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Regional Flood Forecasting using SWMM for Urban Catchment

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Abstract: ***Urban flooding is the inundation of land or property in a designed atmosphere, significantly in additional densely inhabited areas, caused by precipitation overwhelming the capability of drain systems, like storm sewers. Due to expeditious increment and improper urban designing the probabilities of creek, localized or flash urban floods have drastically multiplied. This study explores the application of Storm Water Management Model (SWMM) to densely populated area of Vijayawada city, which is fragmented into 58 sub-catchments. The study area is delineated in SWMM by the assistance of blueprint AutoCAD maps showing drainage network and Reference Level details. From this elaborated elevation data of drain networks, the flow direction has been evaluated to create the descriptive view of the area in SWMM. In this study area 2016, 2017 and 2018 extreme rainfall events of 24 hrs interval is considered for runoff analysis. The focus of the current wok is to model runoff conditions by applying Dynamic wave equation for routing floods and Green-Ampt equation for infiltration in SWMM. The model outputs guided in visualizing the runoff from extreme precipitation events and to analyze the accuracy of the storm water network system.***

Keywords: ***AutoCAD, Flash Floods, Sub catchments, SWMM, Reduced levels, Green-Ampt infiltration model, Dynamic wave.***

I. INTRODUCTION

India is highly vulnerable to various natural disasters such as, Floods, Cyclones, Droughts, Landslides, etc. Among which flooding situation is very much disastrous as it can cause widespread loss of life and property. Mostly the regions occupying Haryana, North Bihar, West Bengal and some portions of Uttar Pradesh along with coastal belt regions of Andhra Pradesh, Gujarat and Orissa are predominantly affected by floods. The districts of Krishna, Guntur(Krishna river), West and East Godavari (Godavari river) along with cities and towns like Vijayawada, Guntur (Krishna river), Eluru, Machilipatnam, Bhimavaram, Rajahmundry, Kakinada(Godavari river) and some parts of Nellore(Penna river) on the east coast has been marked as Flood hazard zones map issued by National Disaster Management Authority (NDMA).In this study, we have considered the area of densely populated area of Vijayawada city, Andhra Pradesh. Primarily flooding may be considered as a natural phenomenon which has some added benefits but due to human interventions in the flood plain region it is causing tremendous devastation to the livelihood of people [1].

In the past four decades the town because of its increasing population has converted into the flood plains. Flooding is common within the city. Urban flooding leads to insufficient carrying capacity of storm drains, blockages of storm drain due to solid waste, which results in increment of the flood peak from 1.8 to 8 times and volume of flood approximately 6 times. More often it is observed that Urban flooding is occurring very rapidly within the range of few minutes due to the faster flowtimes [2]. Construction of Pavements, Roads, Parking Lots, Houses increases the impervious cover and reduce the infiltration, it is the main cause of the urban floods. Due to the coverage of land features with impervious surfaces chances of conversion of precipitation to runoff increased to manifolds. Unplanned development and encroachments of sprawling habitations aboard rivers and watercourses have meddled with the natural streams and watercourses. Hence, the runoff increased in proportion with respect to Urbanization causing Urban Floods. Thus, urban flood management of should be considered with top priority.

Different models are developed for estimation of Urban runoff like Mike Urban, Mike Flood, Hydrologic Engineering Centers-River Analysis System (HEC-RAS), among which EPA-SWMM is given by Environmental Protection Agency. In case of MIKE URBAN model, the two-dimensional flow routing can be done during an extreme rainfall event occurring in short period which results in the flooding of drainage [3]. To control flooding situations Storm Management is done by diverting the flow of excess water. These techniques helps in attaining sustainable development without increasing the vulnerability to flood [4].

The Land Surface that is delineated through Sub catchments. It is getting precipitation from the Atmosphere within the sort of rainfall and it sends outflow within the kind of infiltration to the bottom levels and additionally as surface runoff and waste material loadings to the Transportation. The Transportation contains a network of conveyance elements like channels, pipes, pumps, and regulators. Inflows to the current compartment will return from surface runoff.

