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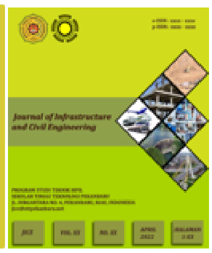

Evaluation of Drainage Channel on Rela–Sutomo Road, Medan, Indonesia

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Abstract

This study evaluated the capacity of the drainage system along Rela–Sutomo Road, Medan, to accommodate rainfall runoff and domestic wastewater. Rapid urban development and population growth have increased impervious surface coverage, surface runoff, and domestic wastewater generation, potentially exceeding the conveyance capacity of the existing drainage channels. This study aimed to determine whether the existing drainage system could accommodate the combined design discharge. The analysis included population projection using the least-squares method, estimation of domestic wastewater discharge, rainfall frequency analysis using the selected probability distribution for a 10-year return period, rainfall intensity estimation using the Mononobe method, runoff calculation using the rational method, and channel capacity calculation using Manning's formula. Sediment depths and channel dimensions were directly measured across 10 drainage segments. The results showed that the design runoff discharge for the selected 10-year return period reached 24.46 m^3/s, whereas the existing channel capacity was only 1.31 m^3/s. Sediment accumulation reduced the effective cross-sectional area and decreased the channel capacity by up to 30%. Consequently, the combined inflow substantially exceeded the available channel capacity, indicating critical hydraulic overload and a high risk of flooding and surface inundation. The existing drainage system is therefore inadequate and requires channel normalization, periodic sediment removal, and hydraulic capacity improvement.

Keywords: *Urban drainage, Channel capacity, Rainfall runoff, Domestic wastewater, Sedimentation, Drainage evaluation.*

1. Introduction

Urban development in Indonesia has increased rapidly in response to population growth and economic expansion. This condition significantly alters land use patterns and reduces infiltration capacity, which consequently leads to higher surface runoff volumes during rainfall events. Urban drainage systems serve as essential infrastructure to convey stormwater and maintain hydrological balance within developed areas. In many Indonesian cities, drainage channels also function as conduits for domestic wastewater due to the limited separation between sewerage and stormwater systems. This mixed-flow condition increases

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hydraulic loading beyond the original design capacity. Field observations in Rela–Sutomo Road, Medan, indicate a densely populated residential area with intensive domestic activity. The drainage network in this location continuously receives wastewater discharge and solid waste input from surrounding households. Sediment accumulation derived from suspended solids and urban debris reduces the effective cross-sectional area of the channel. This process gradually decreases flow velocity and storage capacity, which directly affects hydraulic performance. During high-intensity rainfall, the system fails to accommodate the combined inflow, resulting in surface ponding and localized flooding. These conditions disrupt daily activities and contribute to infrastructure deterioration. Repeated inundation accelerates pavement damage and reduces service life of road structures. In addition, stagnant water conditions degrade environmental quality and create favorable conditions for disease vectors. The interaction between hydrological processes, wastewater input, and sediment dynamics indicates that urban drainage performance is influenced by multiple interconnected factors rather than a single dominant parameter.

Previous studies have evaluated drainage channel capacity using hydrological and hydraulic approaches with different levels of complexity and parameter integration. Based on Table 1, rainfall is consistently used as the primary driver in all 15 reviewed studies, with channel lengths varying from 200 m in tertiary systems to 340,000 m in large primary networks. Domestic wastewater is included in 9 studies, such as Ambon with a channel length of 894 m, Tangerang with 2,516 m, Tasikmalaya with 3,090 m, Medan with 1,000 m, and Tegal with 3,780 m [1], [2], [3], [4], [5]. Sediment volume is evaluated in 10 studies, including Medan Simalingkar with 500 m channel length and Bekasi with 1,081 m [6], [7]. Evapotranspiration is considered in only 6 studies, such as Medan Baru with 3,780 m, Metro with 1,143 m, and Bogor Selatan with 1,668 m [8], [9], [10]. Only a limited number of studies integrate all four parameters simultaneously. Saragi et al. [11] in Medan and Prawati and Fajri [10] in Metro include rainfall, domestic wastewater, sediment, and evapotranspiration in their analyses. Several studies adopt partial approaches. Amrulloh et al. [12] focus solely on rainfall runoff, while Saragih et al. [11] combine rainfall and sediment without accounting for domestic discharge. Other studies such as Wardhani et al. [9] incorporate evapotranspiration but exclude sediment or wastewater components. The selection of projection periods also varies widely, ranging from 2 years to 100 years, with most studies applying 5 to 10 year return periods. This variation affects the comparability of results and introduces uncertainty in design recommendations. The reliance on secondary data is common in several studies, which limits the ability to capture actual field conditions such as sediment thickness and channel deformation. The absence of consistent parameter integration and field-based validation indicates that existing evaluations do not fully represent the complexity of urban drainage systems under mixed-flow conditions.

This study introduces an integrated evaluation of drainage channel capacity using primary field measurements and combined hydrological and hydraulic analysis under high rainfall intensity. The research was conducted along channel segments in Rela–Sutomo Road, Medan, which represents a dense urban drainage system with mixed inflow conditions and frequent surface runoff. Field measurements were performed to obtain channel geometry, including width, depth, and slope, as well as sediment thickness along the channel bed and blockage-prone sections. These data are used to determine the effective hydraulic capacity of the system after sediment-induced reductions. Rainfall runoff is estimated based on precipitation data and catchment characteristics, while domestic wastewater discharge is calculated from population density and water usage rates from surrounding residential areas. The total inflow is defined as the combination of runoff and wastewater contributions. This approach allows comparison between existing channel capacity and loading conditions during peak flow conditions. The use of site-specific primary data improves the reliability of the analysis and reduces uncertainty associated with assumptions or generalized parameters. Unlike previous studies that rely on limited variables, this study integrates rainfall, domestic wastewater, and sediment accumulation, including sediment depth variation and local discharge sources within a single evaluation framework. The objective is to assess whether the existing drainage system can accommodate the combined discharge under current conditions. The findings are expected to provide a more accurate representation of urban drainage performance and support the development of improved assessment methods and maintenance prioritization needs. The results can also serve as a basis for planning channel normalization, sediment removal, or system upgrading strategies in similar urban environments.

