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APPLICABILITY OF SWMM FOR URBAN FLOOD FORECASTING A CASE STUDY OF THE WESTERN ZONE OF SURAT CITY

BAUDHANWALA D., KANTHARIA V., PATEL D., MEHTA D.*, WAIKHOM S.

Department of Civil Engineering, Dr. S. & S.S. Ghandhy Government Engineering College, Surat

(*) darshanmehta2490@gmail.com

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ABSTRACT

Urban flooding is the submergence of an area by a large amount of water that comes from sudden excessive rainfall. As a result, it overwhelms the capability of the drainage system, such as storm sewers. Surat city is located on India's west coast at the mouth of the Tapi River. Surat city has faced many floods for a long time. The main aim of the study is to simulate the existing stormwater drainage system and to identify any overflowing manholes in Surat City (West Zone) by employing the Storm Water Management Model (SWMM). SWMM is an effective tool for simulating urban floods. In the present study, rainfall data for 2018, 2019 and 2020 and stormwater network data were used to evaluate the present stormwater drainage network. The above data are then imported into SWMM to display the inversion level and drainage network details. The flow direction has been assessed from these inverted-level drain network characteristics to produce a descriptive view of the study area. From the above analysis, it is found that some parts of the western zone are mostly affected by flooding. These flooding conditions can be improved by increasing the dimensions of the conduit pipes of the respective drainage system. Recommendations and suggestive measures are provided to improve the resilience of Surat city against floods.

Keywords: Flood Routing, Invert Level, Surat City, SWMM, Urban Flood.

INTRODUCTION

Although flooding is a natural occurrence with some beneficial effects, it may cause enormous human suffering when it happens in a populated region (Hountondji et al., 2019; Remini, 2020; Aroua, 2020; Hafnaoui et al., 2022). Due to inadequate drainage systems, it is exceedingly difficult to prevent floods during high-intensity rainstorm events in urban areas (Agarwal et al., 2019).

Urban flooding is the main component in storm water management (Bouly et al., 2019). It includes subcatchments, invert levels, runoff, nodes and conduits. It causes storm drains to become overloaded and blocked with solid waste, which increases the flood peak by 1.8 to 8.0 times and the flood volume by approximately 6.0 times. Urban flooding is more frequently observed to occur abruptly, within a few minutes, as a result of longer flow periods. (Harsha et al., 2020).

India is extremely susceptible to a wide range of natural calamities, including floods, cyclones, droughts, and landslides, among others. The massive loss of life and property that flooding situations can bring is the most tragic. (Harsha et al., 2020). In India, several large cities, including Bengaluru, Chennai, Hyderabad, and Kolkata, have experienced several urban flood situations in recent years. (Agarwal et al., 2019). In this study, we considered the densely populated area of Surat city (Gujarat).

Urban flood scenarios and flood risk can be effectively modeled in a catchment using a variety of software programs or code solving, such as the numerical method (Benslimane et al., 2020), the storm water management model (SWMM), MIKE URBAN, MIKE FLOOD, the Hydrologic Engineering Centers-River Analysis System (HEC RAS) and the Hydrologic Engineering Centers-Hydrologic Modeling System (HEC-HMS). (Agarwal et al., 2019). This study uses the Strom Water Management Model (SWMM) by the Environmental Protection Agency (EPA) to assess the stormwater drainage system of Surat City (West Zone). According to the laws of conservation of mass, momentum, and energy, SWMM is a simulation model used for rainfall-runoff modeling. This model is utilized to design, analyze and plan drainage systems as well as to assess the quantity of runoff that occurs in urban areas (Rossman et al., 2010). The model can be used for designing and sizing drainage system components for flood control, designing control strategies for minimizing combined sewer overflows, controlling site runoff using green infrastructure practices as low LID controls, evaluating the impact of inflow and infiltration on sanitary sewer overflows and sizing detention facilities and their appurtenances for flood control and water quality protection.

The general factors affecting stormwater management in urban areas are rainfall intensity and duration, area and shape of the catchment, nature of soil and degree of porosity.

