Evaluation of Drainage Channel Capacity along Kolonel Sugiono Street, Waru District, Sidoarjo Regency

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Abstract. *Urban drainage systems in rapidly developing areas often experience reduced performance due to increased surface runoff, resulting in frequent waterlogging. This study evaluates the hydraulic capacity and performance of the existing drainage channel along Kolonel Sugiono Street, Waru District, Sidoarjo Regency, where inundation depths of approximately 15–40 cm are commonly observed during rainfall events. Hydrological analysis was conducted using annual maximum daily rainfall data from the Juanda Meteorological Station for the period 2015–2024. Design rainfall was estimated using the Gumbel extreme value distribution with a 5-year return period and a 90% confidence level, followed by rainfall intensity calculation using the Mononobe method. The design flood discharge was then determined using the Rational Method for a 6.25-ha urban catchment area. Hydraulic analysis employing Manning's equation was performed to evaluate the capacity of the existing drainage channel based on field-measured dimensions. The results show that the design flood discharge is approximately 1.168 m³/s, while the capacity of the existing channel is only 0.293 m³/s, indicating that the channel is hydraulically inadequate. To address this condition, a channel redesign based on the economic cross-section principle was proposed, resulting in increased channel dimensions and the inclusion of a freeboard. The redesigned channel is capable of conveying a discharge of 1.258 m³/s, exceeding the design requirement. These findings provide a technical basis for improving drainage performance and mitigating flooding in the study area.*

Keywords: urban drainage; channel capacity; design flood discharge; hydraulic analysis; channel redesign

1. Introduction

Urban drainage systems function to convey excess surface water so that inundation and flooding do not occur in built-up areas. Increased impervious areas due to urban development significantly increase surface runoff, thereby increasing the pressure on existing drainage networks. This condition is also found along Kolonel Sugiono Street, Waru District, Sidoarjo Regency, where drainage problems such as sedimentation, channel narrowing, and waterlogging during rainfall events are observed. This condition reduces the channel's ability to channel runoff, and at several points, puddles of approximately 15-40 cm in depth often occur during moderate rainfall.

Meanwhile, according to drainage planning standards, the channel capacity must be able to accommodate the design runoff discharge, calculated based on the design rainfall with a specific return period by SNI 03-3424-1994 (Badan Standardisasi Nasional (BSN), 1994). However, it is currently unknown whether the existing channel on Jl. Kolonel Sugiono's dimensions, slope, and physical condition are capable of meeting these requirements. Furthermore, changes in land use in this area in recent years have potentially increased runoff discharge compared to when the channel was first constructed.

To comprehensively evaluate drainage performance, hydrological and hydraulic analyses are required. The hydrological analysis was conducted to determine the planned rainfall using the normal method, then calculate the runoff discharge using the rational method based on the 6.25-ha catchment area and surface characteristics. Next, a hydraulic analysis using the Manning formula was applied to determine the maximum capacity of the existing channel based on its physical conditions. The comparison between the planned runoff discharge and the channel capacity will indicate whether the channel is still capable of functioning as needed or requires capacity increases.

Waterlogging along this corridor not only causes traffic disruption but may also damage public infrastructure and degrade environmental quality. These conditions indicate that the existing drainage system may no longer be functioning optimally and therefore requires comprehensive technical evaluation. In this context, the present research is crucial to provide an accurate and systematic description of the condition and performance of the drainage system along Kolonel Sugiono Street. The results of the analysis are expected to serve as a scientific basis for formulating appropriate technical recommendations related to channel rehabilitation, capacity improvement, and future drainage management in the study area.

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Previous studies by (Anggit and Mahardi, 2023) in Sidoarjo Regency indicate that urban flooding is largely caused by insufficient drainage channel capacity and sediment accumulation. An evaluation of the drainage system along Jalan Raya Tanggulangin showed that the existing trapezoidal channels were unable to accommodate design flood discharges for 2-, 5-, and 10-year return periods, as the planned discharge exceeded the channel capacity. The study applied Gumbel rainfall frequency analysis and hydraulic evaluation using Manning's equation, and recommended redesigning the channels with larger U-Ditch sections to improve capacity. These findings emphasize the need for site-specific drainage capacity evaluations, including along Kolonel Sugiono Street, to reduce urban flood risk.