Table 1. Review of research on evaluation of existing drainage channel capacity

No	Location	Channel Type	Channel Length (m)	Aspek Evaluation Aspects of Existing Drainage Channels				Projection (years)	Ref.
				Rain fall	Waste water	Sediment Volume	Evapotran spiration		
1.	Wolter Mongosidi Street, Paso (Ambon)	Secondary	894	✓	✓	✓	x	5; 10	[1]
2.	Residential Area of Desana, Tangerang Regency (Banten)	Secondary	2,516	✓	✓	x	x	5	[2]
3.	A.H. Nasution Street, Tasikmalaya City (Jawa Barat)	Primary	3,090	✓	✓	✓	x	2;5;10; 25;50	[3]
4.	Air Bersih Street, Sudirejo I Subdistrict (Medan)	Secondary	1,000	✓	✓	✓	x	10	[4]
5.	Tegal City, West Tegal District (JawaTengah)	Primary	3,780	✓	✓	✓	x	2	[5]
6.	Kaliurang Street, Sumbersari District (Jawa Timur)	Secondary	1,000	✓	x	x	x	2; 5; 10	[12]
7.	Perumnas Simalingkar Street (Medan)	Secondary	500	✓	x	✓	x	2; 5; 10; 25; 50; 100	[11]
8.	Pelita 1 Street, Medan Perjuangan District (Medan)	Secondary	3,421	✓	✓	✓	✓	10	[13]
9.	Honipopu Subdistrict, Sirimau District (Ambon)	Primary	340,000	✓	✓	✓	x	10	[14]
10.	Perjuangan Street, Sudirejo Subdistrict, Medan Tembung District (Medan)	Tertiary	200	✓	x	x	✓	2; 5; 25; 50	[50]
11.	Medan Baru District (Medan)	Primary	3,780	✓	x	✓	✓	2; 5; 10; 25; 50; 100	[8]
12.	Gandu Street, Sukadarma Subdistrict, Sukatani District, Bekasi Regency (Jawa Barat)	Primary	1,081	✓	x	✓	✓	2; 5; 10	[7]
13.	Tawes Street, Yosorejo Subdistrict, Metro City (Lampung)	Secondary	1,143	✓	✓	✓	✓	10	[10]
14.	South Bogor District (Bogor)	Secondary	1,668	✓	x	x	✓	2, 5, 10, 25, 50	[9]

2. Methodology

2.1. General Conditions of the Study Area

The study area is located in Medan City and follows a drainage corridor from Rela Street toward Sutomo Street across Medan Tembung and Medan Timur districts. Figure 1 presents the spatial configuration of the observation route and shows a continuous alignment that begins in a dense residential zone and extends toward areas with higher urban activity intensity. The mapped route indicates a connected drainage pathway that intersects multiple local streets and passes through mixed land use dominated by housing blocks and small commercial facilities. Road density appears high and reflects limited open space for natural infiltration. This spatial pattern influences runoff generation and increases dependence on the drainage network. Field access is supported by a well-connected road system which allows direct measurement at each observation point. The upstream section near Rela Street shows closely spaced housing units and narrow channels positioned along the roadside. Downstream sections toward Sutomo Street show wider road corridors and more diverse activities including markets and service areas. The variation in surrounding land use is visible in Figure 1 and corresponds to changes in drainage characteristics along the flow path. The channel alignment follows the road network and indicates direct exposure to household discharge and surface debris [15], [16], [17], [18]. Elevation differences along the corridor are relatively small which supports slow flow conditions in several segments. The observed pathway represents a typical urban drainage system with combined inflow sources and continuous human interaction along the channel boundary [19], [20], [21], [22].

