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Urban Flood Modelling and Management using Storm Water Management Model

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Abstract:
Urban areas are the major hotspots for the origination of floods. Occupying the surfaces with various impervious surface features there is an opportunity of changeover of rainfall to runoff which results in flooding. Variations of atmospheric changes is also a crucial factor for precipitation events in unusual times that outcomes in rising flood peaks. Volume of runoff from the investigation area is assessed by adopting Storm Water Management Model (SWMM). The major purpose of utilizing SWMM is to monitor the quality along with quantity of overflow originating from the sub catchments. This study is to illustrate the flooding situations for the urban area for historical utmost intense precipitation event as well as future intense rainfall situations. Flooding conditions of future is assessed by using RCP 4.5 NOAA-GFDL-ESM2M climate model downscaled data. Infiltration and Flow routing are the two essential aspects of SWMM. Modified Green-Ampt method is used for the infiltration while Dynamic Wave method is chosen for Flow Routing. SWMM outcomes are demonstrated in the form of graphs, tables which helps in understanding the overflow section and nodes.

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I. INTRODUCTION

More than one million population living in 500 major cities across the world which is directly contributing to Urbanization. Due to various anthropogenic activities of human beings the Urban Hydrology gets disturbed causing Urban Heat island effect [1, 2]. This results in high intensity rainfall in a localized area provoking flooding situation. Due to inadequate drainage channels and climate change, Urban planners are facing severe challenges of Urban Flooding. In India 48 million ha of total geographical area is vulnerable to floods which causes great loss of life and property [3,4]. In July 2005, Mumbai floods occurred due to extreme rainfall events and poor stormwater management. Improper planning to cater high rainfall events coupled with human intervention leads to Uttarakhand flood during July 2013 [5,6]. Similar floods occurred in Guwahati 2010, Delhi 2009, Kolkata 2007, Chennai 2004, Hyderabad 2000 etc. Overflowing of Krishna river due to excessive rainfall during monsoon has affected the people living in flood plain areas. Severe rainfall event due to Cyclonic depression or during cloud burst conditions has affected parts of Krishna river basin [7,8]. This enhances reservoirs water level and thus, forcing jurisdiction to release excess water to the downstream side causing floods. Major reason of flooding is human encroachment in flood plain areas due to poor planning and code enforcement. Generally flooding is considered as natural event having added assistance but due to human interventions it is demolishing livelihood of people [9,10]. These events may occur in many ways like overflowing of rivers, lakes, streams etc. during unprecedented rainfall events. The nuisance caused by floods in major cities are proving hazardous to environment and society. Indian cities are encountering large scale obstacle every year because of intense and extensive flooding events [11,12]. Flooding prevails in urban area due to deficiency in storm water carrying capacity of drains and disposal of solid waste. LULC change like vegetation removal, perviousness changes reduced infiltration and increases peak of runoff and volume. [13, 14] have identified some urbanization effects like increasing conversion of rainfall to runoff, steeper flow Hydrograph rising limb, lag time reduction and time to peak. To model Urban storm water network various software tools like SWMM, Mike Urban, HEC-HMS etc. can be used [15]. These can be used to analyse catchment responses to single event or on continuous basis. In present study SWMM is setup for Vijayawada area to model Urban catchments for flooding using extreme rainfall events for historical and future RCP 4.5 scenario.

II. STUDY AREA

The study area is Vijayawada city which lies along the banks of river Krishna, A.P. India. It is a municipal corporation which forms major part of Andhra Pradesh Capital region. Vijayawada is the main business center of Krishna district with a good number of Offices, Institutional, regional, district and Mandal level offices of the state government. Now, Chief Minister Office is in Vijayawada and entire administrative setup within the City. The city population is second in the state and is lying above Krishna delta. It is 71 km away from Ocean and surrounded by Indrakiladri Hills from west and Budameru river from north. It is situated 39 ft above mean sea level and located at 16°31' N & 80° 37' E as shown in Fig- 1.

