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Urban Drainage and Stormwater Management Using GIS and SWMM Software in Tenali Municipality, Guntur District, Andhra Pradesh, India

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Abstract: Rapid urbanization has significantly altered natural hydrological processes in many Indian towns, resulting in frequent urban flooding during monsoon rainfall events. The expansion of impervious surfaces reduces infiltration and increases surface runoff, often overwhelming existing stormwater drainage systems that were designed based on outdated rainfall and population projections. Tenali Municipality, located in Guntur District of Andhra Pradesh, experiences recurrent waterlogging and flooding during moderate to heavy rainfall events due to inadequate drainage infrastructure and improper system planning. In the present study, the urban stormwater drainage system of Tenali Municipality was analysed using an integrated approach combining Geographic Information System (GIS) techniques and the United States Environmental Protection Agency Stormwater Management Model (EPA-SWMM). Spatial data required for the study were extracted using Google Earth Pro and processed in ArcGIS to delineate drainage networks, catchment areas, and land use characteristics. A detailed SWMM model was developed by defining sub-catchments, junctions, conduits, outfalls, and rainfall inputs, and simulations were carried out at 15-minute time intervals to evaluate system performance under high-intensity rainfall conditions. The simulation results indicate that several drainage conduits experience surcharge conditions, leading to localized flooding in low-lying areas. Insufficient conduit capacity, inadequate slopes, and downstream flow obstructions were identified as major contributors to flooding. Flood-prone locations were spatially mapped using GIS to clearly visualize vulnerable zones within the municipality. The study demonstrates that the integrated use of GIS and SWMM is an effective tool for diagnosing deficiencies in urban drainage systems and provides valuable insights for improving stormwater management strategies. The findings can assist municipal authorities in planning infrastructure upgrades and mitigating urban flood risks in Tenali and similar medium-sized towns in India.
Keywords: Urban flooding, Stormwater drainage, GIS, SWMM, Tenali Municipality, Hydrologic Modelling.

I. INTRODUCTION

Urban flooding has become a growing concern in rapidly developing cities due to accelerated urbanization and extensive land-use changes. The increase in impervious surfaces such as roads, rooftops, and pavements reduces natural infiltration and significantly increases surface runoff during rainfall events. As a result, even moderate or short-duration rainfall often leads to waterlogging, traffic disruption, infrastructure damage, and public health issues. Although stormwater drainage systems are essential for managing urban runoff, they have historically received less priority in many Indian cities compared to water supply and sewerage systems. Many existing drainage networks were designed decades ago and are inadequate to handle present-day rainfall intensities, population growth, and changing land-use patterns. Additionally, climate change induced high-intensity rainfall events have further increased urban flood risks. In recent years, urban flooding has not been limited to major metropolitan cities but has also become frequent in medium and small towns across India. These towns often lack proper stormwater management planning, regular maintenance, and systematic performance evaluation of drainage systems. Common issues include insufficient drain capacity, poor connectivity, inadequate slopes, encroachments, and blockage due to solid waste. Therefore, a detailed assessment of urban drainage systems is necessary to understand their performance under varying rainfall conditions.

Tenali Municipality, located in the Guntur District of Andhra Pradesh, is a rapidly growing town situated in a low-lying and relatively flat region of the Krishna River basin.

The town frequently experiences waterlogging during monsoon seasons, with several areas remaining inundated for prolonged periods. These problems are mainly attributed to inadequate drainage capacity and inefficient system layout. Despite recurring flooding, a comprehensive evaluation of the stormwater drainage system in Tenali has been limited. Recent advances in geospatial techniques and hydrological modelling have enabled effective analysis of urban stormwater systems. GIS facilitates the analysis of spatial data such as land use, topography, and drainage networks, while EPA-SWMM is a widely used model for simulating urban runoff and drainage performance. The present study evaluates the existing stormwater drainage system of Tenali Municipality using an integrated GIS and EPA-SWMM approach to identify drainage deficiencies and flood-prone locations. The outcomes of this study can support improved stormwater management and provide guidance for other medium-sized towns facing similar flooding issues.

II. STUDY AREA

The study area lies between 80°35′30″ to 80°40′30″ East longitude and 16°13′15″ to 16°16′15″ North latitude, covering an area of about 16.63 km², as shown in Figure (1) Tenali Municipality is located in the southern deltaic region of the Krishna River basin in Guntur District, Andhra Pradesh, at an average elevation of approximately 13 m above mean sea level. The town forms part of the Western Delta System of the Krishna River and is traversed by the East, West, and Nizampatnam canals originating from the Krishna River. The terrain is predominantly flat with gentle slopes, underlain by alluvial deposits with red and black soils. Due to its low-lying topography and rapid urbanization, the area is highly prone to waterlogging and localized flooding during intense monsoon rainfall. The existing stormwater drainage system, consisting of open and closed drains, is affected by inadequate capacity, poor connectivity, encroachments, and blockages, leading to frequent drainage congestion in several parts of the municipality. Consequently, Tenali was selected as the study area to assess urban drainage characteristics and stormwater management issues typical of medium-sized Indian towns.