Inflows to the current compartment will return from surface runoff. The elements of the Transportation area unit sculptured with Nodes, Junctions, Outfalls, storage/treatment units, Links, conduits, pumps, outlets. Rain Gages provide precipitation information for sub catchment areas in an exceedingly study region. The area is divided into various Sub catchments into permeable and imperviable sub catchments. The Surface runoff is infiltrating mainly to higher soil root zone depth of the surfaces which are permeable in nature instead of area which is impervious.

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The impervious area is further divided into two units mainly one with depression storage and another lacking that. Runoff can be due to one sub catchment area during a rainfall event will be routed to the another subarea, or each subarea will drain to the sub catchment outlet.

As per Florida Department of Environmental Protection (FDEP), the rainfall occurring in pervious area there will contribute to average evaporation of 50%, surface runoff entering to nearby water bodies as 30% and nearly 20% will undergo infiltrate and contribute as Ground water reserve [5]. Infiltration of precipitation from the permeable space of a sub catchment into the unsaturated higher soil zone is represented exploitation four completely different models: Horton infiltration, modified Horton infiltration, Green-Ampt infiltration, modified Green-Ampt infiltration and Curve number infiltration. Flow routing contains three methods for the discharge of runoff Steady Flow, Kinematic Wave, Dynamic wave [6]. The present study is mainly focusing on runoff through Urban sub catchments of Vijayawada City, Andhra Pradesh, India where the excess runoff is a major concern to the environment due to dense population [7].

II. STUDY AREA

The study area is lying between 16.50 N Latitude and 80.64 E Longitude of Krishna district in A.P. having geographical spread area of 62 Sq. Km. The town is that the second largest city within the state by population and third most densely inhabited urban settled areas within the world. Vijayawada city is lying at the top of the Krishna delta which is nearly 70 km away from ocean and encircled by Indrakiladri Hills on the west while Budameru stream on the north. The land of town of Vijayawada is regarding thirty-nine feet on top of the ocean level. Majorly three Canals namely Ryves, Eluru and Bandar is incepting from reservoir beneath Prakasam barrage.

Topography:

It is the most crucial feature of Geographic landscape of Vijayawada city. It is mainly dominated by undulating hillocks which are tiny and medium sized and comprised of intensive plain lands between them.

Climatology:

The city is having Tropical type of Climate having hot summers & moderate winters. The temperature rising to 47 °C in June, while winter temperature is ranging from 20 to 27 °C. The climate of Vijayawada is also marked by a considerable amount of rain fall. The common humidity is 78% and also the average annual rain fall is 103 cm. Vijayawada gets its rainfall from each the south- west monsoon and north-east monsoon. Cyclones are also pretty common in the Vijayawada climate. The location map of Vijayawada is shown in Fig. 2 shows boundaries of the study space that shows landform is undulating that is appropriate for investigation and finding out.

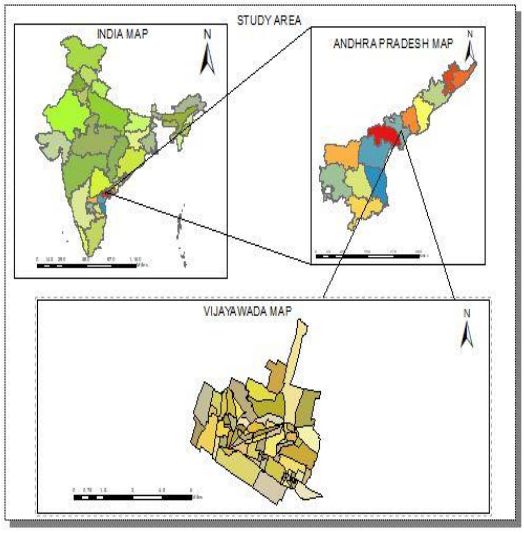


Fig – 1 Study area representation as ARC-GIS map

III. DATA REQUIREMENTS

The base map of Vijayawada has been collected from the Andhra Pradesh Township and Infrastructure Development corporation (APTIDCO). Strom Water Network data of Vijayawada has been collected form Vijayawada Municipal corporation (VMC). Daily Rainfall data of 2016, 2017, 2018 has been collected from Andhra Pradesh State Disaster Management Authority (APSDMA). Sentinel data has been downloaded from United States Geological Survey (USGS) for making LULC map of the area.