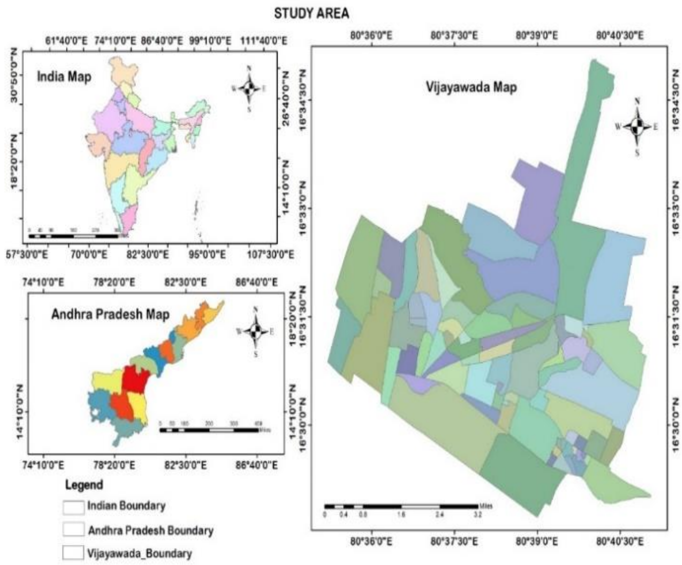

Fig 1: Study area map

- **Topography and Geography:**

It is one of the important characteristics of the area as it gives vital information about the land feature. The present study area is flat and having small and medium size hills. These hills are located at north western and south western part of the region which are fertile agricultural land. The area is having slope from west to north east and south of river Krishna towards north. The geographical area of the city is 61 km^2 having 110 slums with 3 Lakhs population.

- **Climate and Rainfall:**

The rainfall occurring in the region is 965 mm annually from North-East & South–West Monsoons. Major portion of precipitation is generating from south west monsoon during June to September month which is nearly 30 % of total precipitation. The temperature in the region is ranging from 28°C during winter (December, January and February) to 45°C in summer (April, May, June). In winters the temperature may drop from 27°C to 20°C during night.

III. DATA REQUIREMENTS

For setting the model, base map of the study area is gathered from APTIDCO (Andhra Pradesh

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Township and Infrastructure Development Corporation) to discretize the sub catchments. To plot the Junctions (or) Nodes and conduits for sub catchments the Reduced levels of the study area is identified using AutoCAD master plan of the region. Vijayawada storm water network drainage data is collected from VMC (Vijayawada Municipal Corporation). The data of extreme rainfall events for historical and future is taken from APSDPS (Andhra Pradesh State Development Planning Society). For making of Land use and Land Cover maps the Sentinel data of 2019 and Landsat 8 data of 2009, 2010, 2011 is downloaded from USGS (United States Geological Survey).

IV. METHODOLOGY

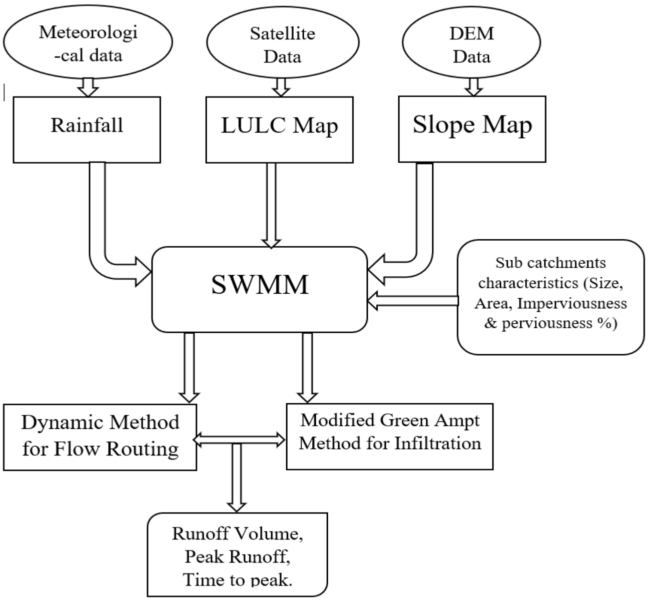

Fig-2 SWMM working model

The above flow chart in Fig- 2 expresses the SWMM working process. The model operates by various input parameters like precipitation data, Land use Land cover map, Slope map. The precipitation data is sorted for the uttermost rainfall events. The LULC map is used to estimate the imperviousness percentage along with perviousness surface percentage which are one of the most crucial parameters. Slope map is achieved by the DEM (Digital Elevation Model) for the assessment of slope percentage to the SWMM model. Along with sub catchment characteristics like Width, Area, Length etc. are measured by the base map of area in AutoCAD.