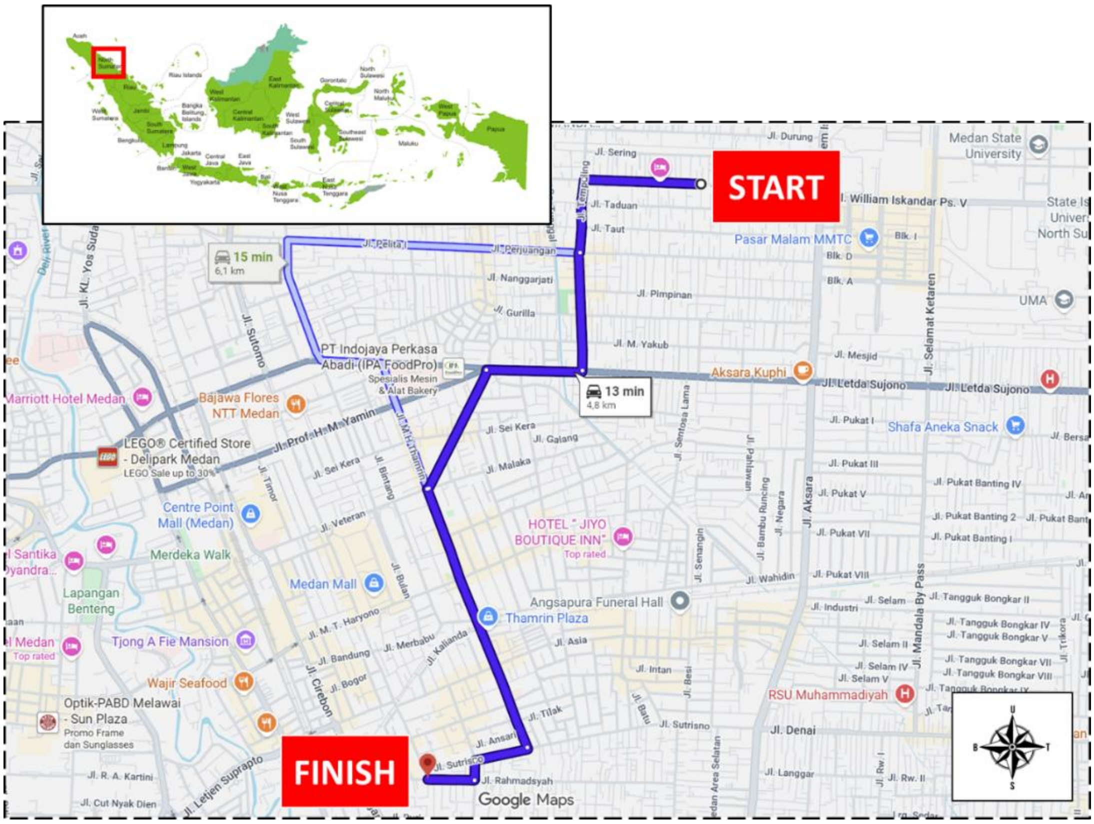

Figure 1. Map of the Study Area: Rela–Sutomo Street, Medan City, Indonesia

Table 2 provides detailed coordinate data and geometric characteristics for each observation segment distributed along the drainage corridor. Segment 1 is located at Rela Street No. 94–107 with coordinates (3.606889, 98.702905) and shows a channel width of 0.70 m with depth 1.00 m and sediment height 0.60 m. Segment 2 at Rela Street No. 76 with coordinates (3.606832, 98.704441) has a width of 1.62 m with depth 1.00 m and sediment height 0.45 m. Segment 3 at Keruntung Street with coordinates (3.607099, 98.697343) presents a width of 1.40 m with depth 1.20 m and sediment height 0.25 m. Segment 4 at Sutomo Ujung Street with coordinates (3.607774, 98.680091) has a width of 1.00 m with depth 0.70 m and sediment height 0.20 m. Segment 5 at Sutomo Ujung Street No. 90 with coordinates (3.606136, 98.679906) shows a width of 1.00 m with depth 0.90 m and sediment height 0.15 m. These measurements indicate variation in channel dimensions and sediment deposition along the flow direction. Upstream segments show higher sediment accumulation which reduces effective flow area [23], [24]. Downstream segments present lower sediment thickness and slightly more stable geometry. The coordinate distribution in Table 2 aligns with the route shown in Figure 1 and reflects gradual spatial transition from residential dominated zones toward mixed urban areas with different loading conditions under varying environmental and hydraulic influences.

Table 2. Location and existing conditions of the drainage channel

Segment	Location and coordinates	Width, B (m)	Total depth, D (m)	Sediment height, Ds (m)	Effective depth, De (m)	Estimated bed slope, S (m/m)	Equivalent slope
Segment 1	Rela Street No. 94–107, Sidirejo, Medan Tembung, Medan, North Sumatra 20222; (3.606889, 98.702905)	0.70	1.00	0.60	0.40	0.0010	0.10%
Segment 2	Rela Street No. 76, Sidirejo, Medan Tembung District, Medan City, North Sumatra 20222; (3.606832, 98.704441)	1.62	1.00	0.45	0.55	0.0010	0.10%
Segment 3	Keruntung Street, Medan Tembung, Medan, North Sumatra 20235; (3.607099, 98.697343)	1.40	1.20	0.25	0.95	0.0010	0.10%
Segment 4	Sutomo Ujung Street, Medan Timur, Medan, North Sumatra 20235; (3.607774, 98.680091)	1.00	0.70	0.20	0.50	0.0010	0.10%
Segment 5	Sutomo Ujung Street No. 90, Durian, Medan Timur District, Medan City, North Sumatra 20236; (3.606136, 98.679906)	1.00	0.90	0.15	0.75	0.0010	0.10%

2.2. Population Projection and Domestic Wastewater Discharge Analysis

Population projection analysis was conducted to estimate population growth within the study area over a specific period, which directly influences the increase in domestic wastewater discharge [18], [25], [26]. The approaches applied include the arithmetic method, geometric method, exponential method, least square method, and logarithmic method. The arithmetic method describes population growth as a constant annual increment and is suitable for stable growth conditions. The geometric method represents growth based on a fixed percentage, reflecting compound population increase. The exponential method models continuous growth and better represents long-term conditions. The least square method establishes a linear relationship between population and time using historical data and produces a regression equation for projection. The logarithmic method represents a non-linear relationship between time and population under non-uniform growth conditions. The results from each method were compared using error parameters including mean absolute error, mean squared error, and root mean square error to determine projection accuracy. The coefficient of determination was also used to assess the strength of the relationship between observed and calculated data. The method with the lowest error value and highest coefficient of determination was selected as the basis for population projection. The projected population was then used to estimate domestic wastewater discharge based on population size, water demand, number of house connections, land area, and direct field measurements. Each approach provides a different estimation of wastewater inflow into the drainage system and allows the determination of a more representative value under actual conditions. This framework enables a more comprehensive assessment of the relationship between population growth and increasing domestic wastewater load in urban drainage systems.

Population projection analysis was conducted to estimate population growth within the study area over a defined period that directly affects domestic wastewater discharge. The applied approaches include the arithmetic, geometric, exponential, least square, and logarithmic methods. The arithmetic method represents population growth with a constant annual increment as expressed in Equation (1) and is suitable for stable conditions. The geometric method describes growth based on a fixed percentage as shown in Equation (2), reflecting compound increase. The exponential method models continuous growth as expressed in Equation (3), which better approximates long-term trends. The least square method determines the linear relationship between population and time using historical data as shown in Equation (4), producing a regression equation for projection. The logarithmic method describes a non-linear relationship between time and population as expressed in Equation (5) under non-uniform growth conditions. The results from each method were compared using error indicators such as mean absolute error, mean squared error, and root mean square error to evaluate projection accuracy. The coefficient of determination was used to assess the correlation between observed and calculated values. Additional validation was performed using percentage error as expressed in Equation (8) to strengthen the selection of the most appropriate method. The method with the lowest error and highest coefficient of determination was selected for population projection. The projected population was then used to calculate domestic wastewater discharge based on population size and water demand as expressed in Equation (6), as well as peak discharge analysis as expressed in Equation (7). Each approach produces different estimates of wastewater inflow into the drainage system and supports the determination of values that better represent actual field conditions. This approach enables a more comprehensive analysis of the relationship between population growth and increasing domestic wastewater load in urban drainage systems.

$$P_n = P_0 + K_a(T_n - T_0) \tag{1}$$

Where P_n is the population in year n, P_0 is the initial population, K_a is the growth constant, T_n is the projected year, and T_0 is the base year.

$$P_n = P_0(1 + r)^n \tag{2}$$

Where P_n is the population in year *n*, P_0 is the initial population, *r* is the growth rate, and *n* is the time interval.

