

Assessing Urban Surface Runoff Management Using the SWAT Model, GIS, and the Rational Method: A Case Study of Karapakkam

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Abstract

Urban surface runoff management encompasses strategies aimed at regulating rainwater flow, reducing urban flooding, enhancing groundwater recharge, and contributing to disaster risk mitigation for sustainable urban development. This study seeks to optimize surface runoff management in urban settings by using the soil and water assessment tool (SWAT) model integrated with geographic information systems (GIS) to minimize flood risks. The research focuses on the peak runoff in Karapakkam, a locality within the Chennai Metropolitan Zone. Karapakkam is a rapidly developing hub along the bustling Old Mahabalipuram Road (OMR), characterized by significant IT, industrial, and commercial activity. Its strategic importance is further highlighted by its proximity to major neighborhoods like Sholinganallur, Thoraipakkam, Pallikaranai, and Injambakkam. A primary survey, including a detailed analysis of comprehensive land use and land cover (LULC), reveals that the area is predominantly residential, with additional insights derived from the distribution of building ages. Analysis of how information technology and industrial blooms like micro- and macro-industries affect the residential zone and urban sustainable pattern of Karapakkam. During the transition, agricultural areas have vanished. Karapakkam features a variety of water bodies, with Okkiyam Maduvu standing as the largest river contributing to its hydrological diversity. Commercial sectors are primarily concentrated along state highway 49A (SH 49A), and with anticipated growth in these areas, encouraging mixed-use development can integrate multiple functions within a single building, enhancing urban sustainability. By using the SWAT model, the surface runoff can be simulated, and peak runoff is calculated by the rational method to develop mitigation strategies.

Keywords: Urban resilience, peak runoff, rational method, SWAT model, disaster risk

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INTRODUCTION

Urban surface runoff is the major issue in urban areas, such as Karapakkam, particularly in regions prone to extreme weather events. The physical characteristics of an urban area and its design, structures, buildings, settlement layout, street planning, open spaces, recreation spaces, and infrastructure. 'Land use' refers to the utilization of land in an area, including residential, mixed-use, commercial, institutional, industrial, recreation, and open spaces. Optimizing urban planning can minimize surface runoff and urban forms to achieve sustainable and liveable cities.

Aim

This study aimed to enhance urban surface runoff management by integrating the soil and water assessment tool (SWAT) model to minimize flooding risk in urban environments.

Objectives

- Evaluate water management practices and the distribution of water bodies in Karapakkam.
- Examine peak surface runoff behavior in Karapakkam.
- Assess the topographical characteristics of Karapakkam.
- Analyzing the location of water stagnation in Karapakkam.
- Utilize the SWAT model and GIS to simulate surface runoff and analyze peak runoff.

BACKGROUND

In the background study, the urban stormwater runoff quantity and the existing infrastructure may become overloaded, leading to deteriorating stormwater quality. Adaptive strategies are necessary to enhance urban water security and environmental sustainability in cold regions [1]. Identifies low-impact development (LID) stormwater control measures (SCMs) for runoff control and flood mitigation [2]. A synthetic storm pattern approach is introduced, ensuring consistent return frequencies for storm pattern inputs. The method is validated against probabilistic models, proving to be a reliable approximation for peak flow estimation [3]. Many drainage systems fail due to inadequate sizing, poor maintenance, and tidal effects, leading to urban flooding [4]. Rainfall intensity contributes the most to overall uncertainty, followed by catchment area estimations [5]. A sensitivity analysis evaluates key variables in sustainable drainage systems (SuDS) design, ensuring optimal stormwater management solutions [6]. Rapid urbanization in Malaysia has led to increased stormwater runoff and water quality degradation. GI practices, such as wetlands, parks, and floodways, are essential for improving urban water management [7]. Traditional urban stormwater management approaches are unsustainable and require an ecosystem-based strategy [8]. Visualizes runoff control effects using runoff flow rate–rainfall duration curves and bridges the gap between runoff control design and storm sewer planning [9]. Traditional rational approaches may underestimate peak and design flows, leading to potential inefficiencies in stormwater network design [10]. Optimization and risk analysis should be integrated into storm sewer network design to minimize costs and improve efficiency. The rational method was applied to the same region, but its total design cost was 5% higher than that of the dynamic method [11]. The digital elevation model (DEM) was modified to incorporate roof drainage systems and stormwater inlets, thereby enhancing the accuracy of surface runoff predictions [12].

Karapakkam is a rapidly developing residential cum commercial suburb of Chennai. Prominent areas, such as Sholinganallur, Thorapakkam, Pallaikaranai, and Injambakkam, are located nearby. Karapakkam is strategically located close to the Old Mahabalipuram Road (OMR). In 1971, the total area of Karapakkam was approximately 3.6 sq km. In 1991, the area of Karapakkam decreased to 2.4 sq km, and in 2001, the area was approximately 2.44 sq km. In 2011, the area increased to 2.89 sq km (Figures 1 and 2). The increase in residential and commercial areas is due to the development of commercial and industrial sectors along the state highway. Karapakkam is predominantly characterized by residential development, accounting for approximately 66% of the built environment. The area accommodates a diverse range of income groups, including the Middle-Income Group (MIG), Low-Income Group (LIG), Economically Weaker Sections (EWS), and High-Income Group (HIG), reflecting a socially mixed urban fabric. Institutional land uses are represented by key educational establishments such as KCG College of Technology, Chennai, India and the Government Higher Secondary School, which serve as major academic hubs within the locality. Commercial activities are primarily concentrated along SH 49A, forming a significant economic corridor. Industrial presence is marked by major entities such as Sanmar and Emerson, contributing to the area's economic base. Additionally, open spaces are interspersed within residential neighborhoods, while substantial vacant land parcels are located in the eastern part of Karapakkam, indicating potential zones for future development.