MATERIALS AND METHODS

Dynamic Wave Routing

Dynamic wave routing is applied to completely solve the one-dimensional Saint Venant flow equations, resulting in a more precise solution. These equations include a volume continuity equation for nodes as well as continuity and momentum equations for pipes. With this type of routing, the pressured flow that can surpass the value of the full-flow Manning equation can be represented when a closed conduit fills. Flooding occurs when a node's water depth is greater than the depth that can be supported by the system, and the surplus flow either escapes the system or can accumulate on top of the node and re-enter the water system. (Storm Water Management in Otteri Nullah, 2014).

Dynamic wave routing can take channel storage, backwater, flow reversal, entrance/exit losses, and pressurized flow into consideration. Any drainage network, including those with several downstream diversions and loops, can be used for water levels at nodes and flow in pipes. It is the ideal approach for systems that have weirs and orifices in place to control flow and that experience severe backwater effects as a result of downstream flow constraints. (Storm Water Management in Otteri Nullah, 2014).

Modified Green Ampt Method

The Modified Green Ampt technique is based on the statement that a distinct wetting front separates early damp soil from saturated soil in the soil column. The initial deficiency of soil moisture, the soil's hydraulic conductivity, and the suction head at the wetting front are the three most important input variables. (Storm Water Management in Otteri Nullah, 2014).

STUDY AREA AND DATA SOURCE

Surat City

Surat city is located between latitudes 21° 06′ to 21° 15′ N and longitudes 72° 45′ to 72° 54′ E on the bank of the Tapi River, where its course swerves suddenly from the southeast to southwest. The river, which is mostly flat but has a moderate slope from north to southwest, controls the topography. The city is separated into eight distinct zones, including the North, West, Central, North, East, East A, East B, South, South West, and South East zones. In this study, the western zone is considered for the analysis of the storm water management model. The important areas in the western zone are Rander-Adajan, Pal, Palanpore, and Jahangirpura. Due to the zone’s rapid expansion, these four well-known areas of Surat city are under several town planning schemes.

The area of Rander-Adajan, which is represented by T.P. Scheme No 14 was flooded when the water level was between 9 and 12 meters, submerging 1.46 km^2 of land. It is considered a low-rise location in the west zone by T.P. Scheme because they are built in the flood plain of the river, and illegal settlements along the Tapi River bank are also susceptible to minor flood occurrence. Jahangirpura, represented by T.P. Scheme No 46 is a high rise area that shares similar characteristics and was submerged to a depth of 13 meters, or approximately 0.88 km^2. (Dhruvesh et al., 2013). For the above reasons, the western zone of Surat city is selected as the study area.

Data Source

Hourly rainfall data were obtained for 2018, 2019, and 2020 from the India-WRIS website. The storm drainage network details drawings are collected from the West Zone of the Storm Department under the Surat Municipal Corporation.

Fig. 1 represents the index map of the study area, and Fig. 2 represents the location map of the western zone of Surat city.