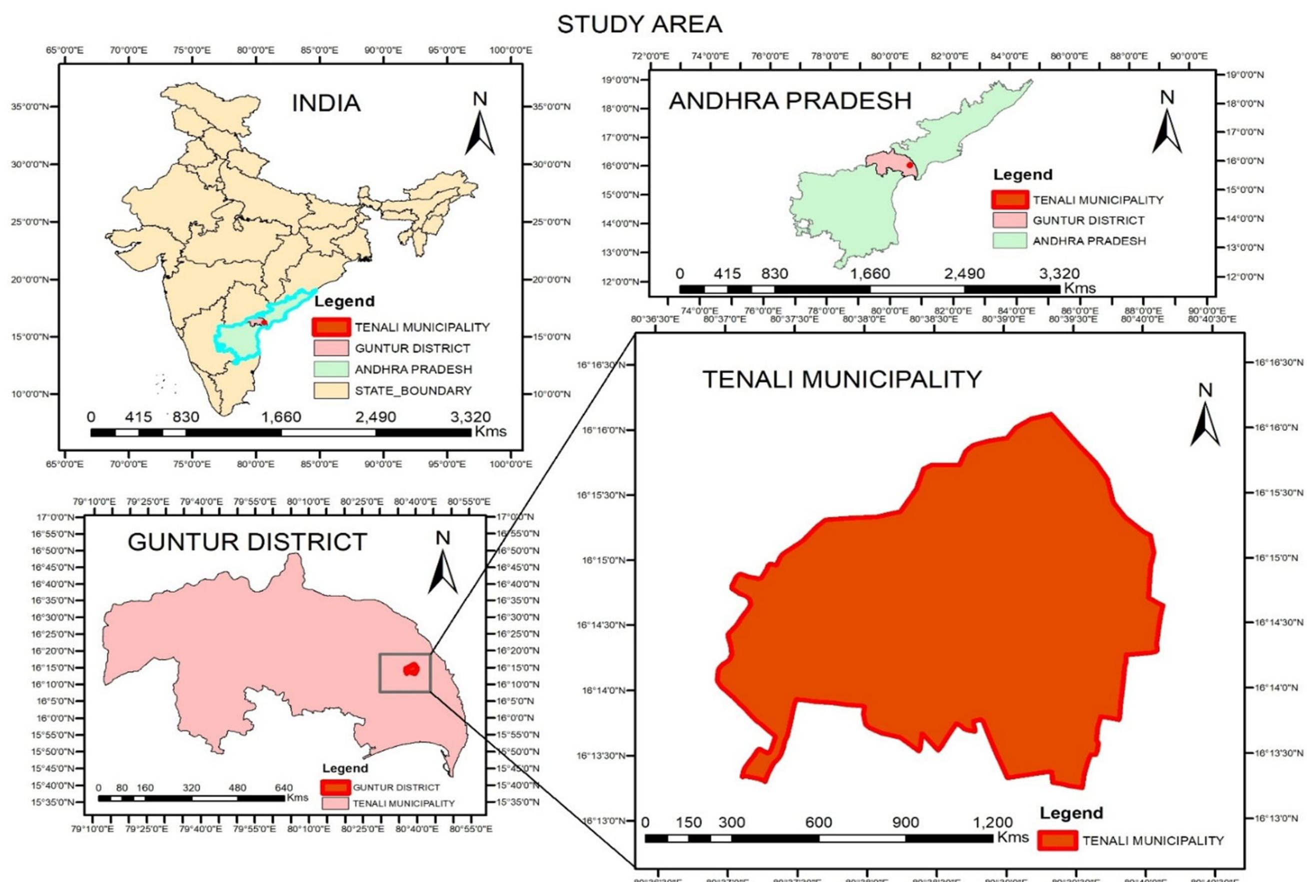

Figure – 1: Study Area

III. METHODOLOGY

The present study adopts a hybrid methodology integrating Geographic Information System (GIS) techniques with the United States Environmental Protection Agency Storm Water Management Model (EPA-SWMM) to evaluate the performance of the urban stormwater drainage system. This integrated approach is widely used in urban stormwater studies for analyzing rainfall–runoff behavior and assessing drainage system efficiency (Rossman, 2010; EPA, 2015). GIS tools were employed for spatial data preparation, drainage network mapping, and visualization, while EPA-SWMM was used to simulate hydrological and hydraulic processes within the drainage system. The combined application of geospatial analysis and hydraulic modeling enables effective identification of drainage deficiencies, surcharge conditions, and flood-prone locations within the study area.

A. Drainage Planning

Drainage planning involves understanding the natural flow paths, existing drainage infrastructure, and land-use characteristics of the urban area. In the present study, the planning process included mapping of existing drains, identification of natural low-lying zones, and assessment of connectivity between primary and secondary drains. Proper drainage planning is essential to ensure efficient conveyance of stormwater and to minimize flooding during high-intensity rainfall events.

