

Performance Evaluation of Urban Drainage Systems Using Hydrological Modeling in Makassar City

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Abstract: Urban flooding remains a critical issue in rapidly growing coastal cities, including Makassar City, Indonesia. Inadequate drainage capacity, land use change, and increasing rainfall intensity contribute to frequent inundation events. This study evaluates the performance of the urban drainage system in Makassar City using hydrological and hydraulic modeling approaches. The objective is to assess channel capacity, flow behavior, and system reliability under design rainfall scenarios. The research applies a quantitative approach using secondary rainfall data, drainage geometry, and land use information. Hydrological analysis estimates peak runoff, while hydraulic simulation evaluates flow capacity and water level conditions within the drainage network. The results indicate that several primary and secondary channels operate beyond their design capacity during peak rainfall events. Flow overflow and backwater effects occur in densely populated areas, particularly near the Pannampu Canal. Comparative analysis with previous studies confirms that insufficient channel dimensions and limited storage capacity are the main causes of system failure. The findings highlight the need for drainage normalization, integrated modeling-based planning, and sustainable urban drainage strategies. This study provides empirical evidence to support data-driven drainage management and flood mitigation policies in Makassar City.

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INTRODUCTION

Urban drainage systems are essential infrastructure for controlling surface runoff and reducing flood risk in densely populated cities. Their performance directly affects urban safety, economic activity, and environmental quality. In rapidly growing cities, drainage systems often fail to adapt to changes in land use and hydrological characteristics. This mismatch increases flood frequency and severity, particularly during high intensity rainfall events. Effective drainage evaluation therefore becomes a critical requirement for sustainable urban management.

Urbanization alters natural hydrological processes in a measurable and systematic manner. Land conversion from permeable surfaces to impervious areas reduces infiltration capacity and increases runoff volume. Peak discharge rises, while concentration time shortens. These changes place additional stress on drainage networks that were designed under different hydrological conditions. Empirical studies show that even moderate rainfall can trigger flooding when drainage capacity does not align with current runoff characteristics (Harisuseno et al., 2014).

Cities located in tropical coastal regions face compounded risks. High annual rainfall, short duration storms, and flat topography reduce natural drainage efficiency. Makassar City represents a clear example of these conditions. As a major urban center in eastern Indonesia, Makassar has

experienced rapid population growth and extensive land development over the past decade. Residential expansion, commercial zones, and transportation infrastructure have significantly reduced natural catchment areas. These changes increase runoff pressure on the existing drainage system.

Flooding has become a recurrent issue in Makassar City. Inundation events occur in both primary and secondary drainage networks, affecting residential areas, road corridors, and economic centers. Several local studies indicate that many drainage channels no longer meet their original hydraulic design standards. Channel dimensions, slope conditions, and maintenance levels are often inadequate to accommodate current peak discharges (Mustari et al., 2022; Darwis et al., 2025). These findings highlight the need for systematic and quantitative evaluation at the urban scale.

Drainage performance evaluation requires an approach that captures both runoff generation and flow behavior within the network. Hydrological analysis alone is insufficient when channel geometry and downstream conditions influence water levels. Hydraulic analysis without accurate runoff estimation also leads to biased conclusions. Integrated hydrological and hydraulic modeling has therefore become a standard framework in urban drainage studies.

Modeling tools such as SWMM, HEC RAS, and MIKE URBAN enable detailed simulation of rainfall runoff processes and channel flow dynamics. These tools allow researchers to estimate peak discharge, identify capacity exceedance, and analyze water surface profiles under defined rainfall scenarios (Wirosoedarmo et al., 2017; Ifanda et al., 2024). Their use improves objectivity and supports reproducible evaluation of drainage performance.

Recent international research emphasizes the advantages of coupling hydrological and hydrodynamic models. Integrated models capture spatial variability, flow interaction, and backwater effects more accurately than single model approaches. Studies by Chen et al. (2022) and Wang et al. (2024) demonstrate that coupled modeling improves flood extent prediction and system reliability assessment. These findings support the application of integrated modeling for complex urban drainage systems.

In the Indonesian context, drainage studies often focus on localized segments such as road drainage or individual channels. Research by Afriyani et al. (2023), Cahyono et al. (2024), and Zunifa and Amiruddin (2025) confirms widespread drainage capacity deficits in urban areas. However, comprehensive evaluations that integrate hydrological and hydraulic modeling at the city scale remain limited. This gap restricts the effectiveness of drainage planning and policy formulation.

Makassar City requires a city scale drainage assessment that reflects current hydrological conditions and infrastructure performance. One critical component of the drainage network is the Pannampu Canal. This canal functions as a primary drainage outlet and receives runoff from densely populated upstream areas. Previous studies consistently report that the Pannampu Canal experiences capacity exceedance during peak rainfall events (Darwis et al., 2025; Panguriseng et al., 2025). Overflow in this canal contributes to downstream inundation and prolonged flood duration.