Another studies, in Waru District, Sidoarjo Regency have shown that urban flooding is closely related to insufficient drainage channel capacity and sedimentation. (Kurniawan, Saves and Safitri, 2025) evaluated the existing drainage system in Medaeng Village and found that several channel sections were unable to convey design flood discharges due to limited dimensions and increased runoff caused by land-use changes. The study emphasized the need for drainage system normalization or redesign to reduce inundation. These findings support the importance of conducting site-specific drainage capacity evaluations, including along Kolonel Sugiono Street, to mitigate urban flood risk.

However, in this study, the evaluation of the drainage system along Kolonel Sugiono Street was conducted by examining the existing physical and hydraulic condition of the channel and assessing whether its present capacity can accommodate the design runoff discharge. The research includes determining the design runoff for the catchment area and analyzing the adequacy of the channel capacity based on hydraulic performance criteria, as well as identifying the main factors that contribute to waterlogging in the study area during rainfall events.

2. Research Methodology

This research was conducted in the area of Kolonel Sugiono Street, Waru District, Sidoarjo Regency, an urban area with drainage channels that channel surface runoff to the nearest river. The study area encompassed a segment of drainage channels in a clustered, connected residential area, approximately 490 meters long, viewed from the west, on Raya Waru Street, heading east, entering Kolonel Sugiono Street. This segment was chosen because it exhibited problems such as high sedimentation, puddles approximately 15-40 cm deep, and a small channel cross-section, all of which impact the surface runoff capacity.

Figure 1. Study area along Kolonel Sugiono Street (Source: Google Maps)

The research method describes the stages of the research to be conducted, including data collection, calculations, and analysis to answer the problems posed in the research questions. In this study, the methods used include data collection, both secondary and primary, and hydrological and hydraulic data analysis. Primary data was obtained through direct field observations on October 18, 2025, including measurements of channel dimensions, physical conditions, sedimentation levels, material structures, and visual documentation. Secondary data included maximum daily rainfall information from rainfall stations, maps of supporting areas, and relevant technical standards.

Hydrological data analysis methods to determine corrected runoff flow and hydraulic data analysis, specifically open channel analysis, to identify channel cross-sectional dimensions, channel conditions, and channel capacity. The research was conducted using steps to describe the research objectives. The research stages to be implemented include data collection, data analysis, and formulation of analysis results. The overall stages of the research methodology used in this study are illustrated in the following flow chart.