$$P_n = P_0 e^{rn} \quad (3)$$

Where P_n is the population in year *n*, P_0 is the initial population, *r* is the growth rate, *n* is the time period, and *e* is the exponential constant.

$$Y = a + bX \quad (4)$$

Where *Y* is the projected population, *a* is the constant, *b* is the regression coefficient, and *X* is time.

$$Y = a + b \ln X \quad (5)$$

Where *Y* is the population, *a* is the constant, *b* is the coefficient, *ln* is the natural logarithm, and *X* is logarithmic time.

$$Q\text{limbah} = f \times Q_{\text{air bersih}} \quad (6)$$

Where *Q_{*wastewater*}* is the wastewater discharge, *f* is the conversion factor, and *Q_{clean water}* is the clean water discharge.

$$Q_{peak} = f_{\text{peak}} \times Q_{\text{rata-rata}} \quad (7)$$

Where Q_{peak} *is the peak discharge,* f_{peak} *is the peak factor, and* Q_{average} *is the average discharge.*

$$PE = \frac{|P_{obs} - P_{calc}|}{P_{obs}} \times 100\% \quad (8)$$

Where *PE* is the percentage error, *P_{obs}* is the observed data, and *P_{calc}* is the calculated data.

2.3. Hydrological Analysis and Drainage Channel Capacity Evaluation

Hydrological analysis represents a key stage in processing rainfall and wastewater data to estimate the total water volume flowing into and occupying the drainage channel system. The analysis begins with rainfall frequency assessment, followed by the determination of rainfall intensity, and concludes with the calculation of runoff discharge and wastewater flow. Rainfall frequency is evaluated using three probability distribution methods, namely Gumbel, Log-Normal, and Log Pearson Type III. For the Gumbel method, the design rainfall for a return period t years (X_t) is calculated using the equation $X_t = X_r + K \cdot S_x$, where X_r represents the mean maximum rainfall, K is the frequency factor, and S_x is the standard deviation. The standard deviation is obtained from the expression $\sqrt{((X_i - X_r)^2 / (n - 1))}$, where X_i denotes individual rainfall values, X_r is the mean maximum rainfall, and n is the number of observations. The frequency factor K is determined using $(Y_t - Y_n) / S_n$, where Y_t is the reduced variate, Y_n is the mean reduced variate, and S_n is the standard deviation of the reduced variate. This method is considered appropriate when the skewness coefficient (C_s) is less than or equal to 1.1396 and the kurtosis coefficient (C_k) is less than or equal to 5.4002.

The Log-Normal distribution is derived from the normal distribution by transforming the variable into logarithmic form. The design rainfall (R_t) is calculated using $R_t = X_r + K_t \cdot S_x$, where X_r is the mean rainfall, K_t is the standard variable corresponding to the return period, and S_x is the standard deviation. This method is considered suitable when $C_s \approx 3C_v + C_v^2 \approx 3$

and $C_k \approx 5.383$. The Log Pearson Type III distribution approaches the Log-Normal distribution when the skewness coefficient (C_s) equals zero. The rainfall estimation using this method follows $\log R_t = \log \bar{X} + G_t \cdot S\log X$, where G_t is the frequency factor in logarithmic form. This method is selected when the skewness coefficient does not equal the coefficient of variation ($C_s \neq C_v$). Rainfall intensity is determined using the Mononobe method expressed as $I = (R_{24}/24)\ (24/t)^{2/3}$, where I is the rainfall intensity (mm/h), R_{24} is the 24-hour design rainfall (mm), and t is the rainfall duration (hours). Runoff discharge is calculated using the rational method, which is appropriate for relatively small catchment areas with uniform rainfall distribution. The equation is given by $Q = 0.278 \cdot C \cdot I \cdot A$, where 0.278 is a unit conversion factor, C is the runoff coefficient ($0 \leq C \leq 1$), I is rainfall intensity (mm/h), and A is the catchment area (km^2). Domestic wastewater discharge represents the volume of effluent generated from household activities and conveyed into the drainage system. Its magnitude is strongly influenced by population size within the study area. According to SNI 6728.1:2015, the estimated clean water demand for metropolitan areas with populations exceeding 1,000,000 ranges from 150 to 200 L/person/day, while approximately 80% of this consumption is converted into domestic wastewater discharge.

