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Civil Engineering – Research Article

Development of a Drainage System to Enhance Flood Resilience in Santi Urban Village, Bima City

Sulis Syaputri

Department of Civil Engineering, Universitas Muhammadiyah Bima, Jl. Anggrek No. 16, Ranggo, Rasa Nae Barat, Bima City, Indonesia

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CORRESPONDENCE

Sulis Syaputri
E-mail: sulisp07@gmail.com

A B S T R A C T

Flooding is a recurrent urban problem driven by increased surface runoff and inadequate drainage performance. Santi Urban Village in Bima City frequently experiences inundation during heavy rainfall because of insufficient channel capacity, sediment accumulation, and solid-waste blockage. This study evaluates the existing drainage system, estimates the design flood discharge, and develops an improved primary-channel design. Hydrological and hydraulic analyses were performed using rainfall records, channel dimensions, and field-condition data. The design flood discharge was estimated using the Rational Method, while channel conveyance capacity was calculated using Manning's equation. The results show that the design flood discharge is 4.25 m^3/s, whereas the existing channel capacity is only 1.15 m^3/s, equivalent to approximately 27% of the required capacity. A redesigned rectangular channel with a width of 2.0 m and a depth of 1.5 m provides a calculated capacity of 5.2 m^3/s and a safety factor of 1.22. The proposed design can therefore accommodate the design discharge. Nevertheless, sustainable flood resilience also requires regular sediment removal, effective solid-waste management, infiltration measures, and community participation.

INTRODUCTION

Flooding is a major and increasingly prevalent urban problem associated with population growth, land-use change, and rising rainfall intensity. Rapid urban development converts infiltration areas into built-up land, including housing, roads, and public facilities. This conversion reduces the capacity of soil to absorb rainwater and increases surface runoff, ultimately heightening the potential for inundation and flooding (Kementrian PUPR 2021; Suripin 2020). Urban flooding is therefore influenced not only by natural processes but also by human activities and spatial-development practices.

Within the urban hydrological system, increased surface runoff directly raises the flow volume that must be conveyed by the drainage network. Drainage systems that are not designed or upgraded in response to changing catchment conditions experience declining performance. Rainwater can consequently no longer be conveyed effectively, resulting in inundation and flooding at multiple locations. Global climate change further contributes to the increasing intensity and frequency of extreme rainfall, thereby increasing surface-runoff discharge. Existing drainage systems frequently lack sufficient capacity to accommodate these higher stormwater flows (Fletcher et al. 2015; Noviana, Putri, and Saputra 2023).

Bima City is among the Indonesian cities with relatively high flood vulnerability. In recent years, recurrent flooding has occurred with considerable intensity and significant consequences. These events have damaged infrastructure, disrupted community social and economic activities, and created potential environmental-health problems. Data from the Indonesian National Disaster Management Agency indicate an increasing trend in both the frequency of flooding and the extent of affected areas in Bima City (BNPB 2022). This trend suggests that the existing flood-control system, particularly the drainage network, is not functioning optimally.

From a technical perspective, flooding in Bima City is influenced by relatively flat topography in several areas, inadequate drainage-channel capacity, and insufficient maintenance. Sediment accumulation reduces the effective channel cross-section and consequently diminishes conveyance capacity. Obstructions caused by domestic waste also impede flow and increase the likelihood of inundation (Hidayat, Pratama, and Siregar 2023). The drainage problem therefore involves not only technical deficiencies but also management practices and community behavior.

Santi Urban Village, a residential area in Bima City, faces similar problems. Its relatively high population density and predominance of built-up land produce a high runoff coefficient. Inundation frequently occurs at several locations during moderate-to-heavy rainfall. This condition is attributable to the insufficient capacity of the primary drainage channels to accommodate increasing surface runoff. Furthermore, the tertiary, secondary, and primary drainage networks are not adequately integrated, preventing stormwater from being conveyed efficiently to the main channel or receiving water body (Putra and Rahman 2022).

Primary channels are critical components of an urban drainage system because they receive flows from secondary and tertiary channels and convey them to the receiving water body. Insufficient primary-channel capacity may generate backwater effects, causing water to overflow and inundate residential areas. The performance of primary drainage channels therefore largely determines the effectiveness of the overall drainage system (Kodoatie and Sjarief 2020).