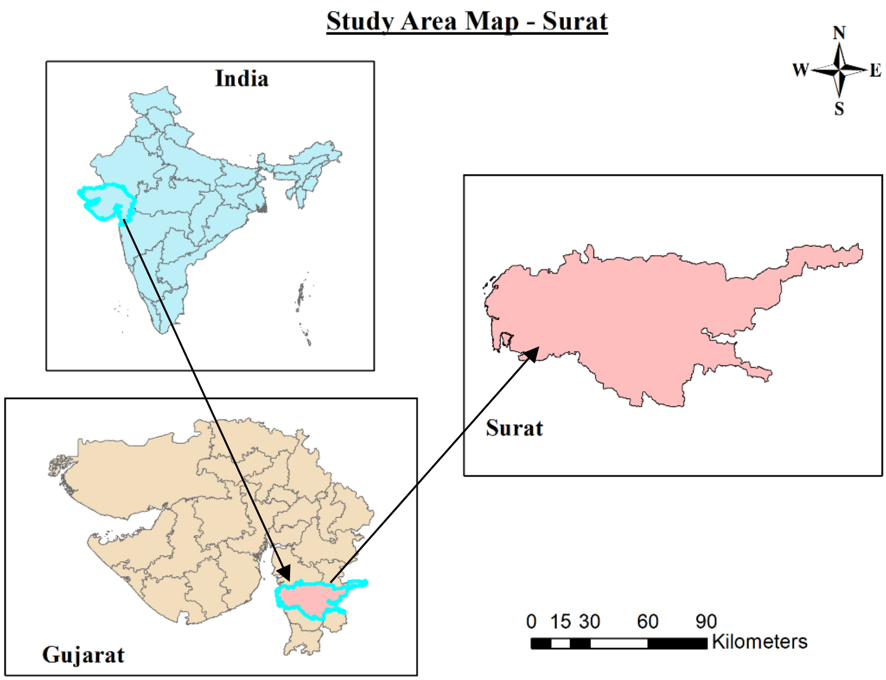
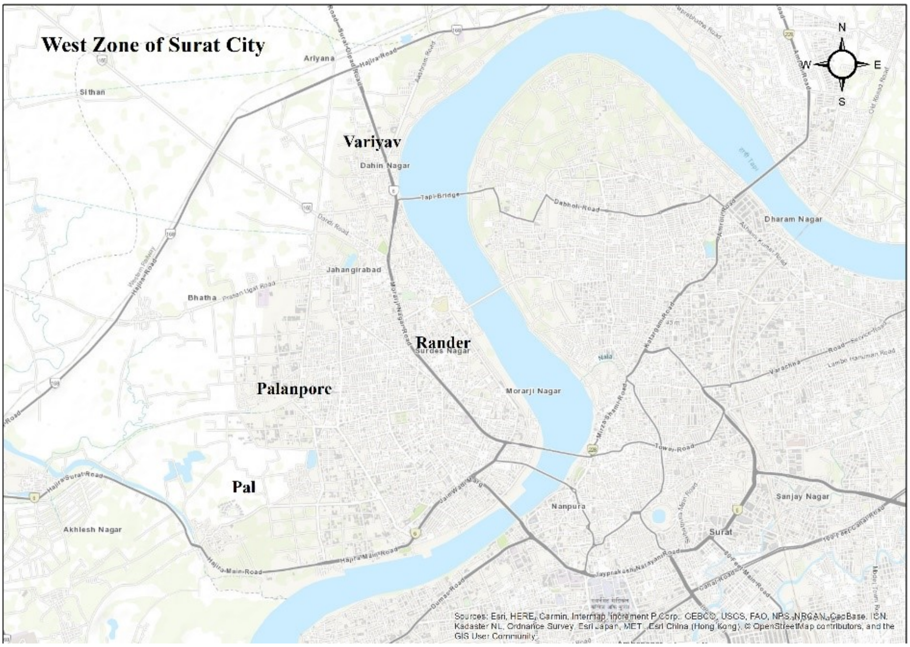


Figure 1: Index map of the study area



(Source: Location map from ArcMap, Esri.)

Figure 2: Location of the western zone in Surat City.

Selection of Input Parameters

Table 1 shows the details of various TP schemes considered in the study.

Table 1: Input Parameters in SWMM

TP Schemes No	TP Scheme Name	Area (hectare)	N-Imp	N-Perv	Slope (%)	Imperviousness (%)
10	Pal	140	0.001	0.1	0.50	25
46	Jahangirpura	93	0.001	0.1	0.50	25
14	Rander-Adajan	116	0.001	0.1	0.50	25
8	Palanpore	100.84	0.001	0.1	0.50	25

The study area is fragmented into subcatchments, and storm networks are displayed using nodes, junctions, conduits, and outfalls. Using the Rainfall-Runoff Block in SWMM, it is assumed that the rainfall events of 2018, 2019, and 2020 may be modeled. When analyzing infiltration, the Horton approach is employed, whereas when analyzing catchment flow routing, the dynamic wave method is employed. A Storm network map was extracted using AutoCAD imagery and loaded into SWMM using the load image option. To create a schematic of the study area, the SWMM discretizes the Storm network map layout.