B. Drainage Considerations

General drainage design considerations include adequate drain capacity, sufficient longitudinal slope, proper connectivity, and safe disposal of stormwater at outfalls. Factors such as rainfall intensity, catchment area, surface imperviousness, and maintenance conditions significantly influence drainage performance. In urban areas, improper sizing of drains, encroachments, sediment deposition, and blockages often reduce system efficiency. These aspects were considered while evaluating the existing drainage system and interpreting model results.

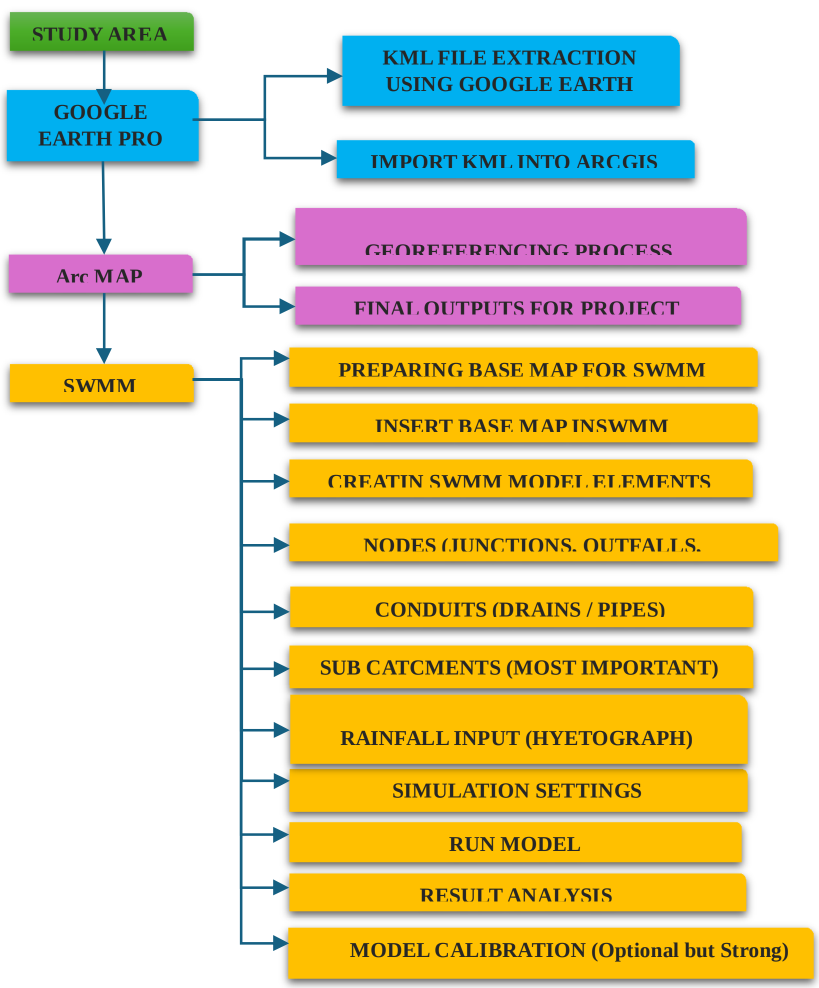

Figure – 2: Flowchart of Methodology

Google Earth Pro was used as a primary source of high-resolution satellite imagery to identify land-use patterns, road networks, built-up areas, and visible drainage alignments within the study area, and to verify spatial features prior to GIS digitization. ArcGIS was employed to develop a comprehensive geospatial database by processing spatial data and generating thematic layers such as drainage networks, catchment boundaries, and land-use features required for stormwater analysis. ArcMap, a core component of the ArcGIS platform, was used for detailed digitization, spatial analysis, and preparation of location, drainage, and flood-prone area maps, with attribute information assigned to each drainage feature. EPA–SWMM was utilized to simulate surface runoff and hydraulic behavior of the urban drainage network under varying rainfall conditions, including unsteady flow, conduit surcharge, and flooding at junctions, making it an effective tool for urban stormwater and flood assessment.

C. Procedure For Stormwater Management Modelling

The SWMM model for Tenali Municipality was developed using GIS-derived spatial data, including the drainage network, sub-catchment boundaries, and base maps prepared in ArcGIS. The geo-referenced base map was imported into the SWMM environment to ensure accurate spatial representation of model elements. Junctions, conduits, outfalls, and sub-catchments were defined based on the existing drainage layout, while rainfall inputs were applied using a 15-minute interval hyetograph to represent high-intensity monsoon events. Dynamic wave routing was adopted to simulate unsteady flow conditions, including surcharge and flooding, and the model was executed to evaluate runoff generation and drainage system performance.

IV. SWMM MODELLING WORKFLOW USING TENALI STUDY AREA

The SWMM modelling workflow for the Tenali study area was carried out using a systematic approach by integrating GIS-derived spatial data with hydraulic modelling. The workflow includes base map preparation, model element creation, simulation, and result interpretation.