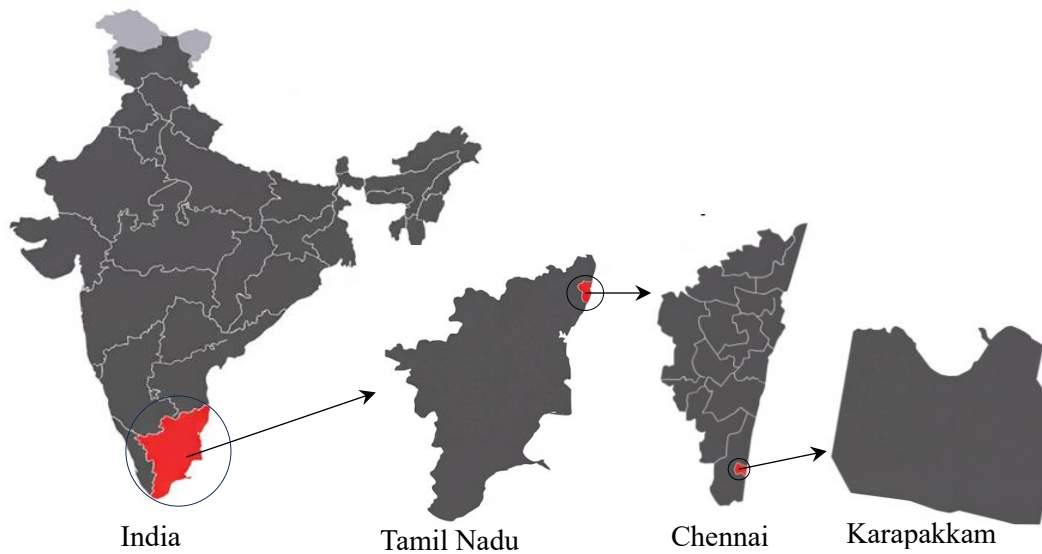


Figure 1. Key map.

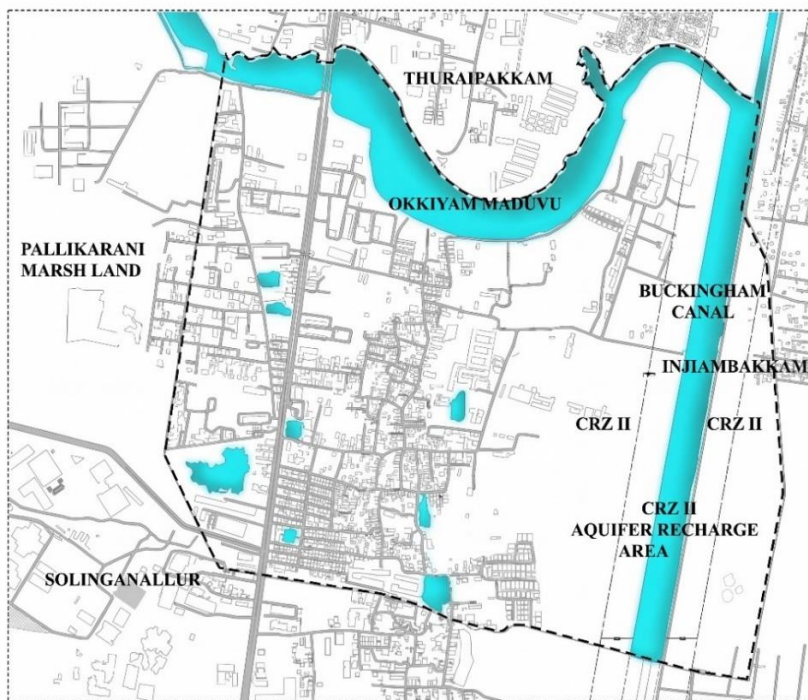


Figure 2. Basemap.

METHODOLOGY AND METHOD

A literature review and case study analysis were conducted using both national and international journals. Karapakkam was chosen because of the effects of water stagnation during a cyclone and other disasters in 2024.

This study incorporates secondary data, including base maps, precipitation records, and existing water supply usage in Karapakkam (Figure 3), and gathers primary data through field surveys and sampling to evaluate current conditions in the area. The SWAT model is employed to effectively simulate and enhance urban surface runoff management. The methodology follows a structured approach comprising data collection, preprocessing, model setup, scenario analysis, and

recommendations. The key input datasets include land use and land cover (LULC) maps, soil characteristics, and climate data, which are integrated into the SWAT model for watershed delineation in Karapakkam.

DATA COLLECTION

Data on rainfall patterns from 2000 to 2024, temperature, and land use maps were collected from the government office. This information served as the basis for analyzing surface runoff patterns and creating effective water management strategies for Karapakkam.

Water Bodies

Okkiyam Maduvu (Figure 4), also known as Okkiam Maduvu, is a 2.8 km long water channel situated in the southern suburbs of Chennai, Tamil Nadu. It originates from the Pallikaranai Wetland and flows eastward, passing through areas like Karapakkam, Okkiampet, and Thoraipakkam, before draining into the Buckingham Canal (Figure 5), near Injambakkam. The marked numbers indicate the locations of water bodies and ponds in Karapakkam. The Buckingham Canal is a 796 km long freshwater navigation canal that runs parallel to the Coromandel Coast, connecting Kakinada in Andhra Pradesh to Parangipettai near Chidambaram in Tamil Nadu. In Karapakkam, the canal serves as a major drainage route, receiving water from Okkiyam Maduvu and other local sources (Figure 6). Originally constructed during British rule, it was an important waterway for transportation but later suffered from pollution and neglect. Recent efforts have focused on rehabilitating the canal, including initiatives to restore its ecological balance and improve flood protection. Both water bodies are vital for urban water management and flood mitigation in Chennai; however, they require sustained conservation efforts to maintain their functionality and ecological health. During the cyclone, the northeastern part of Karapakkam experienced severe flooding, resulting in water stagnation in the institutional zone, particularly around KCG College of Technology, Chennai, India.