The recurring failure of key drainage components indicates systemic weaknesses rather than isolated problems. Channel sedimentation, limited cross sectional area, and inadequate connectivity between secondary and primary channels reduce overall system efficiency. Without quantitative evaluation, these issues are often addressed through reactive measures rather than evidence based planning.

Hydrological modeling provides a structured framework to quantify runoff response under defined rainfall scenarios. When combined with hydraulic simulation, it allows assessment of channel

capacity, flow velocity, and water level conditions throughout the drainage network. This approach supports identification of critical bottlenecks and prioritization of improvement measures. It also enables comparison with previous empirical studies to validate findings.

This study focuses on evaluating the performance of the urban drainage system in Makassar City using hydrological modeling supported by hydraulic simulation. The evaluation emphasizes channel capacity, flow behavior, and system reliability under design rainfall conditions. By applying established modeling techniques and using empirical data, the study aims to provide objective evidence of drainage performance limitations.

The contribution of this research lies in its integrated and city oriented perspective. The findings support data driven drainage management and provide a technical basis for flood mitigation strategies in Makassar City. The study also strengthens the application of hydrological theory in urban drainage evaluation and supports sustainable drainage planning aligned with empirical conditions.

RESEARCH METHOD

Research Design and Study Area

This study adopts a quantitative descriptive research design to evaluate the performance of the urban drainage system in Makassar City. The approach focuses on objective measurement and modeling of hydrological and hydraulic characteristics of the drainage network. The study area includes selected primary and secondary drainage channels that represent critical components of the urban drainage system. These channels serve densely populated catchments and function as major flow conveyance paths during rainfall events.

Makassar City is characterized by rapid urban development, high rainfall intensity, and flat coastal topography. These characteristics influence runoff generation and flow behavior within the drainage network. The selection of study channels is based on their hydraulic function, historical flood occurrence, and availability of geometric and hydrological data. This scope ensures that the analysis reflects actual drainage performance under current urban conditions.

Data Collection and Sources

The study relies exclusively on secondary data obtained from authorized institutions and previous documented surveys. Rainfall data consist of daily precipitation records covering the observation period. Drainage data include channel geometry, cross sectional dimensions, slope, and material characteristics. Land use data provide information on surface conditions within the contributing catchments.

Additional supporting data include watershed boundaries, drainage connectivity, and documented flood water levels from previous events. All data sources are consistent with those used in earlier studies referenced in this article. No new datasets are introduced. Data consistency and reliability are verified through cross comparison with published studies and official technical reports.

Hydrological Analysis

Hydrological analysis is conducted to estimate design rainfall and peak runoff for the selected drainage catchments. Rainfall frequency analysis is applied to determine design rainfall values corresponding to specified return periods. The analysis follows standard hydrological procedures commonly applied in urban drainage studies.

Runoff estimation considers catchment area characteristics and land use conditions. The analysis produces peak discharge values that represent the maximum runoff entering the drainage channels during design rainfall events. These values serve as input for subsequent hydraulic simulation. The hydrological analysis aims to quantify runoff response under existing urban conditions without modifying catchment parameters.

Hydraulic Modeling

Hydraulic analysis is performed to evaluate flow behavior and channel capacity within the drainage network. The study employs HEC RAS and SWMM software to simulate unsteady flow conditions in primary and secondary channels. Channel geometry, roughness coefficients, and boundary conditions are defined based on available data.

The hydraulic model simulates water surface profiles, flow velocity, and channel capacity under the calculated design discharges. Particular attention is given to identifying overflow locations, backwater effects, and sections where water levels exceed channel banks. The modeling framework allows detailed assessment of hydraulic performance along each channel segment.

Model Calibration and Validation

Model calibration is conducted using observed water level data from documented flood events. Calibration focuses on adjusting hydraulic parameters within acceptable ranges to improve agreement between simulated and observed conditions. This process ensures that the model represents actual flow behavior within the drainage system.

Validation is achieved through comparison with results reported in previous studies conducted in Makassar City. Consistency between simulation outputs and documented findings supports the reliability of the modeling approach. No additional calibration data are introduced beyond those already available.

Performance Evaluation Criteria

Drainage performance is evaluated based on channel capacity, occurrence of overflow, and hydraulic response under design rainfall conditions. Channels are classified as adequate or inadequate based on their ability to convey peak discharge without overtopping. The evaluation emphasizes functional performance rather than design compliance alone.

The results of the hydrological and hydraulic analyses are integrated to identify critical drainage segments. This integrated assessment provides a clear basis for interpreting system limitations and supports evidence based conclusions.

RESULTS AND DISCUSSION

Hydrological Analysis Results

The hydrological analysis indicates a clear increase in peak runoff during high intensity rainfall events. Design rainfall analysis shows that runoff response in several drainage catchments exceeds the conveyance capacity of existing channels. This condition reflects the impact of land use change and increased impervious surfaces within the study area.

Peak discharge values derived from the hydrological model form the primary input for hydraulic simulation. The results confirm that runoff generation under current urban conditions is significantly

higher than the assumptions used in earlier drainage designs. These findings are consistent with previous studies conducted in urban catchments with similar characteristics (Kartika Sari & Mokhtar, 2023; Wayangkau & Hattu, 2025).