1) Preparation of Base Map for SWMM: A geo-referenced base map of the study area was prepared using ArcGIS. This base map included the study area boundary, drainage network, and major urban features. The base map served as a spatial reference for accurate creation of the SWMM model elements.
2) Export of Geo-Referenced Base Map from ArcGIS: The prepared base map was exported from ArcGIS in a compatible image format. Care was taken to preserve spatial accuracy during export so that the base map could be correctly aligned within the SWMM environment.
3) Insertion of Base Map into SWMM: The exported geo-referenced base map was imported into the SWMM interface as a background layer. This facilitated accurate placement of model components such as nodes, conduits, and sub-catchments according to real-world spatial locations.
4) Creation of SWMM Model Elements: After inserting the base map, the SWMM project was initialized by defining essential model elements. The overall structure of the stormwater drainage system was developed by creating nodes, conduits, sub-catchments, and outfalls based on the drainage layout.
5) Definition of Nodes (Junctions, Outfalls, and Storage Units): Nodes representing junctions, outfalls, and storage units were defined in the SWMM model. Junctions represent drain intersections, outfalls represent discharge points, and storage units represent temporary storage locations. Elevation and depth parameters were assigned based on available data and field observations.
6) Conduits (Drains and Pipes) and Sub-Catchment Delineation: Conduits representing drains and pipes were created to connect the defined nodes. Parameters such as conduit length, slope, cross-sectional shape, and roughness coefficient were assigned based on drainage characteristics. These conduits simulate the conveyance of stormwater through the drainage network. The study area was divided into multiple sub-catchments representing runoff contributing areas. Sub-catchment boundaries were defined based on surface slope, drainage flow direction, and land-use characteristics. Parameters such as area, imperviousness, and slope were assigned to each sub-catchment.
7) Rainfall Input and Hyetograph Development: Rainfall data corresponding to intense monsoon events were input into SWMM as time-series data. A hyetograph was developed using rainfall values at 15-minute intervals to accurately represent rainfall intensity and temporal distribution during storm events.
8) Simulation Settings: Simulation settings such as time step, flow routing method, and simulation duration were defined. Dynamic wave routing was selected to simulate unsteady flow conditions, including surcharge and flooding, within the drainage system.

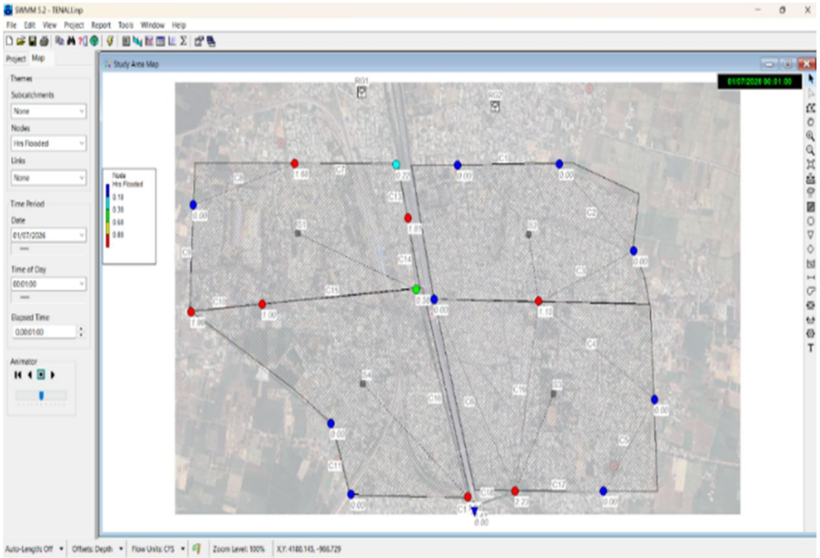

Figure – 3: Simulation setting

9) Model Execution: After completing model setup, the SWMM model was executed to simulate stormwater runoff and drainage behavior. The model generated outputs related to runoff, conduit flow, and flooding at junctions.
10) Result Analysis and Interpretation: The simulation results were analyzed to identify drainage bottlenecks, surcharged conduits, and flood-prone junctions. Output graphs, tables, and summary reports generated by SWMM were examined to assess the performance of the drainage system.
11) Model Calibration (Optional): Where observed flooding information or historical rainfall data were available, model calibration was carried out by adjusting sensitive parameters such as roughness coefficients and imperviousness. Calibration improved the reliability of simulation results and enhanced model accuracy.

A. Stormwater Management

Stormwater management in Tenali Municipality aims to safely convey rainfall runoff through the existing drainage network to reduce flooding. The study results indicate that increased impervious surfaces, inadequate drain capacity, poor connectivity, and insufficient slopes are the main causes of waterlogging during high-intensity rainfall. Many drains operate under surcharged conditions, leading to localized flooding at low-lying junctions. Improving critical drain capacities, ensuring regular desilting, preventing encroachments, and adopting basic source-control measures can significantly enhance drainage performance. The integrated GIS and SWMM approach provide a practical basis for identifying priority areas for stormwater management improvements.

