achieved. Even in cases where there is no depression area, the remaining portion of each sub-catchment is represented as impervious.

RESULTS & ANALYSIS

Total Peak Runoff from No LID [with 9.52% Impervious Area, zero percentage Zero Depression

Impervious Area and Evaporation from Monthly averages] Option = 207.17 m^3/s

Table 3 Comparison of various LID Control Options for Runoff Reduction

LID Control Option	Description of LID Control Option	Total Peak Runoff [m^3/s]	Percentage of total runoff reduction w.r.to NO LID Option (1)
No LID	with 100% Impervious Area, 100% Zero Depression Impervious Area, Evaporation from Monthly Averages	207.88	-0.34
Bio-Retention Cell	with 90% Impervious Area, 90% Zero Depression Impervious Area, Bio-Retention Cell for 10% Area	172.13	16.91
Infiltration Trench	With 50% Impervious Area, 50% Zero Depression Impervious Area and 50% Area with Infiltration Trench	3.52	98.30
Permeable Pavement	With 90% Impervious Area, 90% Zero Depression Impervious Area and 10% Area with Permeable Pavement	169.74	18.07
Rain Barrel	With 50% Impervious Area, 50% Zero Depression Impervious Area and 50% Area with Rain Barrel	176.24	14.93
Rain Garden	With 50% Impervious Area, 50% Zero Depression Impervious Area and 50% Area with Rain Garden	131.32	36.61
Vegetative Swale	With 50% Impervious Area, 50% Zero Depression Impervious Area and 50% Area with Vegetative Swale	133.29	35.66

For alternative LID options, like infiltration trenches, rain gardens, permeable pavement, rain barrels, and vegetative swales, the same process is used as for bio-retention cell LIDs. A comparison is made between the total peak runoff outcomes from several LID control options and that from a specific No LID option.

SWMM Model Calibration and Validation

Following table gives observed precipitation data over various areas and from various sources which are used for further calibration purpose.

Table 4 Observed Precipitation Data

S.No.	Area	Time Period	Precipitation, mm	Source
1	Proposed Amaravati City	From 01-Jan-1982 to 28-Feb-1989	5286.78	IMD, Gannavaram Station
2	Mangalagiri mandal	From 01-Mar-1989 to 31-Jul-2014	27552.30	AP CRDA / AMRDA
3	Tulluru mandal	From 01-Mar-1989 to 31-Jul-2014	24327.06	AP CRDA / AMRDA

Table 5 NSE Check for Total Runoff

Sub basin	Total Precipitation from SWMM Model, mm	SWMM Simulated Total Runoff, mm	Total Precipitation from Observed data, mm	Runoff Coefficient from SWMM Model	Observed Total Runoff, mm
1	53085.09	33859.21	53172.88	0.638	33924.30
2	53085.09	34225.42	53172.88	0.645	34296.51
3	53085.09	33766.53	53172.88	0.636	33817.95
4	53085.09	34123.38	53172.88	0.643	34190.16
5	53085.09	33796.69	53172.88	0.637	33871.12
6	53085.09	33963.58	53172.88	0.640	34030.64
7	53085.09	34690.56	53172.88	0.653	34721.89
8	53085.09	33940.30	53172.88	0.639	33977.47
9	53085.09	33803.52	53172.88	0.637	33871.12
10	53085.09	33778.27	53172.88	0.636	33817.95
11	53085.09	33430.33	53172.88	0.630	33498.91

Thus, Nash-Sutcliffe Efficiency for Total Runoff, NSE = 0.96

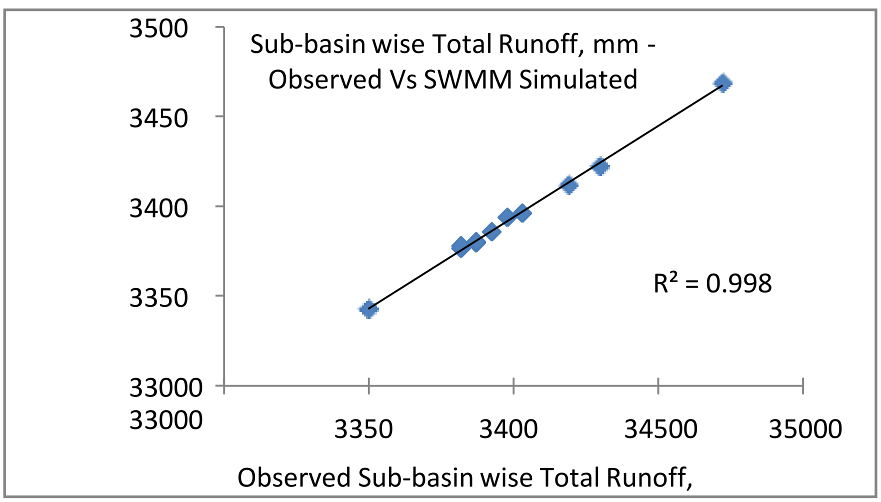

Figure 2 Sub-basin wise Total Runoff, mm - Observed Vs SWMM Simulated

Table 6 Mandal wise Maximum Daily Rainfall(Source: AP CRDA/AMRDA)

S.No.	Name of Mandal	Maximum daily rainfall, mm/day
1	Mangalagiri	203.00
2	Tulluru	183.00

Percentage change in maximum precipitation over two mandals = 9.85%

Thus, adopting the above percentage change as percentage increase for maximum precipitation to account for *uncertainties and calibration purpose,* Considering, maximum precipitation from Mangalagiri mandal = 203.00 x 1.0985 = 223.00 mm/day.