Fig 3: Discretization of sub catchments in SWMM.

The above Fig -3 model expressing the discretization of sub catchments in SWMM. The sub catchments of the study area are divided into various zones. For these sub catchments numerous junctions are added according to the Reduced Levels of area. Storm water network and conduits are also added to connect these junctions to the outlets for the discharge of the storm water.

- **Computational methods adopted in SWMM:**

To model surface runoff, continuity equation is used to analyse water depth in sub catchments with respect to time.

$$\frac{dV}{dt} = \frac{d(A.d)}{dt} = A.i_e - Q$$

where, V = Volume of water in a sub catchment.

D = Water depth in the catchment.

A = Watershed area.

i_e = Rainfall intensity.

Q = Discharge.

Manning’s equation is used to compute surface runoff through the catchment;

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$$Q = \frac{A_c R_h^{2/3} S_o^{1/2}}{n}$$

Where, A_c= Area of flow through a cross-sectional.
R_h= Hydraulic radius.
n= Rugosity coefficient.
S_o= slope of the channel.

Saint Venant equation is used to route flow in the channel which is a function of space and time as given below;

$$\frac{1}{A}\frac{\partial Q}{\partial t} + \frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + g\frac{\partial y}{\partial x} - g(S_o - S_f) = 0$$

Where, X = distance along conduit
S_f = Frictional slope.
S_o = Slope of bed.

Horton equation is used to determine infiltration from the catchment which depends upon various observation. It illustrates that when intensity of rainfall exceeding the maximum rate of infiltration then it decreases exponentially for a prolonged rainfall event. It is represented by following mathematical expression;

$$f_t = f_c + (f_o - f_c)e^{kt}$$

where, f_t= Infiltration rate.
f_c= Minimum rate of infiltration.
f_o= Initial rate of infiltration.
k = Coefficient of decay.

Land use Land cover map:

For making land use and land cover map of study area, Sentinel data is accumulated from the "USGS" (United States Geological Survey) for the years 2019 and Landsat-8 images is been downloaded for 2009, 2010 and 2011. By processing of these images and interpretation to development of land use and land cover map in ARC-GIS is prepared. The resultant maps are investigated and figure out to recognize the change in urban expansion of populated area and Land use pattern.