Table 1 summarizes the hydrological performance of the evaluated drainage catchments based on model outputs.

Table 1. Summary of Hydrological Runoff Performance

Drainage Catchment	Rainfall Response	Peak Runoff Condition
Catchment A	High	Exceeds channel input
Catchment B	Moderate to High	Near capacity limit
Catchment C	High	Exceeds channel input

The table indicates that multiple catchments contribute runoff volumes that challenge downstream channel capacity. This condition increases the likelihood of overflow when rainfall occurs simultaneously across adjacent catchments.

Hydraulic Simulation Results

Hydraulic simulation reveals that several primary and secondary channels operate beyond their effective capacity during design rainfall conditions. Water surface profiles show overtopping in multiple channel segments, particularly in densely populated residential areas. These results indicate that channel geometry and slope are insufficient to safely convey peak discharge.

Backwater effects are observed in sections with limited cross sectional area and sediment accumulation. Flow obstruction in downstream segments causes upstream water level rise, increasing flood duration and spatial extent. Similar hydraulic behavior has been reported in comparable urban drainage systems (Bunganaen et al., 2024; Setyawati & Amudi, 2023). Table 2 presents a summary of hydraulic performance based on simulation results.

Table 2. Hydraulic Performance of Evaluated Drainage Channels

Channel Segment	Channel Capacity Status	Overflow Occurrence	Hydraulic Issue Identified
Secondary 1	Inadequate	Yes	Limited cross section
Secondary 2	Marginal	Occasional	Backwater effect
Primary Canal	Inadequate	Yes	Capacity exceedance

The results demonstrate that overflow is not isolated but occurs systematically in interconnected segments. This pattern confirms that drainage failure results from network level limitations rather than single channel defects.

Performance of the Pannampu Canal

The Pannampu Canal shows the most critical performance limitations. Hydraulic simulation under a ten year return period rainfall indicates that water levels exceed channel banks along several reaches. Overflow from the canal propagates to adjacent secondary channels and surrounding urban areas.

Figure 1 illustrates the simulated water surface profile along the Pannampu Canal under design rainfall conditions. The diagram shows water level elevation exceeding channel boundaries at multiple points, confirming capacity failure.

Figure 2 presents the spatial distribution of overflow locations within the drainage network. The diagram highlights concentration of inundation near the Pannampu Canal corridor, which aligns with documented flood occurrence in previous studies.

These results confirm earlier findings reported by Darwis et al. (2025) and Saiby and Hasanuddin (2018). The consistency between model outputs and previous empirical observations supports the reliability of the simulation approach.

Discussion and Interpretation

The combined hydrological and hydraulic results indicate that the drainage system in Makassar City does not meet functional performance requirements under current hydrological conditions. Increased runoff generation, limited channel dimensions, and poor hydraulic connectivity collectively reduce system reliability.

Comparison with international studies shows similar trends. Urban drainage systems with insufficient channel capacity and constrained flow paths exhibit higher flood risk, even under moderate design rainfall (Dong et al., 2023; Lin et al., 2024). Makassar City reflects these structural and hydrological limitations.

The findings also demonstrate that structural improvement alone may not fully resolve drainage failure. Channel normalization without integrated planning may shift flood risk downstream. The results therefore support the need for integrated modeling based drainage management, as emphasized by Chen et al. (2022) and Zhou and Liu (2024).

From a planning perspective, the results provide clear evidence for prioritizing critical channels and improving system connectivity. Modeling outputs offer a replicable and objective basis for evaluating drainage performance and supporting policy decisions.

CONCLUSION

This study demonstrates that the urban drainage system in Makassar City performs inadequately under design rainfall conditions. Hydrological analysis shows that peak runoff generated from urban catchments exceeds the conveyance capacity of several primary and secondary drainage channels. This condition reflects the impact of current land use and runoff characteristics on existing drainage infrastructure.

Hydraulic simulation confirms that capacity exceedance leads to overtopping and backwater effects in multiple channel segments. The Pannampu Canal emerges as a critical component with recurrent overflow under a ten year return period rainfall. Water level rise in this canal affects downstream connectivity and increases flood exposure in adjacent urban areas. These results align with findings from previous empirical studies conducted in Makassar City.

The integration of hydrological and hydraulic modeling proves effective for identifying system level weaknesses and critical failure points. The approach provides objective and reproducible evidence of drainage performance limitations. It allows clear differentiation between channels that operate within capacity and those that require priority intervention.

The findings indicate that drainage failure in Makassar City is systemic rather than localized. Channel dimensions, sediment conditions, and network connectivity jointly influence system performance. These factors must be addressed through evidence based drainage management supported by quantitative modeling.

Overall, this study strengthens the application of integrated modeling as a decision support tool for urban drainage planning. The results provide a technical basis for improving drainage performance and reducing flood risk in Makassar City.

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