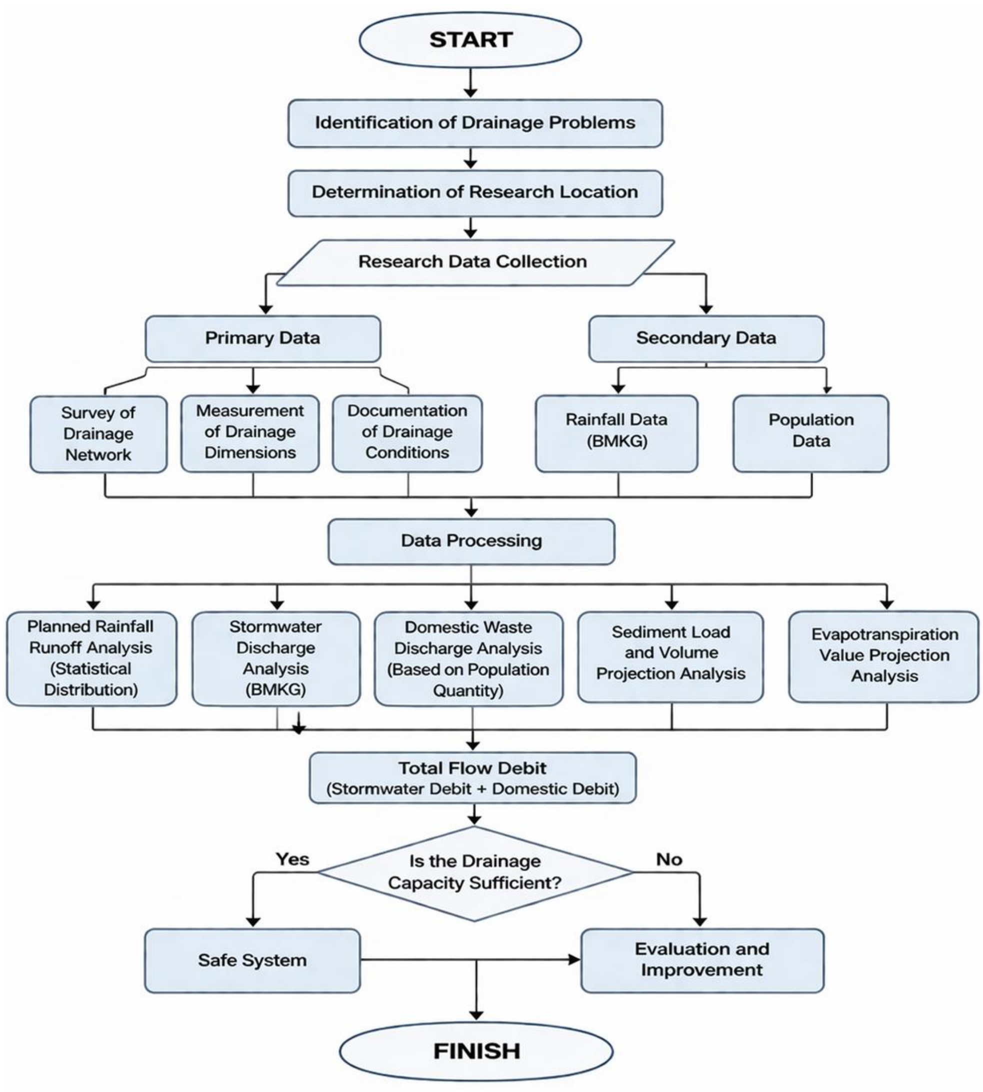

Figure 2. Drainage Channel Capacity Evaluation Process

3. Results and Discussion

3.1. Hydrological Analysis and Drainage Channel Capacity Evaluation in Rela–Sutomo Road Area

The population projection results shown in Figure 3(a) indicate a consistent increasing trend across all applied methods, with noticeable divergence at longer projection periods. At the 2–10 years interval, the projected population remains relatively close across methods, ranging around 125,000–135,000 people, which reflects similar short-term growth assumptions. At the 25-year projection, differences begin to appear, where the exponential and geometric methods estimate values above 150,000 people, while the logarithmic method remains lower at approximately 130,000 people. The gap becomes more pronounced at 50 and 100 years, where the exponential method produces the highest projection reaching approximately 310,000–320,000 people, followed closely by the geometric and least square methods. In contrast, the logarithmic method produces the lowest estimate, remaining below 150,000 people at 100 years.

This variation reflects the sensitivity of projection models to long-term growth assumptions, particularly under urban expansion conditions. Similar behavior has been reported in urban population modeling studies where exponential-based approaches tend to overestimate long-term growth in rapidly developing areas, while logarithmic models often underestimate due to growth saturation assumptions [27]. The least square method shows moderate growth and maintains stability across projection intervals, which supports its selection as the most representative model for further analysis. This pattern aligns with findings by Cohen [28], where linear regression-based projections provide more stable estimates in urban systems with fluctuating growth rates. The increasing population trend directly influences domestic wastewater generation, as higher population density leads to increased water consumption and discharge into the drainage system. This relationship is critical in mixed drainage systems where stormwater and domestic wastewater are conveyed simultaneously, increasing hydraulic loading beyond the original design capacity.

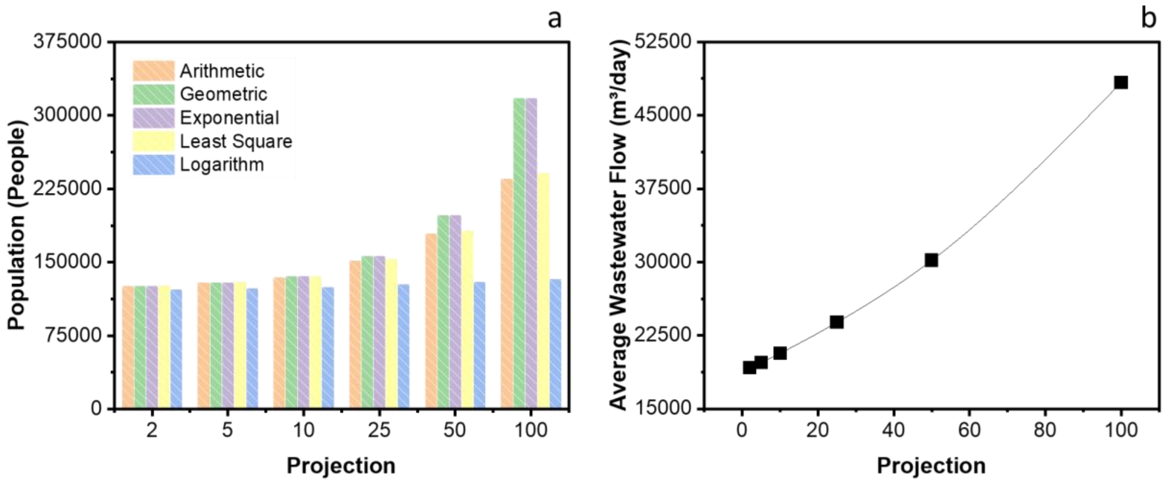

Figure 3. (a) Population projection using arithmetic, geometric, exponential, least square, and logarithmic methods; and (b) Projected average domestic wastewater discharge based on population growth

The projected domestic wastewater discharge presented in Figure 3(b) shows a strong positive correlation with population growth, with discharge values increasing from approximately 20,000 m^3/day at the early projection stage to nearly 50,000 m^3/day at the 100-year projection. The growth pattern follows a nonlinear trend, where the rate of increase becomes more significant at higher projection intervals. At around the 25-year projection, the discharge reaches approximately 30,000 m^3/day, indicating a substantial increase in hydraulic load compared to the initial condition. This escalation reflects the assumption that approximately 80% of clean water consumption is converted into wastewater, which is consistent with standard urban water demand models. The increasing wastewater discharge contributes directly to the total inflow within the drainage channel, particularly in urban systems without separate sewer networks. Similar studies have reported that domestic wastewater can contribute up to 30–60% of total dry-weather flow in urban drainage systems, significantly affecting hydraulic performance [29].