FINDINGS

Flood Risk Areas

The flood risk zones (Figure 7) are located in the northeastern part of Karapakkam and near the Pallikarnai Marshland. Owing to the lack of proper embankments and the unwanted growth of vegetation, there is an overflow of water in the institutional and residential zones. Karapakkam has experienced significant infrastructure development, resulting in fewer kutcha and semi-pucca houses, with most dwelling units now being pucca houses. In cases where residences are damaged by natural disasters, the Pradhan Mantri Awas Yojana (PMAY) scheme is implemented to facilitate reconstruction and rehabilitation efforts.

Peak Surface Runoff

The rational method is a commonly applied technique for estimating peak surface runoff in small urban watersheds. It operates on the principle that runoff is directly proportional to rainfall intensity, the contributing watershed area, and a runoff coefficient, and is particularly useful for stormwater management and drainage.

$$Q = \frac{C.I.A}{360} \quad (1)$$

C: Runoff coefficient

I: Rainfall intensity

A: Catchment area = 360 hectares

Q: Peak runoff

$$Q = \frac{C.I.A}{360}$$

$$Q = \frac{0.69 \times 1865 \times 360}{360}$$

$$=1286 \text{ m}^3/\text{s}$$

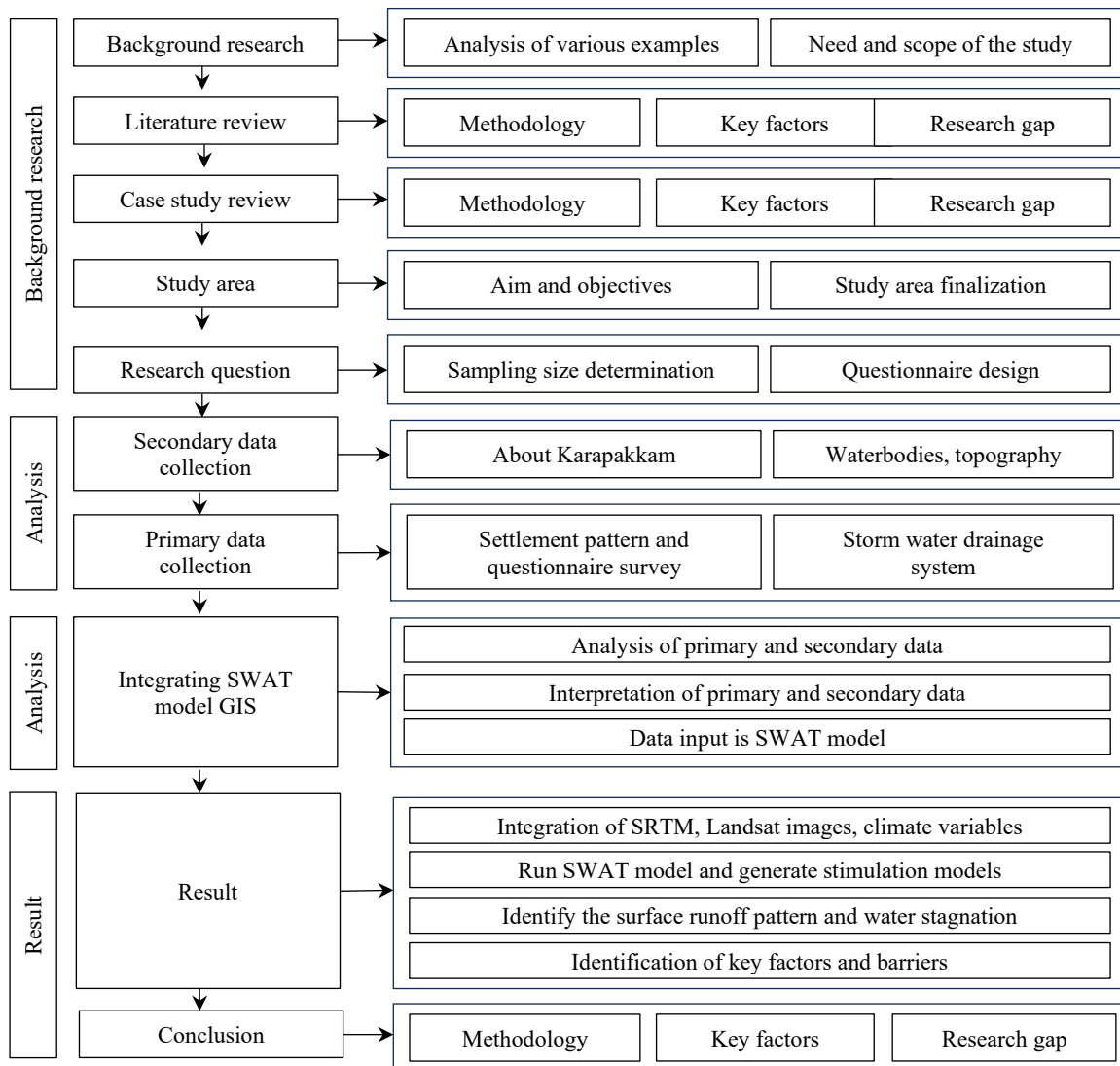


Figure 3. Methodology.