The conditions in Santi Urban Village indicate that the existing primary drainage system cannot accommodate increases in stormwater discharge associated with land-use change and higher rainfall intensity. Insufficient maintenance, substantial sedimentation, and the absence of comprehensive, planned system development further exacerbate the problem. A thorough evaluation of the existing drainage system is therefore required, including hydrological analysis to determine the design flood discharge and hydraulic analysis to assess channel capacity (Arsyad, Wibowo, and Nugroho 2021).

Advances in knowledge and technology have transformed urban drainage management. The conventional approach of conveying stormwater to receiving water bodies as rapidly as possible is increasingly being replaced by more sustainable approaches, including eco-drainage and sustainable urban drainage systems (SUDS). These concepts emphasize managing stormwater through natural processes that enhance infiltration, retention, and rainwater utilization, thereby reducing the burden on drainage systems and minimizing long-term flood risk (Fletcher et al. 2015).

Considering these challenges, developing the primary drainage system in Santi Urban Village is essential. Such development should not only increase channel capacity but also improve the effectiveness and sustainability of the overall drainage network. This study therefore develops a primary drainage-system plan based on comprehensive hydrological and hydraulic analyses, with the objective of reducing flood risk and enhancing local resilience to extreme hydrometeorological events.

Literature Review

1. Definition of Drainage

Drainage is a system designed to convey, control, and discharge excess water from an area to prevent inundation and flooding. It maintains the local water balance by managing stormwater and other surface water so that human activities are not disrupted (Suripin 2020).

According to the Ministry of Public Works and Housing (2021), urban drainage is a network of channels that safely and systematically conveys stormwater from an area to a receiving water body, such as a river or the sea. It is an essential component of urban infrastructure because it directly affects public safety and well-being.

2. Urban Drainage systems

Urban drainage systems generally comprise three principal components:

1. Tertiary channels, which collect runoff from residential areas.
2. Secondary channels, which receive flows from tertiary channels.
3. Primary channels, which convey combined flows to receiving water bodies.

Figure 1. Schematic layout of minor and major urban drainage systems

Primary drainage channels constitute the main stormwater-conveyance pathway. When their capacity is inadequate, backwater effects may cause inundation in residential areas (Kodoatie and Sjarief 2020).

3. Flooding and its causal factors

Flooding occurs when water overflows and inundates an area because the conveyance system cannot accommodate the

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resulting discharge. Urban flooding is generally caused by several factors:
• High rainfall
• Land-use change
• Inadequate drainage capacity
• Sedimentation and channel blockage
• Insufficient drainage-system maintenance

Land-use change is a dominant driver of increased surface runoff because it reduces the extent of infiltration areas (Fletcher et al. 2015). Climate change also contributes to more intense extreme rainfall and a corresponding increase in flood potential (Noviana, Putri, and Saputra 2023).

4. Hydrological analysis

Hydrological analysis determines the discharge that must be accommodated by a drainage system. A key parameter is design rainfall, which is derived through frequency analysis using probability distributions such as Gumbel, Lognormal, or Log-Pearson Type III (Arsyad, Wibowo, and Nugroho 2021).

Rainfall intensity is another important determinant of surface-runoff magnitude and is estimated for a specified rainfall duration and return period.

5. Drainage-System development

Drainage systems require development when the existing channel capacity cannot accommodate the design flood discharge. Potential measures include:
• Increasing channel dimensions
• Channel normalization through sediment removal
• Improving channel gradients
• Integrating the drainage network

Structural interventions should be complemented by nonstructural measures, including solid-waste management and improved public awareness (Arsyad, Wibowo, and Nugroho 2021).

6. Previous studies

Previous studies on urban drainage have reported that:
- Channel capacity is frequently lower than the design discharge (Putra and Rahman 2022).
- Sedimentation and solid waste are major causes of declining drainage performance (Hidayat, Pratama, and Siregar 2023).
- Channel development and eco-drainage implementation can improve drainage-system effectiveness (Noviana, Putri, and Saputra 2023).

These findings indicate that developing the primary drainage system is an appropriate measure for reducing urban flood risk.