Various junction data, such as the inverted elevation and maximum depth, are available, while for conduits, the dimension, depth, shape, roughness, etc., are considered as input parameters. The flow chart in Fig. 4 illustrates the actions that are performed as part of the model development process in SWMM using a variety of datasets. To illustrate the drainage system, all of the networks in SWMM are first generated. Different nodes are then created to represent drainage, each divided into several subcatchments, and these nodes are further connected by conduits. As a result, SWMM includes a well-described schematic representation of the study area along with all the necessary components to predict urban flooding. Profile nodes are used to represent the model's output. Fig. 3 represents the flowchart of the process in the SWMM model.

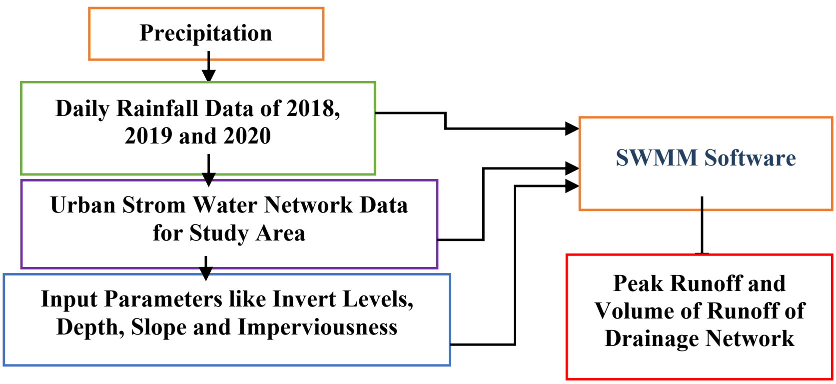


Figure 3: Flowchart of the SWMM process

Fig. 4 illustrates how the study area of Pal, Jahangirpura, Rander-Adajan, and Palanpore is depicted in SWMM. This system consists of a rain gauge station, subcatchments connected by nodes, conduits, and an outlet. The values of imperviousness and slope are assumed in this study. Storm duration is equal to the time of concentration. The time of concentration is relatively short and independent of storm intensity. The runoff coefficient does not vary with storm intensity. The runoff produced by each subcatchment contributes to several nodes that are linked by conduit networks.

Figure 4: TP Scheme 8, 10, 14 & 46 (Palanpore, Pal, Rander-Adajan & Jahangirpura) drainage plan in the SWMM model

RESULT AND DISCUSSION

SWMM created runoff for three extreme rainfall events in a reasonable manner. The study made an effort to ascertain the maximum runoff of each subcatchment.

TP Scheme Palanpore - (2018)

Table 2 contains the locations of the flooding junctions and conduits. According to the simulation result of a design storm with a one-year return period, several conduits C41, C62, C40, C42, and C63 have reached maximum/full depth, with the greatest flooding occurring at junctions J65, J42, J43, and J66. Fig. 5 represents the water surface profile at different junctions in the Palanpore area.

Table 2: Critical Time Elements, Highest Indexes of Flow Instability, Most Frequent Converging Nodes

Critical Time Elements	Highest Indexes of Flow Instability	Most Frequent Converging Nodes
Link C41 (73.16%)	Link C41 (33)	Node OUT1 (5.02%)
Link C32 (10.70%)	Link C62 (18)	Node J65 (3.06%)
Link C73 (5.65%)	Link C40 (16)	Node J42 (1.29%)
Link C62 (4.51%)	Link C42 (13)	Node J43 (1.16%)
Link C15 (1.23%)	Link C63 (13)	Node J66 (1.05%)