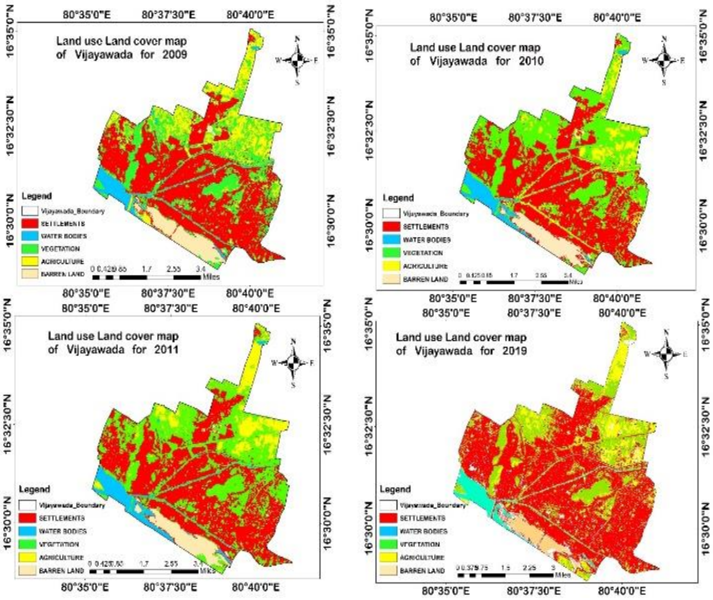

Fig 4. Land Use and Land Cover Map

The images obtained by processing the pictures in supervised classification gives the knowledge about the land use and land cover of the study area required as input for SWMM. The red color expressing the urban Settlements area which are towns and cities, Green color represents the Vegetation, Yellow color expressing the Agriculture Land, Blue color expressing the Water Bodies, Tan color expressing the Barren Land. As compared to 2019 map there is a lot of urban area which are extensively grown up and decreases in vegetative and agricultural land.

Slope map:

For the preparation of slope map the DEM image is acquired from USGS server and analyzed in ARC-GIS 10.2 using the surface tool and finally slope classification map is prepared. The main aim to prepare the slope maps is to prepare major input parameters to setup SWMM for the study area. Slope is an estimation of steepness of ground surface which guides the flow direction. Rise of Remote detecting and GIS frameworks and the accessibility of topographic information in DEM or TIN groups, slope maps can be created utilizing image processing and GIS techniques. It is one of the GIS layers that assume a significant job in the Natural Resources

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and furthermore City construction process. It is required to produce the important slope layer structure that requires accessible computerized topographic information, for example, Carto DEM and open source Digital Elevation Model information. The slope produced from GIS examination can be utilized legitimately for any dynamic arranging reason. The suitability of slope is subject to precision of the DEM utilized for slope generation.

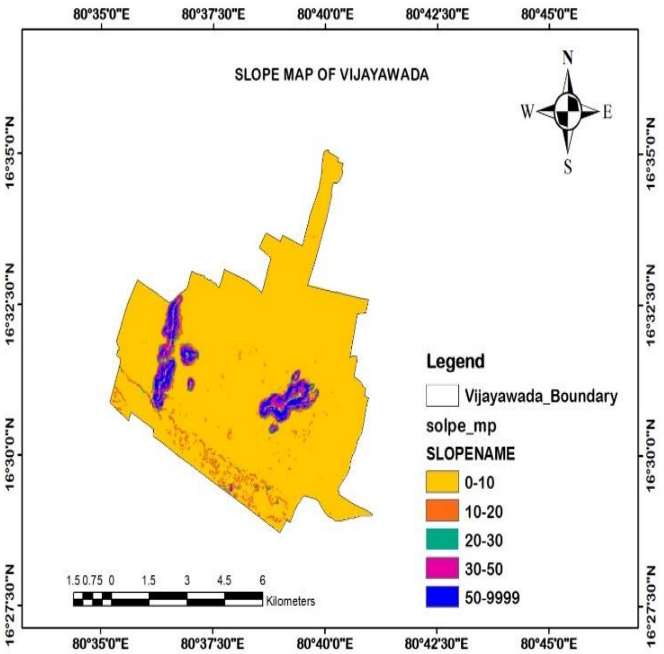

Fig 5. Slope Map of study area

The DEM shows an uncovered earth which do not have spikes or dips which are basic in programmed DEM generation. Hence, to utilize Carto DEM, change to uncovered earth DEM must be completed before slope layer generation. The Fig – 5 represents the slope map of the study area i.e., Vijayawada city. The yellow colour represents the very Gentle slope category which ranges fr0m 0-10 meters. Then the second category is Gentle slope which is represented in orange colour that ranges from 10 to 20 meters. Then the third category comes under very Moderately Steep slope which is represented in light Teal color that ranges from 20 to 30 meters. Then the fourth category is Moderately Steep slope which is shown in the purple color which ranges from 30 to 50 meters. Then comes the final classification of the slope map that is categorized as the Steep slope which is represented in the colour of dark blue and it range from 50 to 9999 meters. Hence, the study area is studied for slope which depicts that almost very Gentle slope is dominating the area as compared to the other classification.