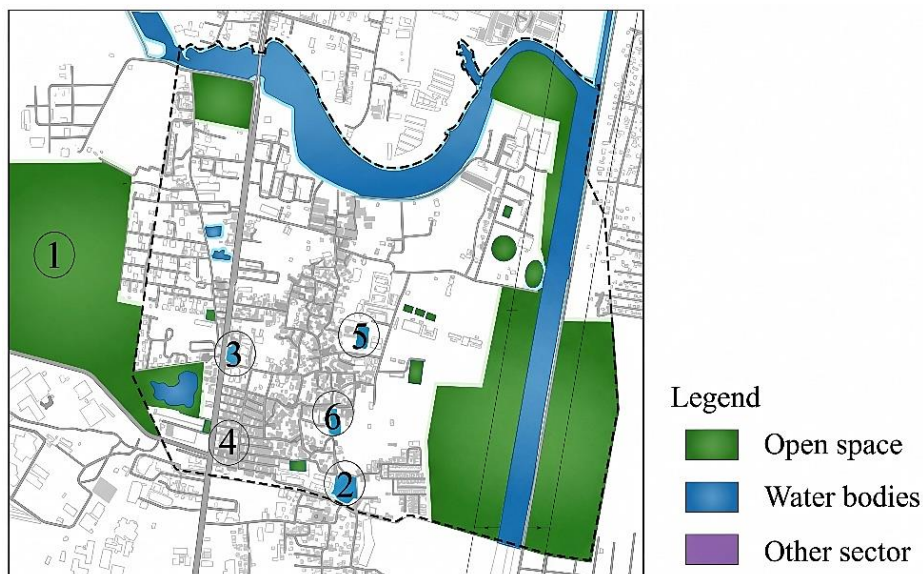


Figure 4. Open space and a water body.



Figure 5. Buckingham Canal.



Figure 6. Okkiyam Maduvu.

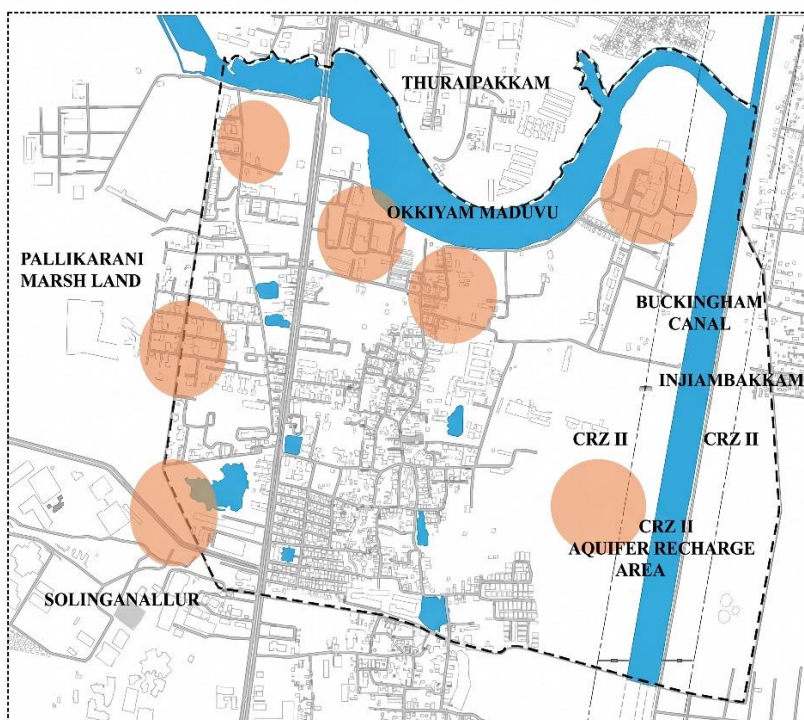


Figure 7. Flood risk areas.

A peak runoff of $1286 \text{ m}^3/\text{s}$ is substantial for an urban region such as Karapakkam; nevertheless, its classification as high or low depends on several factors, including catchment size, land use, drainage capacity, and rainfall intensity (mm/hr .). Karapakkam has a large drainage basin, which accounts for such high runoff rates. However, rapid urbanization has led to an increase in impervious surfaces, such as roads and buildings, thereby reducing infiltration and exacerbating runoff. Additionally, the existing stormwater infrastructure is not adequately designed to handle peak flows of this magnitude, thus heightening the risk of flooding in the area.

Contour

The contour map (Figure 8) of Karapakkam illustrates elevation variations within the area using a color-coded system to represent different height levels. The elevation ranges from -4.8 to 13 m , with low-lying areas marked in green and higher elevations shown in pink. The boundary of the mapped region is marked by a thick dashed black line, enclosing a mix of terrain with gradual elevation changes. The contour intervals indicate topographic shifts, which are essential for urban planning, drainage analysis, and flood risk assessment.

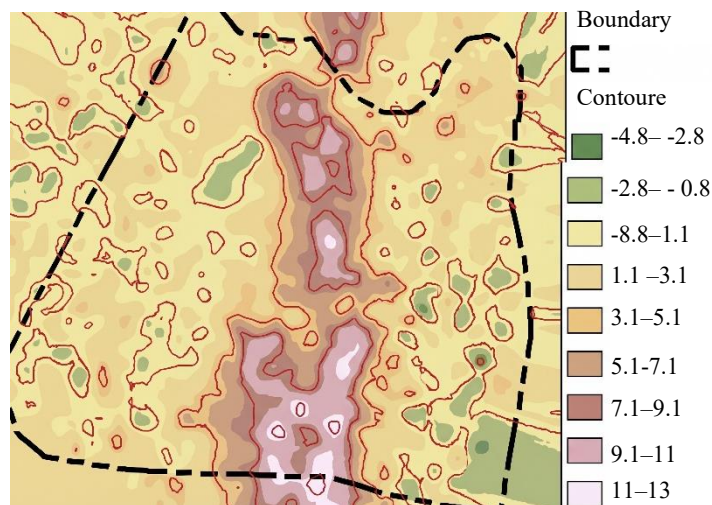


Figure 8. Flood risk areas.

