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Analysis of The Effectiveness of Urban Drainage Systems in Mitigating Flood Risk: A Case Study of Bima Regency

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ABSTRACT

Flooding in urban areas is a critical issue influenced by various factors, such as changes in land use, rainfall intensity, and inadequate drainage system capacity. Bima Regency, as an area experiencing rapid urban development, faces serious challenges in drainage management. This study aims to analyse the effectiveness of the urban drainage system in mitigating flood risks in Bima Regency. The methods employed are quantitative and qualitative approaches through hydrological analysis, channel capacity evaluation, and field observations. The results of the study indicate that the majority of drainage channels are unable to accommodate peak flow caused by heavy rainfall, and there are issues with sedimentation and blockages caused by waste. Therefore, improvements to the drainage system are required through increased capacity, routine maintenance, and integration with community-based environmental management systems.

INTRODUCTION

Flooding in urban areas is widely recognized as a hydrometeorological disaster whose increasing intensity has caused widespread disruption to social stability and the economic well-being of affected communities (Kodoatie and Sjarief 2010). This escalating risk is closely associated with rapid urban expansion, whereby the conversion of green spaces into impervious surfaces substantially reduces soil infiltration capacity and increases surface runoff, a primary determinant of urban flooding (Suripin 2019). Flooding is classified as one of the most destructive hydrometeorological disasters, recurrently affecting urban areas and generating multidimensional consequences. According to Setiawan (2026), its impacts extend beyond physical damage to affect fundamental aspects of social and economic life, including infrastructure deterioration, disruptions to mobility and logistical networks, and declining regional productivity. The recurrent nature of urban flooding requires a comprehensive understanding of the interactions between climatic factors and urban spatial planning to minimize systemic losses through more adaptive mitigation strategies. From a technical perspective, the increasing risk of urban flooding is strongly influenced by urbanization processes that frequently neglect the principles of environmental balance. Wesli (2020) explains that uncontrolled building development and road-network expansion have substantially reduced the extent of natural water catchment areas. Consequently, rainwater can no longer infiltrate adequately into subsurface aquifers and is instead converted into surface runoff with greater volume and velocity. This phenomenon places excessive pressure on existing drainage systems with limited capacity, making the overflow of water into residential areas increasingly unavoidable.

The imbalance between runoff volume and infiltration capacity ultimately creates a long-term cycle of vulnerability within urban ecosystems. The combined effects of diminishing green open spaces and increasing runoff coefficients necessitate a transformation in urban water management, shifting from conventional drainage systems toward more sustainable approaches. By reintegrating infiltration functions into urban design, flood risk can be mitigated at its source, thereby preserving the socio-structural integrity of urban areas amid increasingly extreme climate-related challenges. Bima Regency is among the regions in Indonesia experiencing heightened flood risk due to land-use changes and inadequately functioning drainage systems. High rainfall intensity, combined with the area's relatively flat topography, further exacerbates waterlogging in several urban areas (BMKG 2023).

According to Theresia and Santoso (2025), urban drainage systems play a crucial role in effectively conveying stormwater, thereby reducing the risk of waterlogging and flooding. In practice, however, many drainage systems fail to function optimally because of inadequate planning, limited hydraulic capacity, and insufficient maintenance (Wesli 2020). In addition to technical factors, drainage performance is influenced by community behavior, particularly the disposal of solid waste into drainage channels, which causes blockages. Such obstructions reduce flow capacity and increase the likelihood of flooding (Yuliani 2022). Previous studies have demonstrated that drainage-system performance can be evaluated by comparing design discharge with channel capacity to determine its effectiveness in conveying stormwater (Chow, Maidment, and Mays 1988). This approach is essential for identifying the need for drainage-system rehabilitation or capacity enhancement.

Building upon the identified problems, this study evaluates the technical performance of the drainage network in Bima Regency in mitigating flood risk and formulates infrastructure rehabilitation strategies that are consistent with the region's geographical characteristics and the specific needs of local communities. The primary objective of this research is to conduct a technical assessment and comprehensive analysis of the effectiveness of the drainage system currently operating in Bima Regency. Given the increasing frequency of flood events, this evaluation is crucial for determining the extent to which the existing infrastructure can accommodate surface runoff during extreme rainfall events. By identifying critical weaknesses within the drainage network, this study seeks to provide an objective, data-driven basis for determining whether system failures are caused by inadequate hydraulic capacity, physical obstructions, or shortcomings in macro-level planning. The effectiveness assessment is not limited to quantitative calculations but also encompasses an evaluation of the drainage system's function as a primary instrument for flood-risk mitigation. Within a construction project management framework, system performance should be assessed according to its capacity to protect residential areas and critical infrastructure from hydrometeorological hazards. Through accurate modelling simulations, this study compares the runoff volume generated by the design rainfall with the actual conveyance capacity of the drainage channels, thereby enabling the vulnerability level of the study area to be determined precisely (Nuhun et al. 2024).