V. RESULTS & DISCUSSIONS

The SWMM simulation results provide a comprehensive understanding of the hydrological and hydraulic behavior of the stormwater drainage system in the Tenali study area. The model outputs include runoff volume, peak discharge, conduit flow conditions, node flooding, and surcharge occurrence during intense rainfall events. The simulation successfully captured the response of the drainage network under monsoon rainfall, allowing identification of critical problem areas within the urban drainage system. Analysis of node flooding results indicates that several junctions experience flooding during peak rainfall periods. Flooding was primarily observed at low-lying junctions and locations where multiple drains converge. The duration and depth of flooding at these nodes suggest that the existing drainage capacity is insufficient to accommodate peak runoff, leading to temporary waterlogging and overflow conditions. These findings are consistent with field observations of frequent flooding during monsoon seasons.

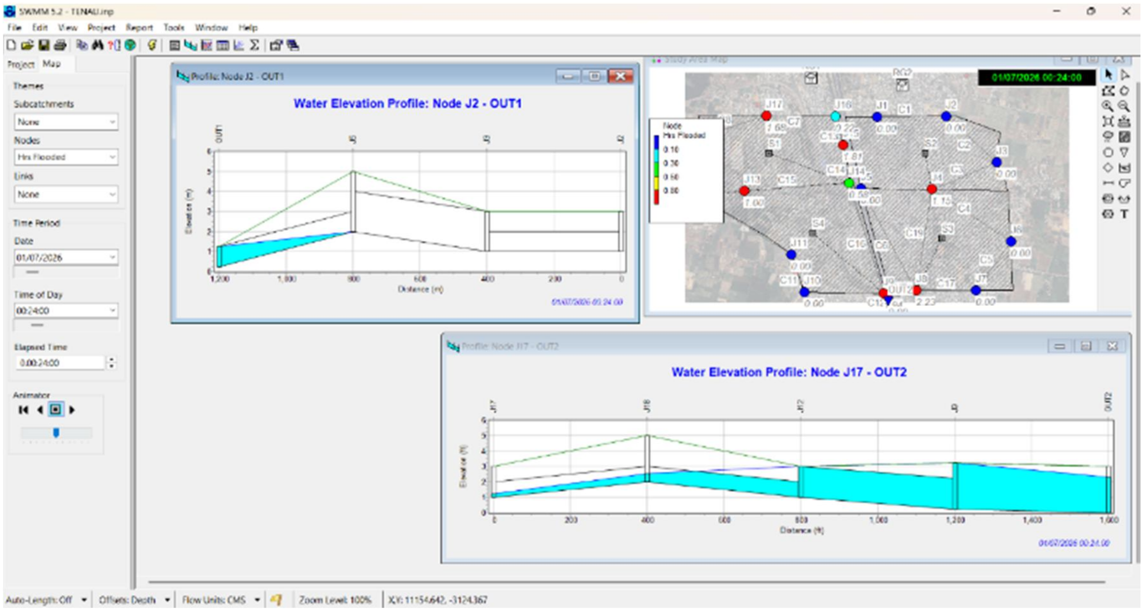

Figure – 4: Node flooding summary obtained from SWMM simulation

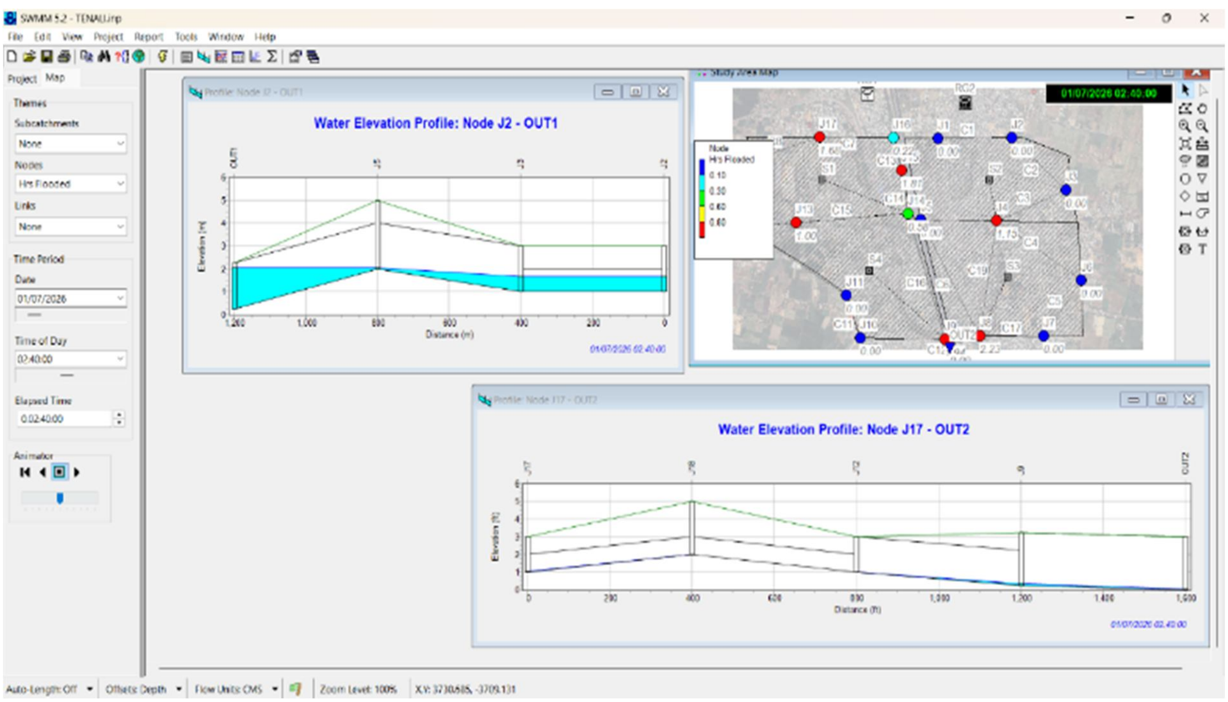

Figure – 5: Flood depth variation at critical junctions

A. Conduit Flow and Surcharge Conditions

Conduit flow refers to the movement of stormwater through drainage pipes or channels within the urban drainage network. Surcharge conditions occur when the flow exceeds the carrying capacity of the conduit, causing the water level to rise above the conduit crown and resulting in pressurized flow and potential upstream flooding.

Summary Results

Topic: Subcatchment Runoff   Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Imperv Runoff mm	Perv Runoff mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff CMS	Runoff Coeff
S1	96.63	0.00	0.00	9.00	72.77	15.27	88.04	4.40	2.09	0.911
S2	96.63	0.00	0.00	9.00	72.77	15.27	88.04	4.40	2.09	0.911
S3	96.63	0.00	0.00	8.95	72.77	15.31	88.09	4.40	2.09	0.912
S4	96.63	0.00	0.00	9.11	72.75	15.15	87.90	4.40	2.08	0.910

Summary Results

Topic: Node Depth   Click a column header to sort the column.

Node	Type	Average Depth Meters	Maximum Depth Meters	Maximum HGL Meters	Day of Maximum Depth	Hour of Maximum Depth	Maximum Reported Depth Meters
J1	JUNCTION	0.51	0.89	1.89	0	05:48	0.89
J2	JUNCTION	0.52	0.89	1.89	0	05:58	0.89