IV. METHODOLOGY

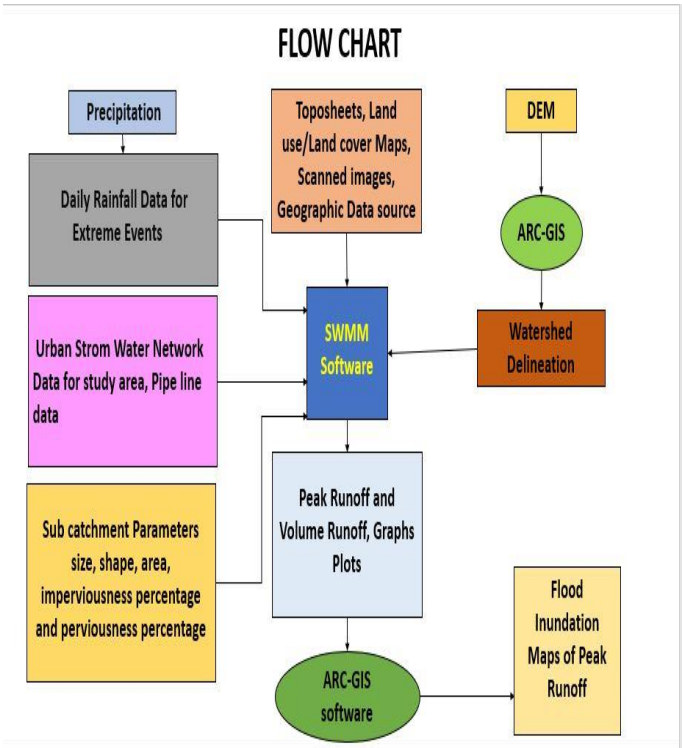


Fig - 2 Flowchart of process in SWMM

Above Flowchart represent the inputs and process of SWMM model. By the collection of AUTOCAD map of study area the sub catchments are extracted and imported to SWMM by converting base map to image file. Then numerous Junctions are added to the sub catchments and then various Conduits are added to join these Junctions. Various input parameters like Invert levels, Depth, Slope, Imperviousness, Area, roughness etc. are defined in the model. The Model building method in SWMM involves series of operations in varied range of datasets that is being described by Fig -2. In SWMM each sub catchments Invert levels and depth are given according to the storm water network map of Vijayawada city.

The imperviousness and slope of particular sub catchments are given according to the preparation of Land use Land cover map which was prepared from Sentinel data. This data is used to develop LULC and slope map of the region. Area of each sub catchments has been given according to the measurement option provided in SWMM itself. Daily Rainfall data of 2016, 2017, 2018 has been analyzed and given input to the rain gauge section of the model. The study area is represented in SWMM as in the below Fig – 3 layout of study area in SWMM. Thus, schematic illustration of the study space is well defined in SWMM with all elements to model Urban Flood. Model output is portrayed by statistic, Profile & Scatter Plots.

Table-1 Manning's n – Overland Flow

Surface	n
Smooth asphalt	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Brick with cement mortar	0.014
Vitrified clay	0.015
Cast iron	0.015
Corrugated metal pipes	0.024
Cement rubble surface	0.024
Fallow soils (no residue)	0.05
Cultivated soils	
Residue cover < 20%	0.06
Residue cover > 20%	0.17
Range (natural)	0.13
Grass	
Short, prairie	0.15
Dense	0.24
Bermuda grass	0.41
Woods	
Light underbrush	0.40
Dense underbrush	0.80

Source: McCuen, R. et al. (1996), Hydrology, FHWA-SA96-067, Federal Highway Administration, Washington, DC.

This **Table-1** represents the N-pervious and impervious values depending on the land type as mentioned. According to the Standard values the Manning's constant is defined in the model for different land classes. Further sub catchment discretization task is done in SWMM to represent each individual sub catchments. The runoff generated through each sub catchments has been routed to various nodes which are spatially configured in the model. Numerous links are used to connect these nodes to route the flow to various outlets which are lying at lowermost elevation of the area. The flow occurring through this conduit are governed by Gravity forces from higher to lower levels.