Storm Water Management Model:

SWMM is a one-dimensional precipitation runoff simulation tool used to evaluate stormwater runoff and adequacy of drainage system. This model functions on collection of surface runoff from various sub catchments through extreme rainfall events. The routing of runoff is done through channels, pipes, pumps, treatment processors etc. The main objective of modeling is to monitor the quality along with quantity of overflow originating from the sub catchments. This is also widely used in planning, design, analysis, forecast similar to runoff, sanitary sewage, combined sewers and various sewage systems. At present EPA SWMM 5.1 is used in simulation. The SWMM model runs in two aspects that is referred as Infiltration and Flow routing. In Infiltration Process the Modified Green-Ampt method has been followed along with Flow routing is followed by Dynamic wave method. Results are achieved in the form of Total volume of runoff, Peak runoff and Graphs. For Infiltration SWMM provides various methods like Horton, Modified Horton, Green Ampt, Modified Green Ampt, Curve Number. For the Flow Routing SWMM basically provides three methods viz. Steady Flow Routing, Kinematic Wave Flow Routing and Dynamic Wave Flow Routing.

V. RESULTS AND DISCUSSION

The SWMM is used to produced runoff for the historical utmost rainfall event of 2017 hourly interval data along with 2026 daily data of future precipitation events of RCP 4.5 scenario. The total infiltration, total runoff, peak runoff, average depth, maximum depth, maximum HGL (Hydraulic Gradient line), maximum flow, maximum velocity and outfall loadings are figured out from the

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SWMM. The results shown will guide us in understanding the runoff from the sub catchments of historical precipitation events along with to predict the future flooding conditions.

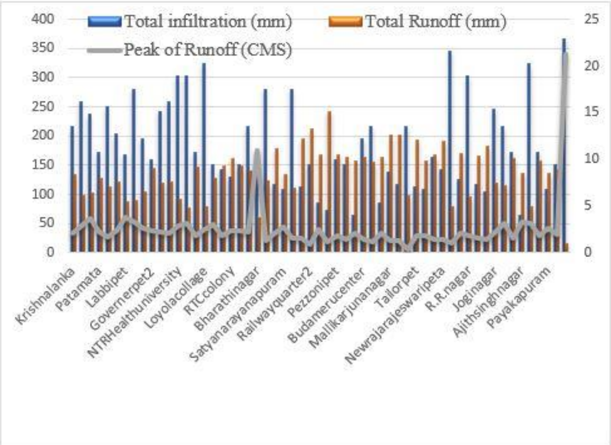

Fig 6. Total Infiltration Vs Total Runoff Vs Peak Runoff for 2017

The above visual representation of Fig 6. expressing the relationship about the Total Infiltration in mm and Total Runoff in mm and Peak Runoff which is generated from the sub catchments of the utmost intense rainfall event of year 2017 on hourly basis.

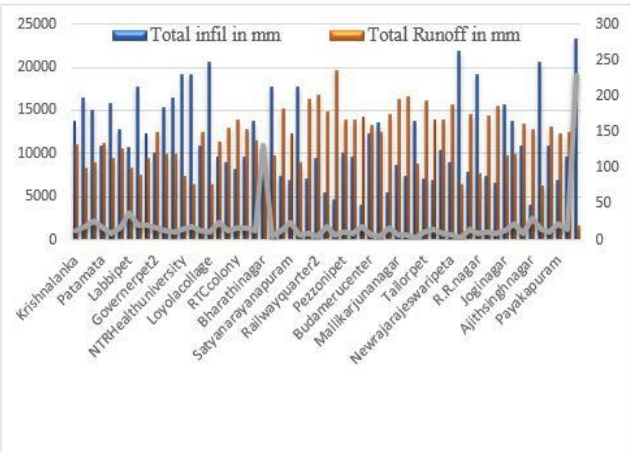

Fig 7. Total Infiltration Vs Total Runoff for 2026

The above visual representation of Fig 7. expressing the relationship about the Total Infiltration in mm and Total Runoff in mm which is generated from the sub catchments of the future utmost intense rainfall event of year 2026.