J3	JUNCTION	0.54	0.89	1.89	0	05:54	0.89
J4	JUNCTION	0.05	0.26	2.26	0	01:30	0.26
J5	JUNCTION	0.03	0.09	2.09	0	01:41	0.09
J6	JUNCTION	0.42	0.73	2.23	0	01:26	0.73
J7	JUNCTION	0.03	0.16	2.16	0	01:31	0.16
J8	JUNCTION	1.59	2.00	2.10	0	01:25	2.00
OUT1	JUNCTION	1.41	1.86	2.11	0	01:38	1.86
J9	JUNCTION	0.11	0.62	0.87	0	01:30	0.62
J10	JUNCTION	0.00	0.00	1.00	0	00:00	0.00
J11	JUNCTION	0.00	0.00	0.75	0	00:00	0.00
J12	JUNCTION	0.00	0.00	1.00	0	00:00	0.00
J13	JUNCTION	0.00	0.00	2.00	0	00:00	0.00
J14	JUNCTION	0.05	0.29	1.29	0	01:30	0.29

Figure - 6: Drainage network profile plot

Runoff generation analysis shows that sub-catchments with high impervious surface coverage produce significantly higher runoff volumes and peak discharges. Dense residential and commercial areas contributed the maximum runoff due to reduced infiltration capacity. The peak discharge values correspond closely with rainfall intensity peaks, highlighting the strong influence of land-use pattern on stormwater response.

Summary Results

Topic: Node Inflow   Click a column header to sort the column.

Node	Type	Maximum Lateral Inflow CMS	Maximum Total Inflow CMS	Day of Maximum Inflow	Hour of Maximum Inflow	Lateral Inflow Volume 10^6 ltr	Total Inflow Volume 10^6 ltr	Flow Balance Error %
J1	JUNCTION	0.000	0.095	0	02:09	0	0.192	384.624
J2	JUNCTION	0.000	0.149	0	02:13	0	0.501	145.027
J3	JUNCTION	0.000	0.282	0	01:41	0	1.13	146.014
J4	JUNCTION	2.090	2.090	0	01:30	4.4	4.58	-0.159
J5	JUNCTION	0.000	0.593	0	01:31	0	1.13	0.704
J6	JUNCTION	0.000	1.815	0	01:22	0	1.46	36.637
J7	JUNCTION	0.000	0.099	0	01:28	0	0.0439	2.019
J8	JUNCTION	2.093	5.276	0	01:29	4.4	9.8	39.700
OUT1	JUNCTION	0.000	0.942	0	01:15	0	2.4	0.000
J9	JUNCTION	2.082	4.087	0	01:30	4.4	8.76	0.154
J10	JUNCTION	0.000	0.000	0	00:00	0	0	0.000
J11	JUNCTION	0.000	0.000	0	00:00	0	0	0.000
J12	JUNCTION	0.000	0.000	0	00:00	0	0	0.000
J13	JUNCTION	0.000	0.000	0	00:00	0	0	0.000
J14	JUNCTION	2.090	2.090	0	01:30	4.4	4.43	-0.047

Figure – 7: Runoff hydrograph at selected sub catchment

Temporal analysis of rainfall and runoff demonstrates a clear lag between rainfall peaks and corresponding runoff response. Peak runoff occurred shortly after peak rainfall, indicating rapid runoff generation typical of urban catchments. The short response time reflects limited storage and infiltration within the study area, leading to quick concentration of flow in the drainage network.