Fig -3 Layout of study area in SWMM

A. MODEL SETUP

The entire geographical study area of Vijayawada has been fragmented into 58 sub catchments and Nodes which are 76 in number for whole study area which connects to the conduits total 75 and further they are connected to the 8 outlets to discharge the runoff. The runoff percolates from each individual sub catchments to the nodes and discharge to outlets through the conduits. Extreme precipitation events of 2016, 2017 and 2018 has been taken as inputs to run the model in SWMM. For the infiltration Modified Green-Ampt method has been applied and simultaneously for flow routing Dynamic wave method has been applied for analysis of surface runoff from various sub catchments.

V. RESULT AND DISCUSSION

It has been visualized that SWMM has moderately computed runoff for 3 years i.e 2016, 2017 and 2018 extreme precipitation events. The runoff which is generated from the sub catchments has been plotted in the form of graphs for different rainfall events as represented in the Fig-4, 5 and 6 respectively. It is ascertained that the SWMM has generated the peak runoff for the three totally different extreme precipitation events of 2016, 2017 and 2018 rainfall events.

These graphs helps in understanding the precipitation relationship for Runoff of each sub catchments with reference to numerous precipitation events in impervious and permeable surface runoff.

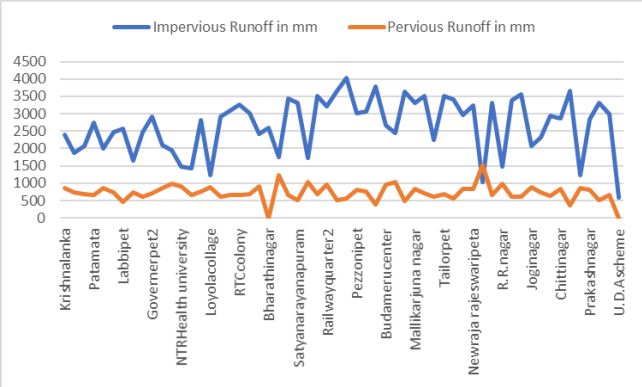
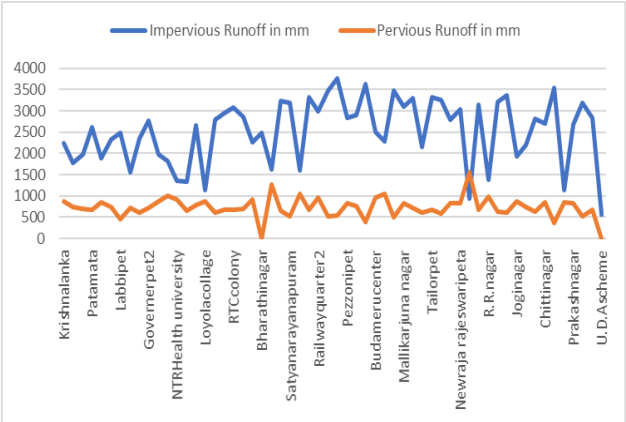


Fig-4 Runoff from Impervious Vs Pervious area for 2016 rainfall events

This graph of **Fig-4** represents the relationship of the impervious runoff and pervious runoff which is obtained from the sub - catchments for the extreme precipitation events of the year 2016.



Fig–5 Runoff from Impervious Vs Pervious area for 2017 rainfall events.

This graph of **Fig-5** represents the relationship of the impervious runoff and pervious runoff which is obtained from the sub - catchments of the study area for the extreme precipitation events of the year 2017.

Table -2 Outfall Loading

Outfall	*Flow freq. %*	*Avg Flow CMS*	*Max Flow CMS*	*Total Volume 10^6 ltr*
59	99.94	1.363	1.377	3413.672
72	99.92	2.11	2.138	5285.747
73	99.9	1.579	1.602	3954.254
74	99.94	2.382	2.437	5972.91
77	99.95	2.46	2.505	6166.223
78	99.93	1.783	1.823	4470.132
84	99.91	0.963	0.991	2416.05
88	99.86	2.16	2.196	5408.664

This **Table - 2** represents the different outfalls showing flow frequency in percentage, average flow in CMS, Max Flow in CMS and also Total Volume in litres which the SWMM produced from the extreme rainfall event of the year 2018.