SWAT Model

The SWAT is a widely used hydrological model that helps simulate surface runoff in watersheds. In the case of Karapakkam (Figure 9), a peri-urban area near Chennai, Tamil Nadu, India, the SWAT model can be effectively applied to urban surface runoff management using geographic information systems (GIS) and field data. A DEM was used to delineate watershed boundaries and drainage patterns. LULC helps identify impervious surfaces, urban areas, roads, and pervious surfaces. Climate data, including rainfall, temperature, and evaporation, were input for hydrological simulations. The slope of Karapakkam significantly influences runoff patterns, with most areas classified as low-lying. The central core of Karapakkam has a slight elevation, resulting in lower terrain on both the eastern and western sides.

Owing to the poorly maintained embankments along Okkiyam Maduvu, excess water frequently overflows into surrounding residential and institutional zones, exacerbating flood risk in the region. The proposed measures include constructing embankments along rivers and canals, desilting water bodies to restore their capacity, and enhancing soil permeability to improve water infiltration and reduce surface runoff.

Watershed delineation for Karapakkam involves identifying and mapping the boundaries that define the area contributing surface runoff to a common outlet point. (Figure 10) Using DEMs in GIS, the natural drainage patterns, flow directions, and accumulation points are analyzed to accurately demarcate the watershed extent.

This process helps us to understand the hydrological characteristics of Karapakkam, including runoff pathways, catchment area size, and the location of sub-watersheds. Accurate delineation is essential for surface runoff modeling, water resource planning, and flood management, as it provides a spatial framework for further hydrological and environmental assessments in the region.

In the SWAT model application for Karapakkam, the calibration period refers to the timeframe during which observed hydrological data are used to adjust the model parameters to best match the measured streamflow or runoff conditions (Figures 11 and 12). This step ensures that the model accurately represents the hydrological processes of the watershed under study. The validation period follows the calibration stage and involves applying the calibrated parameters to a different set of observed data to test the model's predictive capability without further adjustments. Selecting appropriate calibration and validation periods—ideally representing diverse hydrological conditions—is crucial for improving the reliability of the model in simulating surface runoff and assessing water management strategies in Karapakkam.

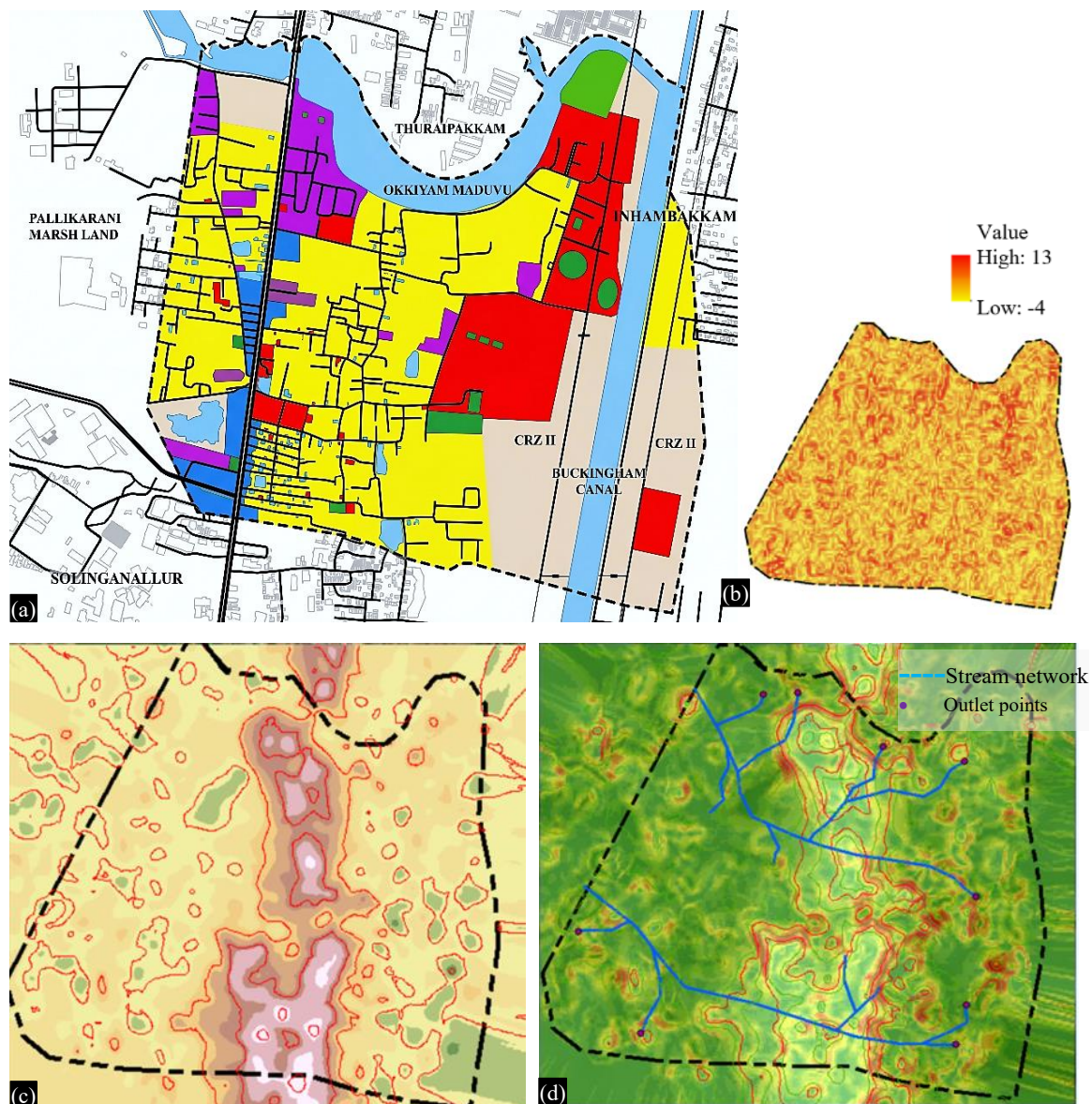


Figure 9. (a–d) SWAT model. (a) Land use, 2024; (b) Slope map; (c) Contour map; and (d) Watershed delineation.