Summary Results

Topic: Outfall Loading   Click a column header to sort the column.

Outfall Node	Flow Frequency %	Avgerage Flow CMS	Maximum Flow CMS	Total Volume 10^6 ltr
OUT2	95.19	0.425	4.053	8.742

Figure – 8: Rainfall hyetograph (15-minute interval)

Integration of SWMM outputs with GIS enabled spatial mapping of flood-prone locations across the study area. The spatial analysis highlights specific zones repeatedly affected by flooding, particularly along major drainage lines and low-lying regions. Flood maps generated through GIS provide clear visual identification of critical areas requiring immediate drainage improvement measures.

VI. DISCUSSION

The overall results indicate that the existing stormwater drainage system in the Tenali study area is inadequate to handle intense rainfall events. Increased urbanization, high imperviousness, and insufficient drainage capacity are the primary factors contributing to flooding and surcharge conditions. The integrated GIS and SWMM-based approach proved effective in diagnosing drainage system deficiencies and identifying vulnerable locations. The findings emphasize the necessity for systematic drainage planning, capacity augmentation of critical conduits, and implementation of improved stormwater management strategies to reduce urban flood risk. The results also demonstrate the importance of using appropriate rainfall temporal resolution, as the 15-minute time step effectively captures peak runoff behaviour critical for urban flood assessment.

Summary Results

Topic: Conduit Surcharge — Click a column header to sort the column.

Conduit	Hours Both Ends Full	Hours Upstream Full	Hours Downstream Full	Hours Above Normal Flow	Hours Capacity Limited
C1	0.01	0.01	0.01	0.56	0.01
C2	0.01	0.01	0.01	1.30	0.01
C5	0.01	0.01	0.69	0.01	0.01
C14	0.01	0.01	0.01	0.28	0.01
C17	0.01	0.01	4.60	0.01	0.01
C18	4.71	4.71	4.85	0.35	0.01
C19	0.01	0.01	0.69	0.01	0.01

Summary Results

Topic: Node Flooding — Click a column header to sort the column.

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr	Maximum Ponded Depth Meters
J8	0.69	4.652	0	01:29	3.231	0.000

Figure – 9: Flood-prone locations within Tenali municipality and SWMM simulation results visualization

1) The SWMM model successfully simulated stormwater runoff and drainage behavior in Tenali Municipality.
2) Several junctions experienced flooding due to limited conveyance capacity and backwater effects.
3) Multiple conduits operated under surcharged conditions during peak rainfall periods.
4) Urbanized sub-catchments generated high runoff volumes with short response times.
5) Flood-prone zones were identified, indicating the need for drainage system improvements.

VII. CONCLUSION AND FUTURE SCOPE

Urban stormwater management has become a critical concern in rapidly urbanizing towns such as Tenali, where increased impervious surfaces, inadequate drainage capacity, and climate-induced high-intensity rainfall events have resulted in frequent flooding and waterlogging. The present study systematically evaluated the performance of the existing stormwater drainage system of Tenali Municipality using an integrated GIS and EPA-SWMM modelling framework. The approach provided a scientific understanding of urban runoff behaviour, drainage system performance, and flood vulnerability within the municipal limits.

A. Major Conclusions

1) *Inadequacy of Existing Drainage Infrastructure:* The existing stormwater drainage system in Tenali is found to be hydraulically inadequate to safely convey peak runoff generated during intense rainfall events. Several drains and junctions operate beyond their design capacity, leading to surface flooding and prolonged water stagnation in low-lying areas.
2) *Impact of Urbanization on Hydrological Response:* Rapid urban expansion and increased imperviousness have significantly altered the natural hydrological response of the catchment. Reduced infiltration and shortened runoff lag time have resulted in increased peak discharges, thereby overloading the existing drainage network.
3) *Effectiveness of GIS-Based Spatial Analysis:* The application of Google Earth Pro and ArcGIS enabled accurate extraction and visualization of drainage networks, sub-catchments, and spatial parameters. GIS-based mapping significantly improved the reliability of drainage network representation and SWMM model development.

4) *Performance of EPA-SWMM Modelling:* EPA-SWMM effectively simulated rainfall–runoff processes, conduit flow conditions, surcharge behaviour, and node flooding under selected rainfall scenarios. Dynamic wave routing successfully captured backwater effects and pressurized flow conditions, particularly near downstream canal outfalls.
5) *Identification of Critical Flood-Prone Locations and Drainage Maintenance:* Flooding was observed to be concentrated at specific junctions and downstream conduits where hydraulic capacity is insufficient or where backwater effects occur. These locations represent priority zones for drainage system improvement and flood mitigation. In addition to structural inadequacies, poor operation and maintenance, including siltation and solid waste accumulation, significantly contribute to flooding. Regular desilting and maintenance can substantially improve system performance even without major structural modifications.