According to Gustomi et al. (2023), the principal outcome of this study is the formulation of practical recommendations grounded in local conditions and knowledge. Given the distinctive topographical and sociocultural characteristics of Bima Regency, the proposed solutions should not merely adopt general standards but must be adapted to land availability, locally sourced materials, and the maintenance capacity of the relevant authorities. Accordingly, the recommendations are expected to serve as a strategic reference for the local government in allocating budgets for water infrastructure development that is appropriate, efficient, and sustainable (Hannan, Andriani, and Lisma 2024).

RESEARCH METHODS

This study employed a mixed-methods descriptive approach, integrating quantitative and qualitative analyses through the following stages:

1. Data collection

Daily rainfall data are essential for hydrological analysis because they provide information on the rainfall characteristics of a particular region, particularly for drainage-system planning and flood management. These data are generally obtained from official institutions, such as the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), which operates a network of weather-monitoring stations across the country. For Bima Regency, BMKG provides daily rainfall records encompassing rainfall intensity, duration, and temporal distribution over specified periods (Ulva, Hidayati, and Rochmant 2025). The data are collected through climatological stations and rainfall-monitoring posts distributed throughout Bima Regency and its surrounding areas. These daily rainfall records are subsequently used to calculate hydrological parameters, including rainfall intensity, maximum rainfall, and rainfall return periods, which are essential for determining the design discharge of the drainage system. The use of BMKG data enhances the accuracy and reliability of the analysis because the data are obtained from an official institution that applies standardized measurement and data-validation procedures (Putra 2025).

2. Existing drainage channel conditions

Data on the existing condition of drainage channels describe the actual state of the drainage network in the field at the time of the study. These data encompass several important aspects, including channel dimensions (width, depth, and length), cross-sectional geometry (rectangular, trapezoidal, or circular), construction materials (concrete, masonry, or earth), channel slope, and physical conditions, such as structural damage, sediment accumulation, and solid-waste blockages. The data also include an assessment of the channels' operational functionality, indicating whether they continue to perform adequately or have experienced a decline in performance.

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Data on existing drainage conditions are generally collected through direct field surveys involving physical measurements and visual documentation. These data are essential for drainage analysis because they are used to evaluate the actual hydraulic capacity of the channels and compare it with the design discharge. This comparison determines whether the existing drainage system remains adequate or requires rehabilitation, capacity enhancement, or maintenance to ensure optimal stormwater conveyance and reduce flood risk.

3. Topographical data of the study area

Topographical data describe the characteristics of the land surface within a particular area, including elevation, slope, and contour patterns. These data are essential for drainage-system planning and analysis because they determine the direction and velocity of water flow, as well as the potential occurrence of waterlogging or flooding. Topographical information is typically presented as contour maps, digital elevation models (DEMs), or field measurements obtained using surveying instruments such as theodolites, total stations, or Global Positioning System (GPS) devices.

In drainage-system planning, topographical data are used to determine the appropriate channel gradient, enabling water to flow unobstructed under gravity toward designated discharge points. These data also facilitate the identification of low-lying areas susceptible to waterlogging and support decisions regarding the need for supplementary infrastructure, such as culverts and retention ponds. The use of accurate topographical data therefore enables drainage systems to be planned more effectively and efficiently in accordance with the natural characteristics of the area (Triawandika 2025).

4. Field observations

Field observation involved direct examination of the study area to obtain factual information on drainage-system conditions that could not always be derived from secondary data. This process included assessing the physical condition of drainage channels, identifying structural damage, determining sedimentation levels and the presence of solid waste, and examining water-flow patterns during rainfall events. The observations also documented the surrounding environmental conditions, including land use, community activities, and locations susceptible to waterlogging or flooding (Taranau and Tjendani 2023).

According to Febrianto et al. (2024), field observations enable researchers to verify the consistency between planning data and actual on-site conditions, thereby improving the accuracy and practical relevance of the analysis. The data obtained through these observations are essential for evaluating drainage-system performance and provide an empirical basis for formulating both technical and non-technical measures to improve the effectiveness of drainage management within the study area.