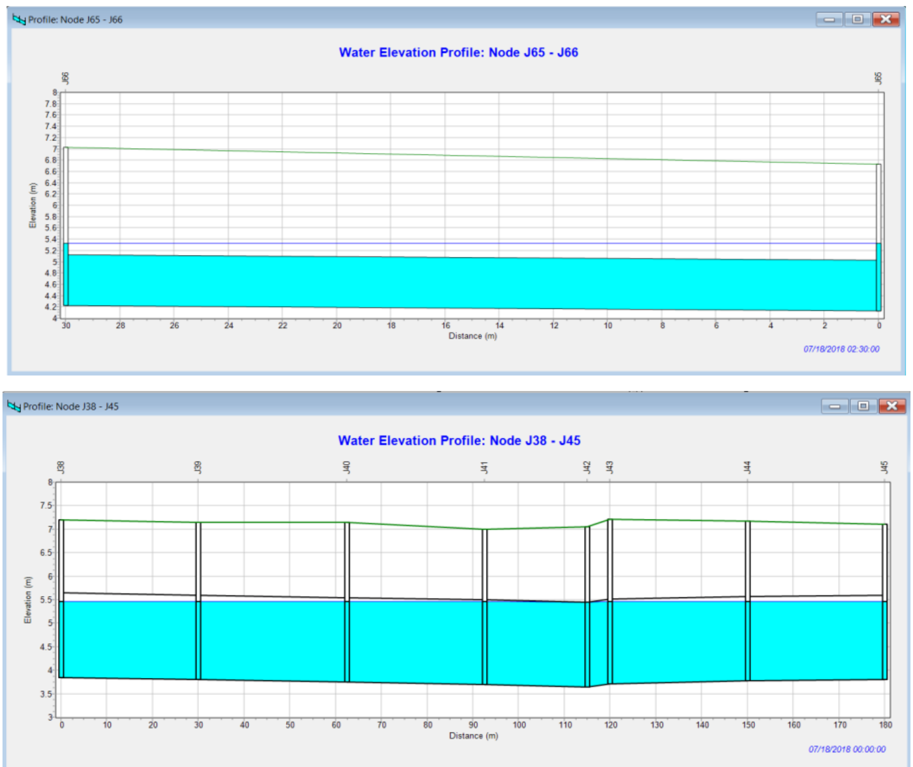


Figure 5: Water surface profile at different junction points-Palanopores

TP Scheme Jahangirpura – (2019)

Table 3 contains the locations of the flooding junctions and conduits. According to the simulation result of a design storm with a one-year return period, several conduits C92, C91, and C44 have reached maximum/full depth, with the greatest flooding occurring at junctions J31, J32, J33, and J30. Figure 6 represents the water surface profile at different junctions in the Jahangirpura area.

Table 3: Critical Time Elements, Highest Indexes of Flow Instability, Most Frequent Converging Nodes

Critical Time Elements	Highest Indexes of Flow Instability	Most Frequent Converging Nodes
Link 92 (81.44%)	Link 92 (1)	Node OUT1 (0.05%)
Link 29 (2.00%)	Link 91 (1)	Node 31 (0.01%)
Link 57 (1.53%)	Link 44 (1)	Node 32 (0.01%)
-	-	Node 33 (0.01%)
-	-	Node 30 (0.01%)

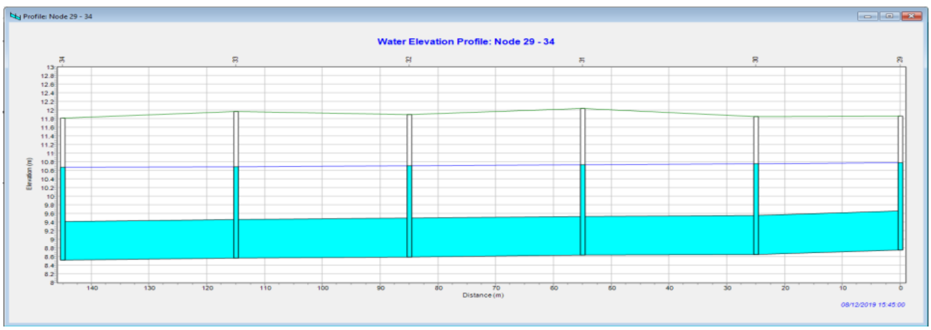


Figure 6: Water surface profile at different junction points-Jahangirpura

TP Scheme Pal – (2020)

Table 4 contains the locations of the flooding junctions and conduits. According to the simulation result of a design storm with a one-year return period, several conduits C23, C48, C18, C43, and C28 have reached maximum/full depth, with the greatest flooding occurring at junctions J31, J42, J28, and J41. Figure 7 represents the water surface profile at different junctions in the Jahangirpura area.