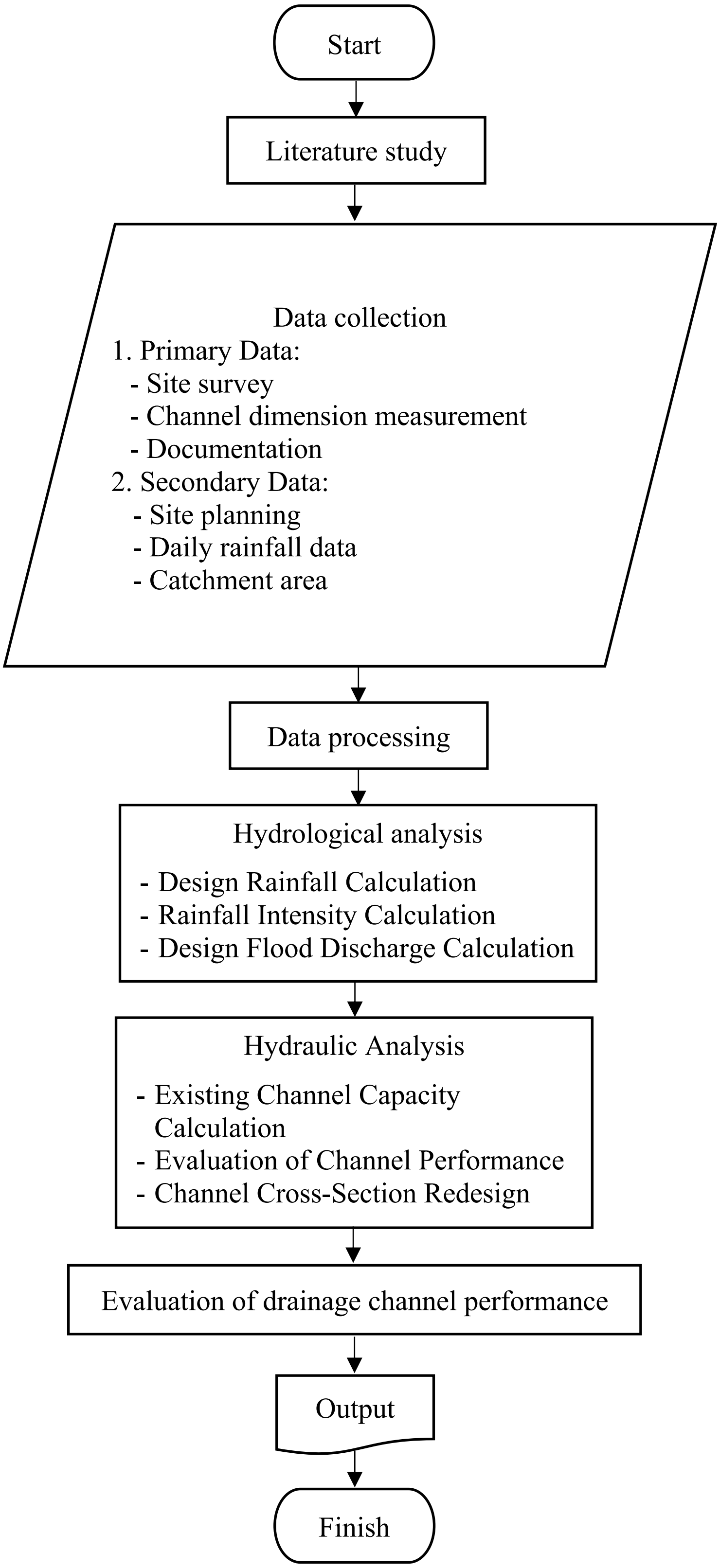

Figure 2. Research flowchart

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3. Result and Discussion

The area extending from Raya Waru Street to Kolonel Sugiono Street constitutes one of the primary urban corridors characterized by intensive transportation activity and the development of built-up areas, including residential zones, commercial facilities, and services. The increasing intensity of land use along this corridor potentially reduces infiltration areas and increases surface runoff during rainfall events. Field observations in several segments indicate the presence of sedimentation, solid waste accumulation, and partial narrowing of channel cross-sections associated with adjacent land-use activities. These conditions may decrease flow capacity and trigger waterlogging during periods of relatively high rainfall, with observed inundation depths ranging from approximately 15 to 40 cm. Therefore, this corridor requires a comprehensive evaluation of drainage system performance to provide a basis for formulating appropriate technical recommendations for improvement.

The following data was collected to evaluate the drainage channel capacity on Kolonel Sugiono Street, Waru District, Sidoarjo Regency.

Rainfall data

Table 1. Annual Maximum Daily Rainfall at Juanda Meteorological Station (2015–2024) (BMKG, 2025)

Year	Rainfall (mm)	Year	Rainfall (mm)
2015	65	2020	127.7
2016	87.5	2021	89.8
2017	106.5	2022	151.5
2018	88.5	2023	107.6
2019	156.6	2024	96.4

The hydrological analysis in this study is intended to determine the design flood discharge corresponding to a 5-year return period, as required for arterial road drainage (*Drainase Perkotaan*, 1997). The main calculation steps include design rainfall determination, rainfall intensity calculation, and design discharge estimation. These stages are conducted systematically to ensure that the resulting design flood discharge accurately reflects the hydrological conditions of the catchment and can be used as a basis for evaluating the capacity and performance of the existing drainage system.