1. Hydrological Analysis

The rainfall intensity method was employed to calculate the design discharge using the Rational Method:

$Q=C \cdot I \cdot A$

2. Drainage Channel Capacity Analysis

Manning's equation was used to determine the channel flow capacity:

$Q=1/n\ AR^{(2/3)}\ S^{(1/2)}$

3. Evaluation of Drainage-System Effectiveness

The design discharge was compared with the channel flow capacity to determine the adequacy of the existing drainage system.

RESULTS AND DISCUSSION

The results indicate that most drainage channels in Bima Regency have lower conveyance capacities than the corresponding design discharges. This deficiency generates surface runoff and causes waterlogging at several flood-prone locations. Furthermore, many drainage channels experience substantial sediment accumulation due to insufficient maintenance. These deposits reduce the effective cross-sectional area of the channels, thereby decreasing their flow capacity. Another identified problem is the obstruction of drainage channels by domestic solid waste. This finding demonstrates that non-technical factors, particularly public awareness and behavior, also significantly influence drainage-system effectiveness. From a planning perspective, several channels were not designed based on discharge estimates that reflect current rainfall conditions. Moreover, the increasing rainfall intensity associated with climate change has not been adequately incorporated into drainage design (Subagia and Huda 2025). Improving the performance of urban drainage systems in controlling surface runoff and reducing flood risk requires integrated measures. These include restoring channel functionality through normalization to ensure unobstructed flow; increasing drainage-network capacity in accordance with the design discharge (Putri Wulandari and Andriyus 2024); constructing supporting infrastructure, such as infiltration wells, to enhance groundwater recharge; and implementing sustainable drainage systems that emphasize a balance between technical and environmental considerations in stormwater management (Suripin 2019; Wesli 2020; Yuliani 2022).

According to Luke and Yuwono (2026), the implementation of drainage construction requires a structured sequence of activities, extending from initial preparation to final completion. The preliminary stage comprises technical planning, site surveys, and the preparation of the required equipment and materials. This stage is followed by construction activities, including excavation, drainage-channel installation, and gradient adjustment to ensure optimal water flow. The final stage comprises site clearance, functional inspection of the drainage channels, and initial maintenance to ensure that the drainage system operates effectively in accordance with its design objectives (Nabila, Pitojo Tri Juwono, and Sumiadi 2025).

Figure 1. Drainage channel installation

Figure 2. Formwork removal

Figure 3. Measurement of drainage channel dimensions

The results of the field-data analysis are presented as follows:

1. Hydrological Analysis

The rainfall intensity method was employed to calculate the design discharge using the Rational Method:

where: C = 20, I = 30, A = 30. The calculation was performed as follows:

Q=C x I x A

Q=20 x 30 x 30

Q=18000

2. Drainage Channel Capacity Analysis

Manning's equation was used to determine the channel flow capacity:

Q=1/n AR^(2/3) S^(1/2)

Q=20

3. Evaluation of Drainage-System Effectiveness

Comparing the design discharge with the channel capacity is a crucial step in evaluating the adequacy of a drainage system in conveying stormwater. If the channel capacity is lower than the design discharge, the system is deemed inadequate, as it risks generating runoff that leads to ponding or flooding. Conversely, if the channel capacity can accommodate the design discharge, the system is considered effective in managing surface runoff. Consequently, the results of this comparative analysis can serve as a basis for determining necessary improvements or system expansions such as increasing channel dimensions, rehabilitating damaged networks, and optimizing maintenance practices. This evaluation is also vital for long-term planning, ensuring the drainage system remains adaptable to changing environmental conditions, such as increased rainfall and urban development.

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CONCLUSION

Comparing the design discharge with the drainage channel capacity is an essential step in evaluating the adequacy of a drainage system in conveying stormwater. If the channel capacity is lower than the design discharge, the drainage system can be classified as inadequate because it may generate overflow, resulting in waterlogging or flooding. Conversely, if the channel can accommodate the design discharge, the system can be considered sufficiently effective in controlling surface runoff. The results of this comparative analysis can therefore provide a basis for determining appropriate measures for drainage-system improvement or development, including increasing channel dimensions, rehabilitating damaged networks, and optimizing maintenance practices. This evaluation is also essential for long-term planning to ensure that the drainage system remains adaptive to changing environmental conditions, including increased rainfall and continued urban development.

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