RESEARCH METHODS

1. Research design

This quantitative study adopted descriptive and analytical approaches to evaluate the existing drainage system and develop a primary drainage-system design based on hydrological and hydraulic analyses. Quantitative methods were used to estimate the design discharge, channel capacity, and optimal channel dimensions.

2. Study area

The study was conducted in Santi Urban Village, Bima City, West Nusa Tenggara Province, an area susceptible to flooding. The site was selected because of its suboptimal drainage conditions and recurrent inundation during the rainy season.

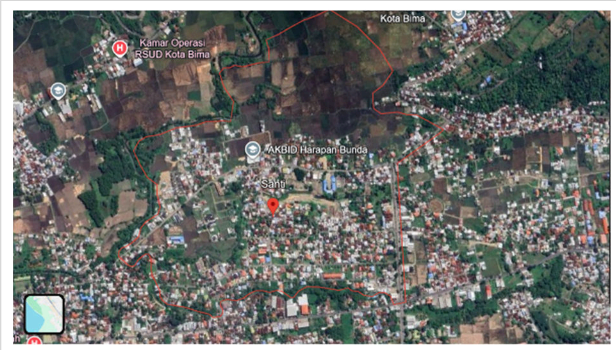

Figure 2. Location of the study area

3. Types and sources of data

a. Primary Data
- Direct observations of drainage-channel conditions, including dimensions, physical condition, and sedimentation
- Field documentation
- Measurement of channel cross-sections

b. Secondary Data
- Daily rainfall data obtained from BMKG or another relevant agency
- Topographical and land-use maps
- Existing drainage-network data
- Flood-event data, including inundation depth and affected area

4. Data-Analysis techniques

a. Rainfall Analysis

The design rainfall for a specified return period, such as 5 or 10 years, was estimated using frequency-distribution methods, including:
• Normal distribution
• Lognormal distribution
• Gumbel distribution

b. Design Flood-Discharge Analys

$$Q = C \,.\, I \,.\, A$$

where:
Q = flood discharge (m³/s)
C = runoff coefficient
I = rainfall intensity (mm/h)
A = catchment area (km²)

c. Drainage-Channel Capacity Analysis

$$Q = \frac{1}{2} A R^{2/3} S^{1/2}$$

where:
Q = flow discharge (m³/s)
A = wetted cross-sectional area (m²)
R = hydraulic radius (m)
S = channel slope
n = Manning roughness coefficient

d. Evaluation of Channel Performance
• Design discharge (Qdesign)
• Existing channel capacity (Qexisting)
where:
• If Qexisting < Qdesign, the channel is inadequate and requires development.
• If Qexisting ≥ Qdesign, the channel capacity remains adequate.

RESULTS AND DISCUSSION

Santi Urban Village is a relatively densely populated residential area dominated by built-up land, including housing, roads, and public facilities. These conditions reduce rainfall infiltration. The relatively flat topography also slows surface flow and increases the potential for inundation.

Field observations showed that several locations in Santi Urban Village experienced inundation depths of approximately 20–50 cm during heavy rainfall, indicating that the existing primary drainage system could not convey stormwater effectively.

1. Rainfall-Data Analysis
The simulated 10-year series of annual maximum rainfall data (mm) used in the analysis is presented below:

Table 1. Simulated annual maximum rainfall data

Year	Annual Maximum Rainfall (mm)
2015	110
2016	125
2017	130
2018	140
2019	150
2020	135
2021	160
2022	170
2023	155
2024	180

A simplified Gumbel-distribution analysis yielded:
• 10-year design rainfall (R_{10}) = 175 mm/day
The rainfall intensity was subsequently calculated as follows:
Assumed effective rainfall duration = 2 h

$$I = \frac{R}{t} = \frac{175}{2} = 87{,}5 mm/h$$

2. Design Flood-Discharge Calculation
The Rational Method was applied.

$$Q = C \,.\, I \,.\, A$$

Given:
• Runoff coefficient (C) = 0.7 (dense residential area)
• Rainfall intensity (I) = 87.5 mm/h = 0.0875 m/h
• Catchment area (A) = 25 ha = 0.25 km²

$$Q = 0{,}278 \,.\, C \,.\, I \,.\, A$$
$$Q = 0{,}278 \,.\, 0{,}7 \,.\, 87{,}5 \,.\, 0{,}25$$
$$Q = 4{,}25\ m^3/detik$$