Calculation of Design Maximum Daily Rainfall

This section presents the calculation of the design maximum daily rainfall, which serves as the basis for the subsequent hydrological analysis. The estimation is performed using the Gumbel extreme value distribution with a 90% confidence level. The Gumbel method is selected because it is widely applied in modeling annual maximum rainfall and is capable of providing reliable estimates of extreme events for design flood analysis. The use of a 90% confidence level represents a balanced approach between statistical reliability and practical applicability, particularly considering the limited length of extreme rainfall records and the need to avoid overly conservative design values.

Table 2. Statistical Calculation of Annual Maximum Daily Rainfall Data

No.	Tahun	Ri	$\overline{R} = \Sigma Ri/n$	Ri−R	$(Ri-R)^2$	St. Dev σR
1	2015	65	107.71	-42.71	1824.14	29.36
2	2016	87.5		-20.21	408.44	
3	2017	106.5		-1.21	1.46	
4	2018	88.5		-19.21	369.02	
5	2019	156.6		48.89	2390.23	
6	2020	127.7		19.99	399.60	
7	2021	89.8		-17.91	320.77	

No.	Tahun	Ri	$\overline{R} = \Sigma Ri/n$	Ri−R	$(Ri-R)^2$	St. Dev σR
8	2022	151.5		43.79	1917.56	
9	2023	107.6		-0.11	0.01	
10	2024	96.4		-11.31	127.92	
Σ		**1077.1**			**7759.17**	

With n = 10 years of data, the corresponding Gumbel reduced standard deviation (σ_n) and reduced mean (Y_n) are 0.9496 and 0.4952, respectively. For a 5-year return period, the reduced variate (Y_t) is 1.5004. Using the Gumbel extreme value distribution, the design maximum daily rainfall (R_t) for a 5-year return period is calculated by applying the following expression:

$$R_t = \overline{R} + \left(\frac{\sigma_R}{\sigma_n}\right)(Y_t - Y_n) \quad (1)$$

Where:

$\overline{R}$ = mean of annual maximum daily rainfall
σ_R = standard deviation of rainfall data
σ_n = Gumbel reduced standard deviation
Y_t = Gumbel reduced variate (for return period T = 5 years)
Y_n = Gumbel reduced mean

Subsequently, the design maximum daily rainfall is evaluated by incorporating the uncertainty of the estimation through the application of a confidence interval based on the Gumbel distribution. In this study, a confidence level of 90% is adopted to represent the reliability of the calculated design rainfall. The confidence range (R_k) is determined using the following expression:

$$R_k = \pm t(a)(S_e) \quad (2)$$

Where:

$t(a)$= critical value corresponding to the selected confidence level
S_e = standard error of estimation

Based on the confidence interval analysis using the Gumbel distribution, the design maximum daily rainfall at a 90% confidence level is obtained as 169.289 mm, which is used as the design input for the subsequent hydrological analysis.

Calculation of Rainfall Intensity

Rainfall intensity, *I* is calculated using the Mononobe method to obtain a representative design rainfall intensity corresponding to the effective rainfall duration. This value is subsequently used in the calculation of runoff discharge for the study area and is given by:

$$S = \frac{H}{0.9 \times L} \quad (3)$$

Where:

S = average slope of the flow path or main channel (m/m)
H = elevation difference between the farthest point of the drainage area and the outlet point (km)
L = length of the main channel or drainage path (km)

$$t_c = \left(\frac{0.87 \times L^2}{1000 \times S}\right)^{0.385} \quad (4)$$

Where:

t_c = rainfall duration or time of concentration (hours)

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$$\boldsymbol{I = \frac{R_{24}}{24}\left(\frac{24}{t_c}\right)^{\frac{2}{3}}} \quad (5)$$

Where:

$\boldsymbol{I}$ = rainfall intensity (mm/hour)
$\boldsymbol{R_{24}}$= maximum 24-hour daily rainfall (mm)

Based on the topographic characteristics of the drainage system along Kolonel Sugiono Street, the elevation difference (H) is 0.508 m and the length of the main drainage channel (L) is 0.5 km. Substituting these values into the time of concentration equation yields a time of concentration (t_c) of 0.53 hours. Using the design maximum daily rainfall of 169.289 mm at a 90% confidence level, the rainfall intensity (I) calculated by the Mononobe method is approximately 89.56 mm/hour and is used in the runoff discharge analysis.

Calculation of Design Flood Discharge

The design flood discharge in this study is estimated using the Rational Method, which is commonly applied for small to medium urban catchments. This method relates rainfall intensity, land-use characteristics, and drainage area to determine the peak discharge, and is expressed as follows (Badan Standardisasi Nasional (BSN), 2016):

$$\boldsymbol{Q_p = 0,00278\, C.I.A} \quad (6)$$

Where:

$\boldsymbol{Q_p}$= design flood discharge (m^3/s)
$\boldsymbol{0,00278}$ = conversion constant, applied when the drainage area is expressed in Ha
$\boldsymbol{C}$ = runoff coefficient, which depends on land-use characteristics
$\boldsymbol{I}$ = rainfall intensity (mm/hour)
$\boldsymbol{A}$ = drainage area (Ha)

Based on field observations, the width and length of the analyzed catchment area are 125 m and 500 m, respectively, resulting in a drainage area of 6.25 ha. The study area is characterized as a continuous clustered residential area; therefore, a runoff coefficient (C) of 0.75 is adopted in accordance with standard urban drainage guidelines (Schwab, G.O., Frevert, R.K., Edminster, T.W., Barnes, 1981). Using the calculated rainfall intensity and the selected runoff coefficient, the Rational Method yields a design flood discharge of approximately 1.168 m^3/s, which is subsequently used for evaluating the capacity of the existing drainage channel.

Following the calculation of the design flood discharge, a hydraulic analysis is conducted to evaluate the capacity of the existing drainage channel to convey the computed flow and to determine whether channel redesign is required.

Existing Channel Capacity Calculation

In the existing condition, the drainage channel along Kolonel Sugiono Street is constructed as a U-ditch concrete channel. Field measurements indicate that the channel has a depth (h) of 0.7 m and a bottom width (b) of 0.5 m. The channel roughness coefficient is taken as n = 0.013, representing a partially filled closed conduit made of concrete with a smooth surface and minimal erosion (Chow, 1985). These geometric and hydraulic parameters are used as the basis for calculating the capacity of the existing drainage channel.

The capacity of the drainage channel is calculated based on the continuity equation, which expresses discharge as the product of flow velocity and cross-sectional area:

$$\boldsymbol{Q_c = V \times A} \quad (7)$$

Where:

$\boldsymbol{Q_c}$ = channel discharge (m³/s)
$\boldsymbol{V}$ = average flow velocity (m/s)
$\boldsymbol{A}$ = channel cross-sectional area (m²)

The flow velocity is determined using the Manning equation:

$$\boldsymbol{V = \frac{1}{n}.R^{\frac{2}{3}}.S^{\frac{1}{2}}} \quad (8)$$

Where:

$\boldsymbol{n}$ = Manning roughness coefficient
$\boldsymbol{R}$ = hydraulic radius defined as $R = \frac{A}{P}$, with P being the wetted perimeter (m)
$\boldsymbol{S}$ = channel bed slope (m/m)

Using the above equations and the geometric and hydraulic characteristics of the existing channel, the calculated capacity of the drainage channel, Q_c is obtained as 0.293 m³/s.