Proposals

Mitigating urban flooding and enhancing permeability are crucial for improving groundwater recharge, and sponge parks (Figure 13) play a vital role in achieving these goals. Sponge parks are green infrastructure solutions designed to absorb and manage stormwater effectively. They incorporate permeable surfaces, rain gardens, bioswales, and retention ponds to capture excess runoff, allowing water to infiltrate the ground rather than overwhelming drainage systems. Sponge parks reduce surface runoff and minimize urban flooding.

They enhance infiltration, replenishing underground water reserves. They lower temperatures by increasing vegetation and reducing heat absorption. Also filters pollutants before the water reaches natural bodies. Constructing embankments and desilting canals and water bodies (Figure 14) are effective flood risk reduction measures. These actions improve water flow, increase storage capacity, and enhance drainage efficiency, thereby minimizing overflow and safeguarding urban areas from severe flooding during heavy rainfall.

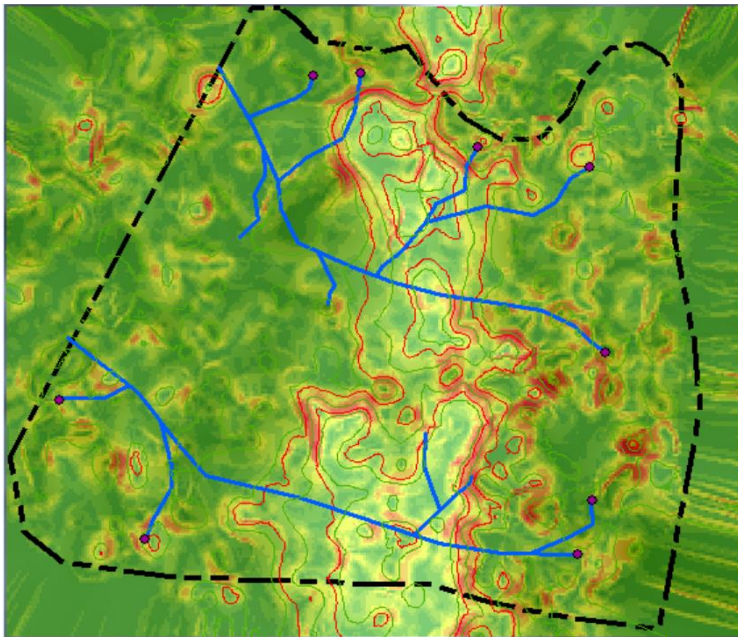


Figure 10. Watershed delineation.

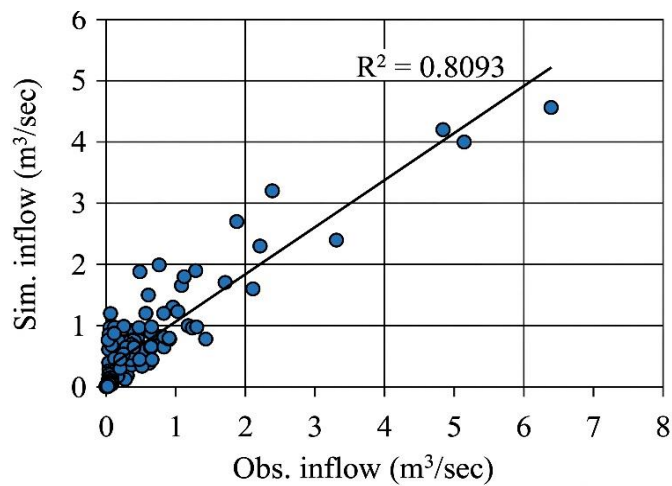


Figure 11. Calibration period.

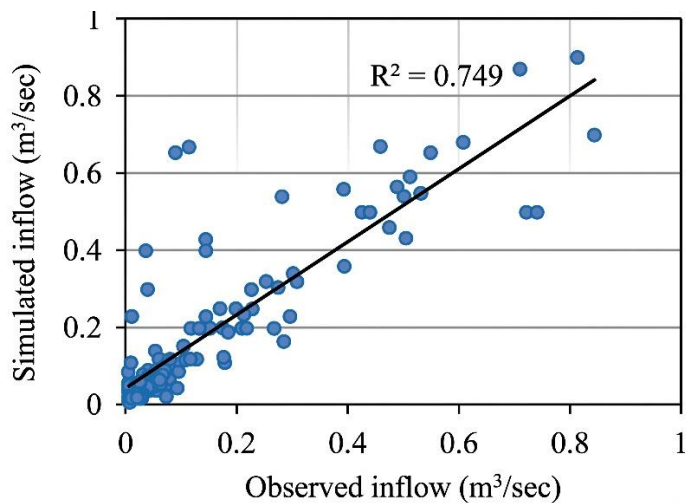


Figure 12. Validation period.