The trend observed in Figure 3(b) indicates that even without extreme rainfall conditions, the drainage system already receives a substantial base flow from domestic sources. When combined with peak runoff during rainfall events, this condition increases the likelihood of system overload. The magnitude of wastewater discharge growth highlights the importance of integrating population dynamics into hydrological analysis, as neglecting this component may lead to underestimation of total discharge and inaccurate evaluation of drainage capacity in urban environments.

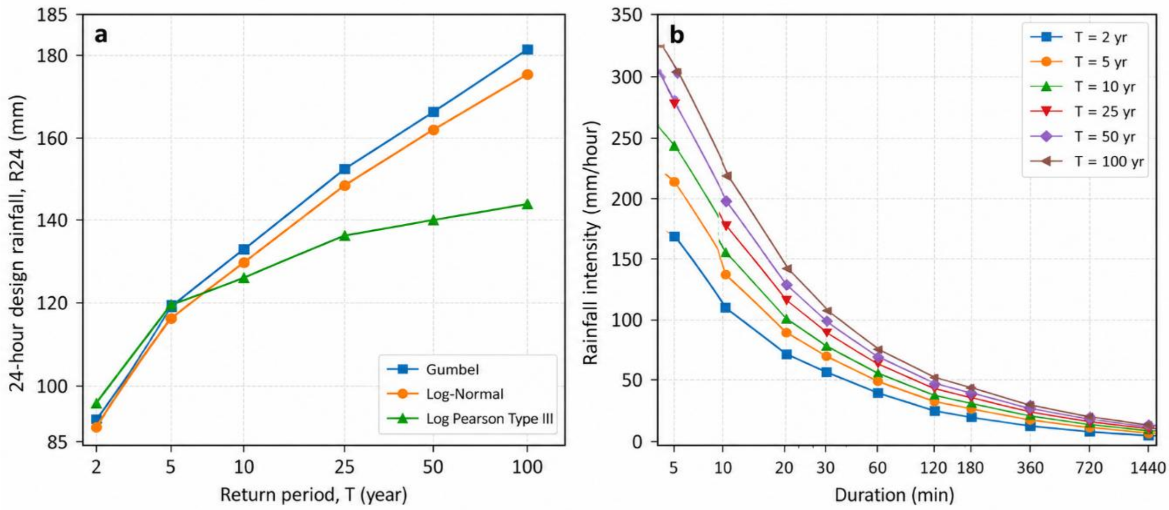

Figure 4. (a) Estimated 24-hour design rainfall, R 24, derived from annual maximum daily rainfall using Gumbel, Log-Normal, and Log Pearson Type III distributions; and (b) IDF curves calculated from the selected 24-hour design rainfall using the Mononobe equation for return periods of 2, 5, 10, 25, 50, and 100 years

3.2. Rainfall and Runoff in the Rela–Sutomo Road Area

The design rainfall estimation presented in Figure 4(a) shows a consistent increase in rainfall depth with increasing return period, with clear differences among the applied probability distributions. At shorter return periods (2–10 years), the three methods produce relatively close values, ranging between approximately 3,000 mm and 3,700 mm, which indicates similar performance in representing observed rainfall variability. At the 25-year return period, divergence becomes more evident, where the Gumbel and Log Normal methods estimate rainfall around 4,100–4,200 mm, while the Log Pearson Type III method remains lower at approximately 3,700–3,800 mm. This gap increases further at the 50- and 100-year return periods, where the Gumbel method produces the highest estimate approaching 4,500 mm, followed by the Log Normal method at approximately 4,300–4,400 mm, while Log Pearson Type III stabilizes below 3,900 mm. The statistical characteristics presented in Table 3 support this behavior. The observed skewness coefficient (Cs = -0.8743) and kurtosis coefficient (Ck = 4.9293) for the Gumbel method fall within the acceptable theoretical limits (Cs ≤ 1.1396; Ck ≤ 5.4002), indicating that the Gumbel distribution remains statistically valid for extreme rainfall estimation in this dataset. In contrast, the Log Normal and Log Pearson Type III distributions show observed values of Cs = -1.2935 and Ck = 5.9659, which deviate from their theoretical conditions, suggesting lower suitability. This result is consistent with hydrological studies where the Gumbel distribution is widely applied for extreme rainfall analysis in tropical regions due to its ability to represent upper-tail events [30]. Similar findings were reported by Koutsoyiannis [31], who showed that extreme value distributions such as Gumbel perform better in representing high-return-period rainfall compared to normal-based transformations. The difference among methods becomes critical in long-term design because higher rainfall estimates directly increase runoff discharge and design load within urban drainage systems.

Table 3. Statistical Parameters for Selection of Probability Distribution in Rainfall Frequency

Method		Cv	Cs	Ck
Gumbel	Observed data	0.1399	-0.8743	4.9293
	Theoretical	–	1.1396	5.4002
Log Normal	Observed data	0.01878	-1.2935	5.9659
	Theoretical	0.01878	0.05635	3.00564
Log Pearson Type III	Observed data	0.01878	-1.2935	5.9659
	Theoretical	–	–	–

The Intensity–Duration–Frequency (IDF) relationship shown in Figure 4(b) indicates that rainfall intensity decreases sharply with increasing duration across all return periods, while maintaining a clear separation between return period curves. At very short durations (≤10 minutes), rainfall intensity reaches extremely high values exceeding 7,000–8,000 mm/hour for higher return periods such as 50 and 100 years. As duration increases to approximately 100–300 minutes, intensity drops significantly to below 1,000 mm/hour, and continues decreasing toward values below 200 mm/hour at longer durations exceeding 1,000 minutes. This pattern reflects the typical inverse relationship between rainfall intensity and duration observed in urban hydrology. Higher return periods consistently produce higher intensity values at all durations, indicating greater potential for peak runoff generation. The steep gradient at short durations is particularly important for urban drainage design, as it controls peak discharge under storm events with rapid concentration time. According to IDF theory, short-duration high-intensity rainfall is the dominant driver of peak runoff in small urban catchments (IDF characteristics), which directly influences the application of the rational method [29]. Similar IDF patterns have been reported in tropical urban regions, where short-duration storms contribute significantly to drainage overload and flooding [32]. The intensity values observed in Figure 4(b) indicate that even moderate return periods such as 10–25 years already generate high-intensity rainfall capable of exceeding channel capacity when combined with domestic wastewater flow. The integration of rainfall frequency analysis and IDF curves provide a comprehensive basis for runoff estimation, as rainfall magnitude and temporal distribution jointly control the hydraulic response of the system under mixed conditions.