B. Recommendations

1) Hydraulic upgrading of critical drains and junctions to accommodate future peak discharges.
2) Adoption of sustainable stormwater management practices such as detention basins, infiltration systems, and permeable pavements to reduce runoff at source.
3) Institutionalization of regular inspection, desilting, and solid waste removal to ensure efficient drainage performance.
4) Integration of stormwater planning with land-use planning and future urban development strategies.
5) Installation of rainfall and flow monitoring stations to improve model calibration and long-term drainage planning.

C. Scope for Future Work

1) Model calibration and validation using long-term observed rainfall and flood data.
2) Assessment of climate change impacts on urban runoff and drainage system capacity.
3) Integration of water quality modelling to evaluate pollutant transport in urban stormwater.
4) Development of ward-level flood risk maps to enhance emergency response and urban resilience planning.

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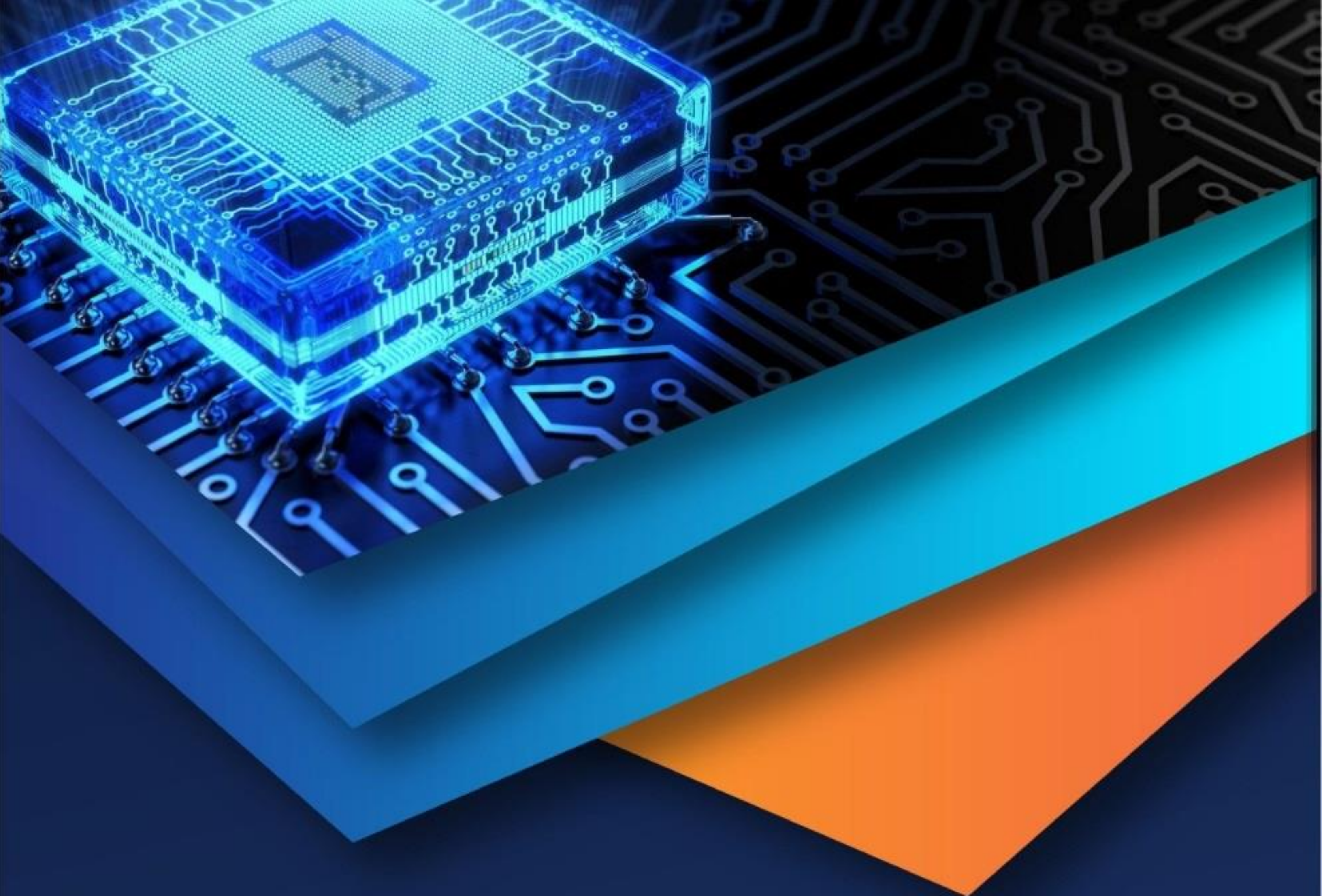

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