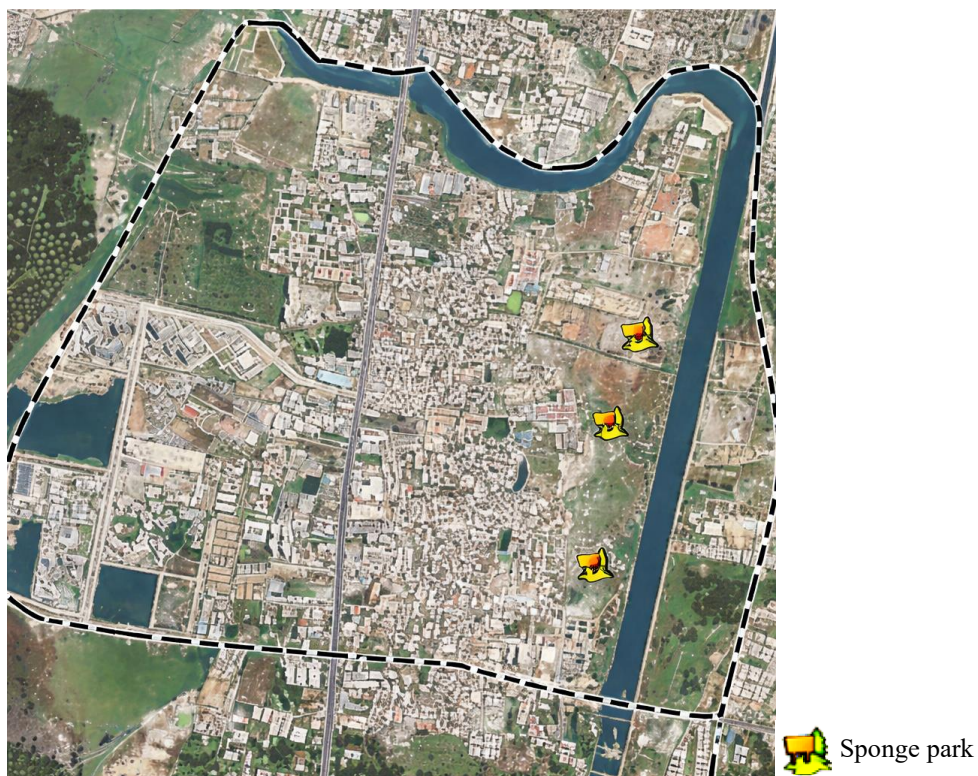


Figure 13. Sponge park.

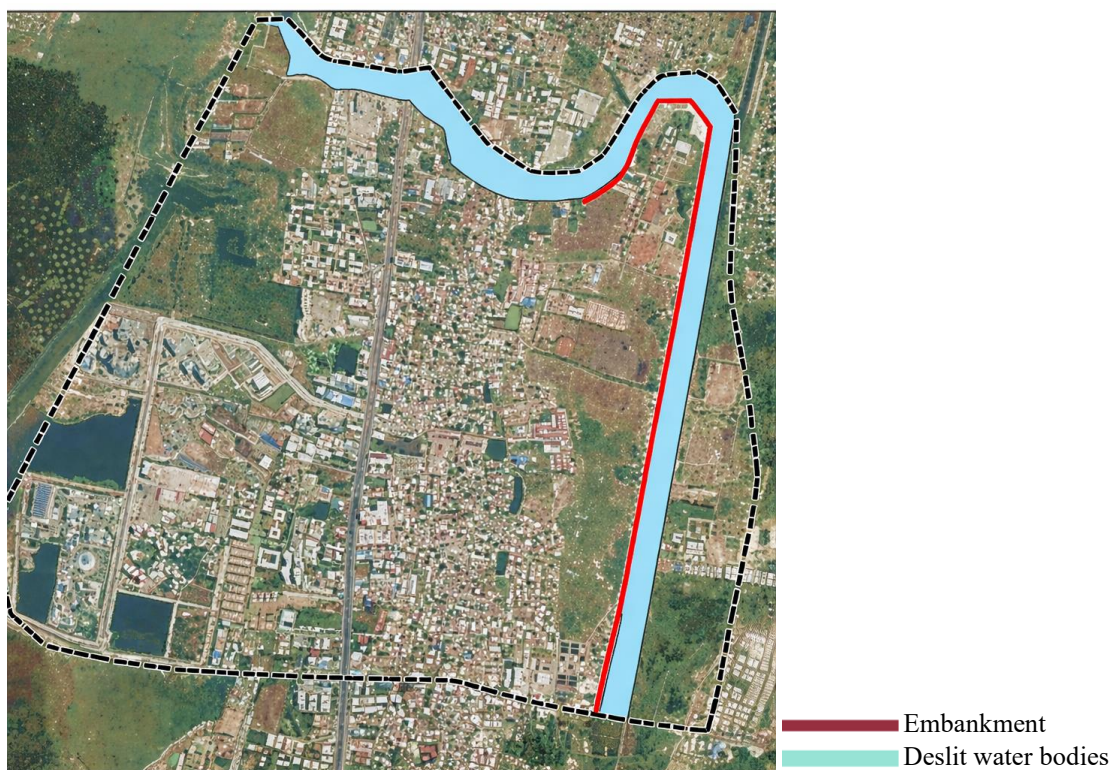


Figure 14. Embankment of water bodies.

Embankments and the desilting of water bodies play a crucial role in flood control, water management, and ecological preservation. Embankments act as protective barriers, preventing rivers and canals from overflowing into urban and rural areas, thereby reducing flood risk during heavy

rainfall. They also help channel water flow efficiently, minimizing erosion and safeguarding infrastructure. In contrast, desilting improves water storage capacity and enhances drainage efficiency by removing accumulated sediments that obstruct the flow, reducing the chances of water stagnation and urban flooding. Additionally, clearing silt restores infiltration rates, aiding groundwater recharge and ensuring better water availability. Maintaining embankments and desilting water bodies is also essential for preserving aquatic ecosystems, as it prevents habitat degradation and supports biodiversity. Together, these measures enhance climate resilience, ensuring sustainable water management and mitigating the impact of extreme weather events.