Table 4: Critical Time Elements, Highest Indexes of Flow Instability, Most Frequent Converging Nodes

Critical Time Elements	Highest Indexes of Flow Instability	Most Frequent Converging Nodes
Link C56 (44.30%)	Link C23 (77)	Node OUT1 (17.55%)
Link C9 (19.59%)	Link C48 (76)	Node J31 (4.65%)
Link C67 (12.41%)	Link C18 (76)	Node J42 (2.79%)
Link C72 (9.69%)	Link C43 (75)	Node J28 (2.29%)
Link C71 (3.25%)	Link C28 (75)	Node J41 (2.28%)

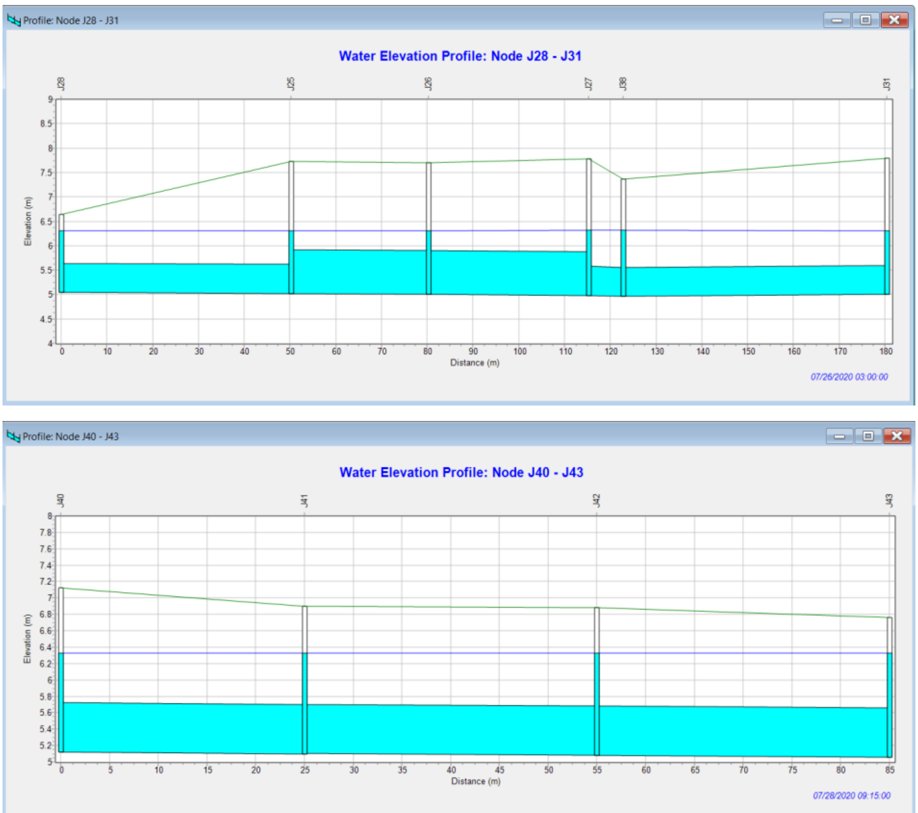


Figure 7: Water surface profile at different junction points-Pal

CONCLUSION

The case study conducted for this study has demonstrated that SWMM works effectively for simulating urban flood scenarios. The storm water drainage network for TP Scheme 8 (Palanpore), TP Scheme 10 (Pal), TP Scheme 14 (Rander-Adajan), and TP Scheme 46 (Jahangirpura) was simulated using the SWMM model. The three extreme daily rainfall events that occurred in 2018, 2019, and 2020 produced the outcome, and the model's results will be more dependable if the method can be used to determine the impermeable and permeable cover of an urban region. The dynamism capacity in a densely populated area will be adhered to by several input characteristics, such as the impermeability and penetrability of a locality along with the roughness coefficient. The maximum depth, maximum flow velocity and frequency, average flow, HGL, and total volume of runoff from each subcatchment are the main findings of the model. The limitations of the model are that it is more unstable than other hydraulic engines, it cannot model manhole or inlet loss directly, and moreover, it is an analytical tool and not a design tool.

FUTURE SCOPE OF WORK

- The SWMM model can be developed for urban flood planning and for preparing mitigation plans for different return periods.
- Sensitivity analysis is carried out to check the performance of the model.
- Urban flood dynamics simulation must be carried out, which is of great significance for assessing a city’s loss and risk assessment in flood disasters.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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