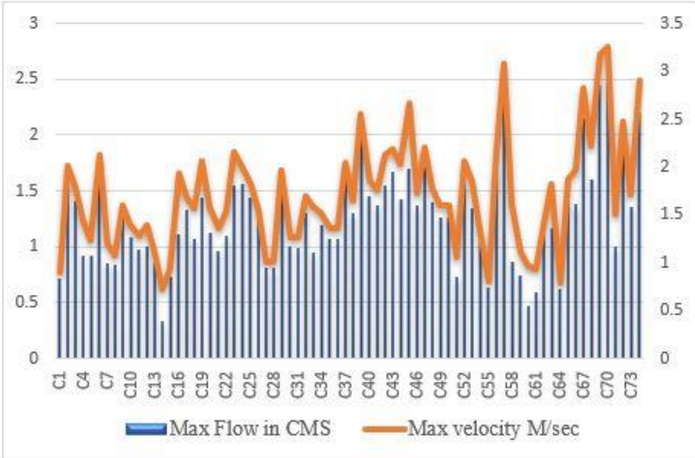

Fig 8. Maximum Flow Vs Maximum Velocity for 2017.

The above visual representation of Fig 8. expressing the relationship about the Maximum Flow in CMS (Cubic Meter Per Second) and Maximum Velocity in M/sec.

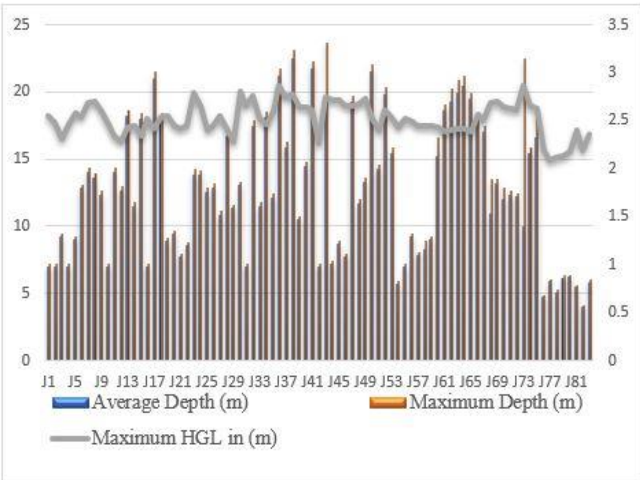

Fig 9. Average Depth Vs Maximum Depth Vs Maximum HGL for 2017.

The above visual representation of Fig 9**.** expressing the relationship about the Average Depth in meters, Maximum depth in meters and Maximum HGL in meters that is (Hydraulic Gradient Line).

The below Table 1. Express the various outlet flows that out come in percentage of flow frequency, Standard flow in CMS that is (Cubic Meter per

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Second), Greatest flow in CMS and also Volume of total runoff in liters.

Table 1. Outlet Flow for 2017

Out-let flow	Flow Freq %	Avg Flow CMS	Max Flow CMS	Total Vol m3
O1	97.7	1.376	1.377	3368.27
O2	97.7	2.136	2.138	5228.97
O3	97.7	1.601	1.602	3918.95
O4	97.7	2.435	2.437	5961.08
O5	97.7	2.503	2.505	6127.05
O6	97.7	1.821	1.823	4457.99
O7	97.7	0.986	0.997	2414.33
O8	97.68	2.083	2.195	5096.97

The below Table 2. Express the various outlet flows that out come in percentage of flow frequency, Standard flow in CMS that is (Cubic Meter per Second), Greatest flow in CMS and also Volume of total runoff in liters.