Evaluation of Channel Performance

The evaluation of channel performance is conducted by comparing the design flood discharge with the capacity of the existing drainage channel. The design flood discharge is calculated to be approximately 1.168 m³/s, while the capacity of the existing channel Q_c is only 0.293 m³/s. This comparison indicates that the existing channel capacity is significantly lower than the required design discharge. Consequently, the drainage channel is unable to adequately convey runoff during peak rainfall events, which explains the frequent occurrence of flooding in the study area. Therefore, redesign and capacity enhancement of the drainage channel are required to improve its hydraulic performance.

Channel Cross-Section Redesign

The redesign of the drainage channel cross-section is performed to accommodate the design flood discharge. The channel dimensions are determined using the economic cross-section principle, as proposed by (Suripin, 2004), which aims to achieve hydraulic efficiency while minimizing construction requirements. In this approach, the channel geometry is designed based on the proportional relationship between flow depth and channel width, where the depth (h) is taken as **0.5 times the channel width** (b). This criterion is applied to ensure an efficient and practical channel design that meets the required discharge capacity.

Based on the previously obtained design flood discharge of 1.168 m³/s, the dimensions of the redesigned channel cross-section are calculated using Equations (7) and (8). Applying the economic section criterion, the resulting channel width is b = 1.362 m ≈ 1.4 m, while the corresponding flow depth is h = 0.7 m. These dimensions are designed to ensure that the redesigned channel is capable of safely conveying the design discharge.

The next step involves calculating the freeboard height (w) to provide additional safety against overtopping. The freeboard is determined using the following equation:

$$\boldsymbol{w = \sqrt{0.5 \times h}} \quad (9)$$

Where:

$\boldsymbol{w}$: freeboard height (m)
$\boldsymbol{h}$: design flow depth (m)

The freeboard is added to the design water depth to account for uncertainties in flow conditions and to enhance the safety of the drainage channel during peak discharge events. Based on the calculation, the freeboard height is 0.592 m (≈ 0.6 m), which is incorporated into the design water depth, and the resulting channel cross-section geometry is illustrated below.

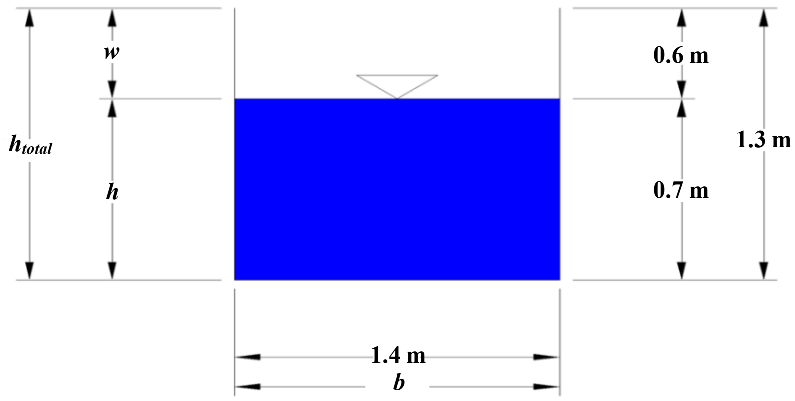

Figure 3. Cross-Section of the Redesigned Drainage Channel

4. Conclusion

This study concludes that the existing drainage channel along Kolonel Sugiono Street is hydraulically inadequate to convey the design flood discharge. The hydrological analysis indicates a design flood discharge of approximately 1.168 m³/s, while the capacity of the existing channel is only 0.293 m³/s, resulting in frequent waterlogging with inundation depths of 15–40 cm during rainfall events. To address this deficiency, the drainage channel was redesigned using the economic cross-section principle, resulting in a channel width of 1.4 m and a flow depth of 0.7 m, supplemented by a freeboard of 0.6 m. With these dimensions, the redesigned channel is capable of conveying a discharge of 1.258 m³/s, which exceeds the design flood discharge and provides an adequate safety margin. Therefore, it is recommended that the existing drainage channel be upgraded in accordance with the proposed design. Further studies considering maintenance conditions, sedimentation, and future land-use changes are recommended to ensure long-term drainage system effectiveness.

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