3.3. Evaluation of Physical Disturbances and Evapotranspiration in the Rela–Sutomo Road Area

The monthly evapotranspiration pattern shown in Figure 5(a) indicates relatively stable but fluctuating values throughout the year, ranging from approximately 114 mm/month to 132 mm/month. The lowest evapotranspiration occurs in November at around 114 mm/month, while the highest values are observed in July and August reaching approximately 131–132 mm/month. The variation reflects seasonal differences in solar radiation, air temperature, and humidity conditions in the study area. The gradual increase from February to July suggests a transition toward drier atmospheric conditions with higher evaporative demand, while the decline after August indicates a shift toward wetter conditions with reduced evapotranspiration intensity. This magnitude is consistent with tropical urban environments where monthly reference evapotranspiration typically ranges between 100–150 mm/month, depending on climatic variability [33]. Similar patterns have been reported in Southeast Asian regions where evapotranspiration remains relatively constant but shows moderate seasonal variation influenced by monsoon cycles [34]. The role of evapotranspiration in this study is limited in terms of direct runoff reduction, as its contribution remains small compared to rainfall input. However, it still affects soil moisture balance and infiltration capacity, which indirectly influences runoff generation. In urban areas with high impervious surfaces, the effect of evapotranspiration becomes less dominant because water retention and infiltration processes are significantly reduced, which aligns with observations reported by Oudin et al. [35] regarding limited evapotranspiration influence in highly urbanized catchments.

The sedimentation distribution presented in Figure 5(b) shows significant spatial variability along the drainage channel segments, with values ranging from approximately 0.05 m to 0.60 m. The highest sediment accumulation is observed in Segment II and Segment VIII, reaching approximately 0.60 m, while the lowest value occurs in Segment IV at approximately 0.05 m. Upstream segments generally show higher sediment deposition compared to downstream sections, which reflects the influence of reduced flow velocity and higher solid input from residential activities. The accumulation pattern indicates that sediment transport capacity is insufficient to mobilize deposited materials under normal flow conditions, resulting in progressive buildup along specific channel sections. This condition directly reduces the effective hydraulic cross-sectional area, which has been quantified in this study as a reduction of up to 30% in channel capacity. Similar findings have been reported in urban drainage studies where sediment deposition significantly alters flow characteristics and reduces conveyance efficiency [29]. In addition, Ashley et al. [36] reported that sediment accumulation in urban drainage systems can reduce hydraulic capacity by 20–50%, depending on maintenance conditions and sediment characteristics. The spatial variability observed in Figure 5(b) also indicates that sedimentation is strongly influenced by local factors such as channel geometry, slope, and external inputs from surrounding land use. Segments with higher sediment thickness correspond to areas with dense residential activity and direct waste discharge, while segments with lower accumulation are associated with relatively smoother flow conditions. This distribution pattern highlights the importance of localized maintenance strategies, as sediment removal in critical segments can significantly improve overall drainage performance without requiring full system reconstruction.

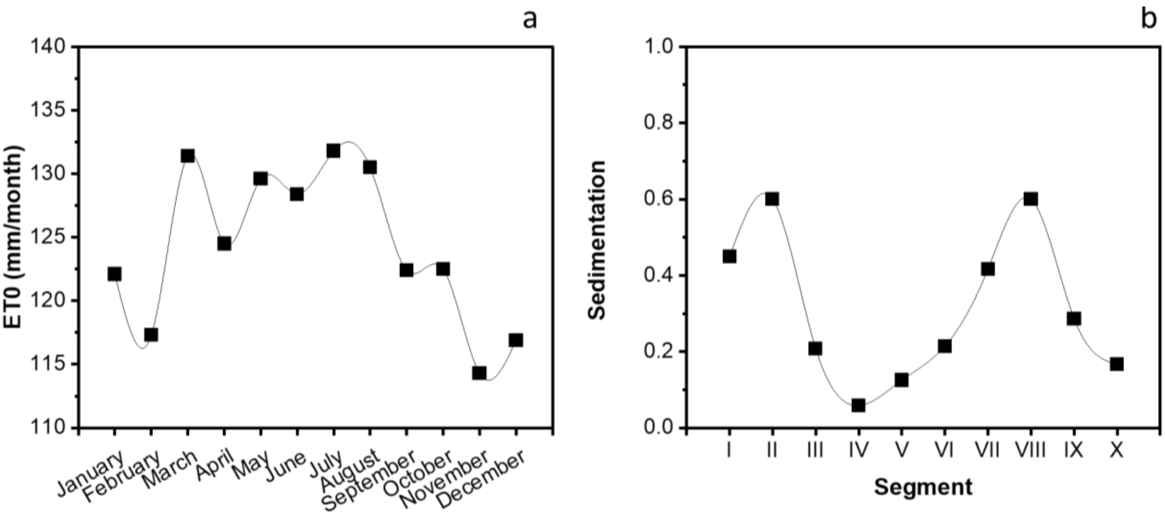

Figure 5. (a) Monthly evapotranspiration (ETo) variation in the study area; and (b) Sedimentation distribution along drainage channel segments

3.4. Drainage Capacity Analysis and Management Strategy Recommendations

The integrated framework presented in Figure 6 illustrates the interaction between rainfall runoff, population growth, domestic wastewater, and sedimentation in determining drainage system performance. The total discharge generated in the study area reaches 24.46 m^3/s, while the existing channel capacity is only 1.31 m^3/s, indicating a significant imbalance between inflow and hydraulic capacity. Sediment accumulation further reduces the effective cross-sectional area by up to 30%, which intensifies flow resistance and decreases conveyance efficiency. This condition confirms that the system operates under continuous overload even before extreme rainfall events occur.