Permeable pavements made of porous concrete, interlocking pavers, or permeable asphalt allow rainwater to pass through the surface and infiltrate into the underlying soil layers, thereby reducing surface runoff volumes. Additionally, strategically placed infiltration trenches and recharge pits can further promote percolation and mitigate flood risk during heavy rainfall events. These measures not only reduce pressure on the existing stormwater drainage network but also help replenish local aquifers, supporting long-term water security. The integration of such nature-based solutions within residential layouts, commercial areas, and along road networks can significantly improve the resilience of Karapakkam against climate-induced extreme rainfall.

DISCUSSIONS

The SWAT simulations effectively captured the impacts of land use changes, particularly high runoff generation in densely urbanized areas resulting from increased impervious surfaces. The results indicated that areas with low vegetation cover and compacted soils experienced significantly higher surface runoff, potentially leading to flooding during heavy rainfall events. A comparison between SWAT and the rational method revealed that while SWAT offered a more comprehensive, long-term hydrological assessment, the rational method was useful for quick peak discharge estimations in smaller subcatchments. GIS-based spatial analysis further helped identify critical flood-prone zones, emphasizing the need for improved stormwater infrastructure. The study highlighted the importance of sustainable urban planning, suggesting measures such as permeable pavements, rainwater harvesting, and retention ponds to mitigate runoff. However, limitations included data constraints, such as limited high-resolution rainfall and soil data, which may affect model accuracy. Future studies could incorporate real-time monitoring and climate change scenarios to enhance predictive reliability. The limited availability of high-resolution rainfall and soil data significantly affects the accuracy of hydrological modeling and surface runoff estimation in Karapakkam. Inadequate spatial and temporal resolution of rainfall data can lead to underestimation or overestimation of runoff volumes, whereas coarse soil datasets may fail to capture localized variations in infiltration capacity and permeability. These limitations reduce the reliability of simulation outputs, making it challenging to develop precise flood management strategies or water resource plans for the area. Consequently, improving the resolution and quality of input datasets is essential for enhancing the accuracy of surface runoff analysis in Karapakkam.

CONCLUSION

This study demonstrated the effectiveness of combining the SWAT model, GIS, and rational method for assessing urban surface runoff in Karapakkam. The findings underscored the significant role of urbanization in altering natural drainage patterns, leading to increased flood risk. The SWAT model successfully simulated runoff dynamics, whereas GIS provided critical spatial insights for targeted mitigation strategies. The rational method complements the SWAT by offering simplified peak flow estimations for urban drainage design.

The results call for the urgent implementation of sustainable urban drainage systems (SUDS) and better land use planning to reduce runoff and enhance water retention. Policymakers and urban planners can leverage these findings to develop flood-resilient infrastructure in rapidly urbanizing areas, such as Karapakkam. Future research should focus on integrating higher-resolution datasets and climate projections to improve long-term runoff predictions under changing environmental conditions. Overall,

this study provides a robust framework for urban water management, balancing development with ecological sustainability.

REFERENCES

1. Yang Y, Zhu DZ, Loewen MR, Zhang W, van Duijn B, Mahmood K. Impacts of climate change on urban stormwater runoff quantity and quality in a cold region. *Sci Total Environ.* 2024;954:176439. doi:10.1016/j.scitotenv.2024.176439.
2. Mani M, Bozorg-Haddad O, Loáiciga HA. A new framework for the optimal management of urban runoff with low-impact development stormwater control measures considering service-performance reduction. *J Hydroinform.* 2019;21(5):727–744. doi:10.2166/hydro.2019.126.
3. Hromadka TV. The rational method in stormwater management modelling of peak flow flood control systems, I: theoretical development. *Environ Softw.* 1989;4(3):123–129. doi:10.1016/0266-9838(89)90042-7.
4. Kyi MP, Zin WW. Analysis of drainage capacity by using rational method and storm water management model. *Int J Res Civ Mech Eng.* 2018;F:0418118. doi:10.15242/IJRCMCE.F0418118.
5. Bondeson S. Uncertainty analysis of the rational method in stormwater management: a case study in Gråbo, Lerum Municipality, using multi-criteria analysis [master's thesis]. Gothenburg: Chalmers University of Technology; 2021.
6. Rodríguez-Sinobas L, Zubelzu S, Perales-Momparler S, Canogar S. Techniques and criteria for sustainable urban stormwater management: the case study of Valdebebas (Madrid, Spain). *J Clean Prod.* 2018;172:402–416. doi:10.1016/j.jclepro.2017.10.070.
7. Haris H, Chow MF, Usman F, Sidek LM, Roseli ZA, Norlida MD. Urban stormwater management model and tools for designing stormwater management of green infrastructure practices. *IOP Conf Ser Earth Environ Sci.* 2016;32:012022. doi:10.1088/1755-1315/32/1/012022.
8. Brown RR. Institutionalisation of integrated urban stormwater management: multiple-case analysis of local management reform across metropolitan Sydney [PhD dissertation]. Sydney: University of New South Wales; 2003.
9. Wang S, Wang H. Extending the rational method for assessing and developing sustainable urban drainage systems. *Water Res.* 2018;144:112–125. doi:10.1016/j.watres.2018.07.022.
10. Freire Diogo A, Antunes do Carmo J. Peak flows and stormwater networks design: current and future management of urban surface watersheds. *Water.* 2019;11(4):759. doi:10.3390/w11040759.
11. Sadeghi S, Samani JMV, Samani HMM. Risk and damage-based optimal design of storm sewer networks using rational and fully dynamic methods: a case study (Tehran region 2). *Water Sci Technol.* 2022;85(12):3419–3435. doi:10.2166/wst.2022.180.
12. Hosseiny H, Crimmins M, Smith VB, Kremer P. A generalized automated framework for urban runoff modeling and its application at a citywide landscape. *Water.* 2020;12(2):357. doi:10.3390/w12020357.