Table 7 NSE Check for Peak Runoff

Sub-basin	Sub-basin Area, km^2	Peak Runoff from SWMM Model, m^3/s	Peak Runoff Coefficient from SWAT Model	Peak Runoff from observed maximum precipitation, m^3/s
1	2.222	6.39	0.87	4.99
2	17.470	50.41	0.95	42.65
3	1.729	4.97	0.90	4.01
4	14.880	42.77	0.85	32.58
5	11.870	34.12	0.94	28.67
6	1.773	5.10	0.89	4.09
7	5.346	15.36	0.94	13.03
8	8.446	24.28	0.94	20.42
9	2.754	7.92	0.94	6.70
10	1.957	5.63	0.92	4.64
11	3.565	10.22	0.78	7.16

Thus, Nash-Sutcliffe Efficiency for Peak Runoff, NSE = 0.877

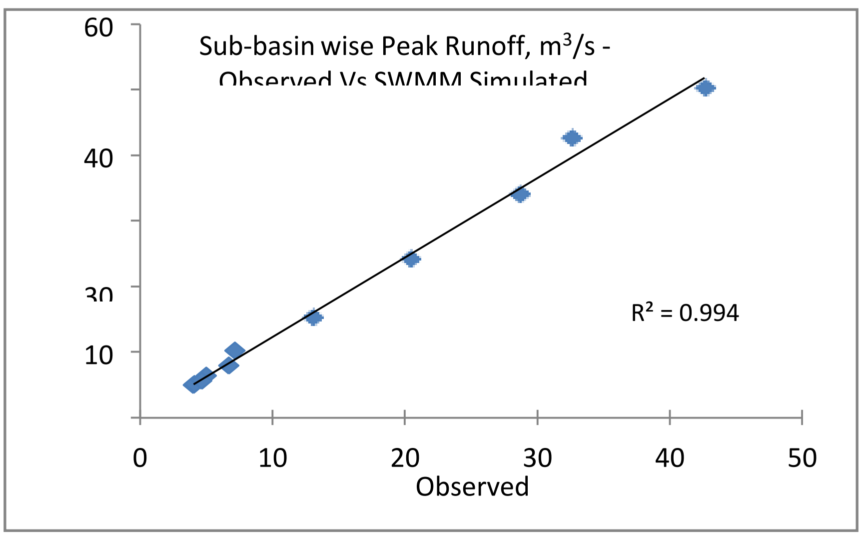

Figure 3 Sub-basin wise Peak Runoff, m^3/s - Observed Vs SWMM Simulated

Table 8 Validation Table

Type of Runoff	Coefficient of determination, R^2	Nash-Sutcliffe Efficiency, NSE
Total Runoff, mm	0.998	0.960
Peak Runoff, m^3/s	0.994	0.877

Validation results from above Table 8 affirm that observed and SWMM simulated runoff results are in very good agreement for the considered study area i.e. proposed Amaravati city of Andhra Pradesh.

CONCLUSIONS

From the above results obtained of various hydrological and field scenarios i.e., No LID and LID control options which are also Best Management Practices [BMPs], number of conclusions can be drawn. Following are the key conclusions. According to monthly averages, the NO LID option is 9.52% impervious, 0% zero depression impervious, and evaporative.With reference to the NO LID option previously mentioned , total peak runoff decreased slightly in other NO LID options such as (i) with 9.52% impervious, zero percent Zero Depression Impervious Area, and (ii) with 100% impervious, 100% Zero Depression Impervious Area, and Evaporation from temperature.

When comparing the following LID control options to the previously described NO LID option, a significant reduction in total peak runoff from the entire watershed can be achieved.

i. with 50% Impervious Area, 50% Zero Depression Impervious Area, Bio-Retention Cell for 50% Area - Percentage of total peak runoff reduction is 97.45 %
ii. With 50% Impervious Area, 50% Zero Depression Area and 50% Area with InfiltrationTrench - Percentage of total peak runoff reduction is 98.30 %
iii. With 50% Impervious Area, 50% Zero Depression Impervious Area and 50% Area with RainGarden - Percentage of total peak runoff reduction is 36.61 %
iv. With 50% Impervious Area, 50% Zero Depression Impervious Area and 50% Area withVegetative Swale - Percentage of total peak runoff reduction is 35.66 %
v. There may be numerous LID control options providing for certain part of each sub-catchment area which may attain slight to substantial total peak runoff reduction with reference to No LID option as mentioned in option (1) above.
vi. Weighted mean method and importance factor is adopted for calibration purpose.
vii. Coefficient of determination, R^2 and Nash-Sutcliffe Efficiency, NSE values confirm thatobserved and SWMM simulated runoff results are in very good agreement

Therefore, it is evident from the above described results and conclusions that various LID limitations and BMP options can significantly lower total runoff and total peak runoff, even for a section of each sub-catchment area. The hydrologic cycle parameters, including runoff, for the proposed Amaravati city have produced important and helpful results. Through the provision of efficient storm water management practises and/or measures, these will allow the proposed smart city to be implemented as a water-sensitive city for an extended length of time.

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