• Design flood discharge = 4.25 m³/s

3. Existing Channel-Capacity Analysis
Assumed existing channel conditions:
• Width (b) = 1.0 m
• Flow depth (h) = 0.8 m
• Channel slope (S) = 0.001
• Manning roughness coefficient (n) = 0.030
• Cross-sectional area:

$$A = b \cdot h = 1{,}0 \cdot 0{,}8 = 0{,}8\, m^2$$

• Wetted perimeter:

$$P = b + 2h = 1 + 1{,}6 = 2{,}6$$

• Hydraulic radius:

$$R = \frac{A}{P} = \frac{0{,}8}{2{,}6} = 0{,}31$$

• Using Manning's equation:

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$
$$Q = \frac{1}{0{,}030} \cdot 0{,}8 \cdot (0{,}31)^{2/3} \cdot (0{,}001)^{1/2}$$
$$Q \approx 1{,}15\, m^3/s$$

4. Evaluation of Drainage Performance
Comparison:
• Design discharge (Qr) = 4.25 m³/s
• Existing capacity (Qs) = 1.15 m³/s
• Because Qs < Qr:
Therefore:
• The channel cannot accommodate the design flood discharge.
• Overflow occurs, causing inundation in Santi Urban Village.

5. Design of the Proposed Channel
A rectangular channel was designed using the following assumptions:
• Width (b) = 2.0 m
• Depth (h) = 1.5 m
• n = 0.015 (concrete)
• S = 0.002
• Area: A = 2.0 × 1.5 = 3.0 m²

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• Wetted perimeter: P = 2.0 + 3.0 = 5.0 m
• $R = \frac{3}{5} = 0{,}6$
• $Q = \frac{1}{0{,}015} x\ 3\ x\ (0{,}6)^{2/3} x\ (0{,}002)^{1/2}$
• $Q \approx\ 5{,}2\ m^3/detik$

6.Evaluation of the Proposed Design
• Design discharge = 4.25 m³/s
• Design capacity = 5.2 m³/s
• The proposed channel can accommodate the design flood discharge.
• The proposed design provides protection against inundation.

The results indicate that flooding in Santi Urban Village is primarily caused by the discrepancy between drainage-channel capacity and the design flood discharge. The existing channel can convey only approximately 27% of the design discharge, which explains the recurrent inundation during heavy rainfall.

In addition to inadequate channel dimensions, sediment accumulation and solid-waste blockage further reduce channel capacity. The drainage problem is therefore associated not only with technical factors but also with maintenance practices and community behavior.

Redesigning the channel with larger dimensions substantially increases its conveyance capacity. Structural interventions alone, however, are insufficient and should be combined with nonstructural measures such as:
1. Solid-waste management
2. Construction of infiltration wells
3. Community education

The combination of these measures can improve the effectiveness and sustainability of the drainage system in Santi Urban Village.

CONCLUSION

The following conclusions were drawn from the analysis and proposed development of the primary drainage system to enhance flood resilience in Santi Urban Village, Bima City: (1) The existing drainage system in Santi Urban Village does not convey stormwater effectively. Its performance is constrained by relatively small channel dimensions, a low gradient, sediment accumulation, and solid-waste blockage, all of which reduce flow capacity; (2) The estimated design flood discharge is 4.25 m³/s, reflecting substantial surface runoff generated by high rainfall intensity and the predominance of built-up land within the study area; (3) The existing drainage channel has a capacity of only 1.15 m³/s and therefore cannot accommodate the design flood discharge. This capacity represents approximately 27% of the design discharge, resulting in overflow and inundation at several locations; (5) Redesigning the drainage channel was effective in increasing its capacity to 5.2 m³/s. This value exceeds the design discharge and corresponds to a safety factor of 1.22, indicating that the proposed channel can safely accommodate the design flood flow; (6) Flooding in Santi Urban Village is caused not only by technical deficiencies but also by environmental and operational factors, including extensive impervious surfaces, insufficient infiltration areas, and inadequate drainage maintenance; (7) Effective flood management requires an integrated approach that combines structural interventions, such as channel rehabilitation and development, with nonstructural measures, including solid-waste management, infiltration-well construction, and improved public awareness.

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