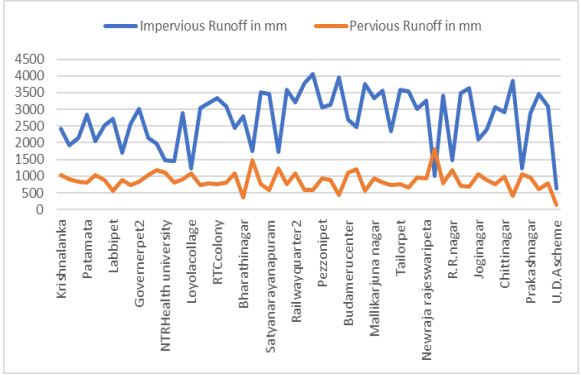


Fig-6 Runoff from Impervious Vs Pervious area for 2018 rainfall events.

This graph of **Fig-6** represents the relationship of the impervious runoff and pervious runoff which is obtained from the sub catchments of the study area for the extreme precipitation events of the year 2018.

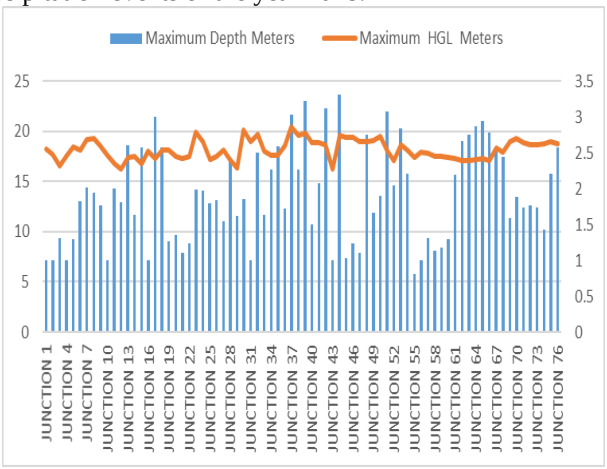


Fig-7 Maximum depth Vs Maximum HGL (Node Depth)

This graph of **Fig-7** represents the relationship of the maximum depth and maximum HGL in meters which represents Hydraulic Gradient Line.

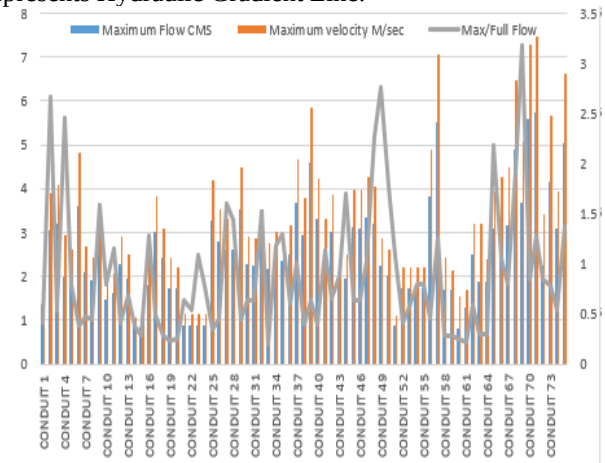


Fig-8 Variability of Maximum Flow, Velocity and Full Flow

This graph of Fig-8 represents the relationship of the Maximum Flow in CMS, Maximum Velocity in m/sec and Max/Full Flow.

VI. CONCLUSION

The case study work out the present analysis of runoff for the densely populated area of Vijayawada which has been proven that SWMM is compatible for modeling and management of Urban flood conditions. It is an appropriate tool for modeling Urban Flood situations and regarded terribly user friendly because of its result interpretation techniques within the type of Graphs, statistical plots, tables etc. Various input parameters like impermeability and penetrability of a locality together with coefficient of roughness will adhere dynamism capability in densely populated area. The impermeability and penetrability are given relevantly consistent with the land use land cover map prepared with the sentinel information and therefore the roughness coefficients and regarded consistent with the literature review as described within the Table-1 Manning's n – Overland Flow. The result is generated from the three extreme daily precipitation events during 2016, 2017 and 2018, thus, the graphs are also plotted accordingly. As per the suitability of the technique to compute impervious and pervious cover of an urban area the results of the model will be more reliable. Presently appropriate values of Imperviousness and Slope of the subcatchments have considered by preparing the land use land cover and slope map from recent data. The results obtained from the model is mainly the peak runoff, volume of runoff, Impervious/Pervious surface runoff, Maximum depth & HGL, Maximum Flow velocity, Flow Frequency, Average Flow and Total Volume of runoff from each Sub catchments.

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