Table 2. Outlet Flow for 2026

Out let flow	Flow Frequency %	Avg Flow CMS	Max Flow CMS	Total Volume m3
O1	99.98	1.374	1.377	3561.084
O2	99.98	2.132	2.138	5525.232
O3	99.97	1.598	1.602	4140.153
O4	99.98	2.424	2.437	6283.44
O5	99.98	2.495	2.505	6464.851
O6	99.98	1.816	1.823	4705.719
O7	99.97	0.983	0.987	2548.309
O8	99.95	2.187	2.195	5666.636

VI. CONCLUSIONS

The present work describes the flooding situations of urban area for the utmost intense historical precipitation events along with prediction of floods for future extreme events. The dynamic downscaled RCP 4.5 scenario data is tested for the future flooding conditions using SWMM. Historical precipitation data of 2017 is also analyzed for the prior conditions in SWMM. In the establishment and operation of SWMM model slope information, perviousness surface and imperviousness surface data are needed, accordingly Slope map and Land use Land cover maps are prepared. Total runoff volume, Flow Frequency, Average Flow in CMS, Maximum Flow are generated in the form of tables and these Total runoff, Peak runoff were represented in the form of graphs respectively. By these out comes proper planning and investigations of the channels can be maintained therefore, the control and prediction of the floods can be carried out.

REFERENCES

1. S. Agarwal and S. Kumar, "Applicability of SWMM for Semi Urban Catchment Flood modeling using Extreme Rainfall Events," Int. J. Recent Technol. Eng., vol. 8, no. 2, pp. 245–251, 2019.
2. Laddimath, R. S. (2016). Sustainable Development of Storm Water Management using SWMM for Bhagyanagar, Belagavi. 3(02), 488–493.
3. Wanniarachchi, S. S., & Wijesekera, N. T. S. (2012). Using SWMM as a Tool for Floodplain Management in Ungauged Urban Watershed. Engineer: Journal of the Institution of Engineers, Sri Lanka, 45(1).
4. Mugisha, F. (2015). Modelling and assessment of urban flood hazards based on end-user requirements. Kigali-Rwanda. 83.
5. S. M. F. Ahamed and S. Agarwal, "Urban flood modeling and management using SWMM for new R.R. pet region, Vijayawada, India," Int. J. Recent Technol. Eng., vol. 7, no. 6C2, pp. 317–322, 2019.
6. Surwase, T., & Manjusree, P. (2019). Urban Flood Simulation -a Case Study of Hyderabad city. National Conference on Flood Early Warning for Disaster Risk Reduction, (June), 133–143.

7. Bhowmick, S., Dey, P. D. A., & Khan, S. M. (2018). Assessment of Storm Water Runoff with Arc-Swat and Swmm in Mymensingh District. 2018(December), 19–21.
8. Naeimi, G., & Safavi, H. R. (2019). Integrated Stormwater and Groundwater Management in Urban Areas, a Case Study. International Journal of Civil Engineering, 17(8), 1281–1294.
9. Harsha, S. S., Agarwal, S., & Kiran, C. H. (2020). Regional Flood Forecasting using SWMM for Urban Catchment. (3), 1027– 1031. https://doi.org/10.35940/ijeat.
10. Rao, B. S. P. (2011). Run-off and flood estimation in Krishna River Delta using Remote Sensing & GIS. (April).
11. Kumar, P. S., Praveen, T. V, & Prasad, M. A. (2017). Rainfall-Runoff Modelling using Modified NRCS-CN, RS and GIS -A Case Study Rainfall-Runoff Modelling using Modified NRCS-CN, RS and GIS -A Case Study. (April 2016).
12. Florida Smart (2006). “Florida Climate- Seasons in Florida,” Retrieved February 10, 2010. Florida Smart Web guide.
13. Huber, W. C., and Dickinson, R. E. (1988). Storm water management model, user’s manual, version 4.0, EPA-600/3-88-001a. U.S. Environmental Protection Agency, Athens, GA.
14. Agarwal, S., Patil, J. P., Goyal, V. C., & Singh, A. (2018). Assessment of Water Supply–Demand Using Water Evaluation and Planning (WEAP) Model for Ur River Watershed, Madhya Pradesh, India. Journal of The Institution of Engineers (India): Series A. https://doi.org/ 10.1007/s40030-018-0329-0.
15. Girish, D., & Agarwal, S. (2019). Utilization of Storm Water Management Model for Urban Flood Scenario. (2), 3716–3721. https://doi.org/10.35940 /ijeat. B3928.129219.