The combination of high runoff input and baseflow from domestic wastewater creates a persistent hydraulic burden. The framework in Figure 6 shows that capacity reduction is not driven by a single factor but by the interaction of multiple processes that occur simultaneously within the drainage network. Similar conditions have been reported in combined sewer systems where excess inflow leads to frequent system failure and overflow events. [37] demonstrated that mixed-flow systems can experience up to 40% overflow reduction requirement under high runoff conditions, while uncontrolled systems may experience severe surcharge. [38] also showed that combined runoff loading increases system sensitivity to rainfall variability, especially when storage and infiltration mechanisms are limited. The results of this study align with these findings, where the absence of flow separation and inadequate capacity leads to a condition where total discharge consistently exceeds the drainage limit.

Figure 6. Integrated framework of urban drainage capacity evaluation under combined runoff and domestic wastewater loading

The management strategies summarized in Table 3 indicate that effective mitigation requires a combination of structural and non-structural approaches rather than reliance on a single intervention. Source-control measures such as bioretention and permeable pavement have shown strong performance in reducing runoff before entering the drainage system. [37] reported 50–99% reduction in CSO volume, while permeable pavement studies by Alam et al. [39] demonstrated runoff reduction from 37.5 m^3 to 0.66 m^3 and peak-flow attenuation up to 86%. [40] also reported 35–41% reduction in surface runoff and 60–75% reduction in peak discharge, indicating strong potential for urban implementation. Storage-based approaches provide additional control at larger scales. Pereira Souza et al. [41] showed that detention ponds can reduce peak flow by 10–30% for single units and 30–60% for distributed systems. However, these approaches require land availability and careful design to avoid unintended flow redistribution. The current condition shown in Figure 6 indicates that immediate improvement should focus on channel normalization, sediment removal, and capacity upgrading, which directly address hydraulic limitations. At the same time, long-term strategies should incorporate distributed runoff control to reduce inflow at the source. The combination of these approaches is necessary to restore system performance and reduce flood risk under increasing urban pressure.

Table 3. Previous studies on efforts to reduce excessive runoff loading in drainage systems

Study Location	Main Problem Identified	Strategy Category	Mechanism	Specific Intervention	Ref.
Small urban catchment with a combined sewer system	Combined sewer overflows caused by stormwater entering an already burdened mixed drainage system; study tested overflow reduction targets up to 40%	SuDS/ decentralized retrofit	Reduce runoff volume and increase concentration time before water reaches the combined sewer	Bioretention cells, permeable pavements, rain barrels, and green roofs were simulated at incremental spatial coverage; maximum CSO volume attenuation reached 50–99%, and achieving 40% CSO reduction cost at most 25% of the equivalent large CSO tank; bioretention and permeable pavement were the most effective/cost-effective options	[42]
Catchment near Zurich, Switzerland	CSO discharge in an urban drainage network under combined runoff loading	Blue-Green Infrastructure (BGI) combinations	Infiltration, detention, and runoff rerouting to reduce CSO volume	60 BGI combinations were assessed using 4 BGI elements (bioretention cells, permeable pavement, green roofs, detention ponds) with 25%, 50%, 75%, and 100% implementation rates; combinations gave substantial CSO reduction, but detention ponds could lower CSO volume while increasing CSO frequency by prolonging runoff	[43]
Japan	Urban storm runoff, flooding nodes, and pollutant transport during design storms	Rain garden / bioretention	Store runoff, reduce network burden, and improve runoff quality	For Chicago hyetographs with 3-, 5-, 10-, 30-, 50-, and 100-year return periods, the best case produced 46.56 × 10^6 L runoff reduction; maximum pollutant	[44]

Study Location	Main Problem Identified	Strategy Category	Mechanism	Specific Intervention	Ref.
				reduction ratios reached 15.50% (TSS), 16.17% (COD), 17.34% (TN), and 19.07% (TP); under the 5-year event, the maximum number of flooding nodes decreased to 87	
Colle Ometti catchment, Genoa, Italy (5 ha)	Flooding and runoff from an existing dense urban catchment	Green roof retrofitting	Detention + evapotranspiration restore storage between storms	Continuous SWMM simulation over 26 years and 1433 rainfall events showed average peak reduction = 0.30 and average volume reduction = 0.30, with maximum values of 0.96 for peak reduction and 0.86 for volume reduction	[45]
Subarctic climate test roofs	Roof runoff contribution to downstream drainage loading	Green roof vegetation design	Rainfall retention and hydrograph attenuation at the roof source	30 green roofs were monitored for 3 years; the systems retained >50% of the 409 mm cumulative precipitation; the study found that a stress-tolerant non-succulent plant mixture outperformed Sedum monoculture hydrologically	[46]
São José dos Campos, Brazil	Increased peak flows and runoff volumes due to impervious urban surfaces	Green roof retrofitting policy	Reduce Effective Impervious Area (EIA), delay hydrograph, attenuate peaks	Under the Ideal scenario with EIA = 16%, green roof retrofitting achieved peak flow reductions of 33–41%, runoff volume reductions of 26–35%, peak delays of up to 33%, and hydrograph centroid delay of 13%; the Mandatory scenario (EIA = 34%) only reduced peak flow by 5–6% and runoff volume by 3–4%	[47]

Study Location	Main Problem Identified	Strategy Category	Mechanism	Specific Intervention	Ref.
Semi-arid South Texas, USA	High runoff and peak discharge from paved urban surfaces	Permeable pavement	Surface infiltration, temporary sub-base storage, and delayed discharge	In monitored events, porous concrete pavement (PCP) reduced runoff from 37.5 m³ on traditional asphalt to 0.66 m³ during a 67 mm storm and gave 86% peak-flow attenuation; PICP produced 0.87 m³ runoff and 84% peak-flow reduction in a 17 mm event; IBPG gave 67% peak-flow reduction in a 15 mm event	[39]
Taiwan	Heavy-rain flooding from conventional impervious pavements	Permeable pavement	Reduce direct surface runoff and lower discharge peaks reaching sewers	Field/data analysis showed permeable pavement reduced surface runoff by 35–41% under heavy rain and reduced peak discharge by 60–75% compared with general pavement	[48]
São Carlos, Brazil	Stormwater runoff under different rainfall regimes in a subtropical urban setting	Bioretention basin	Retention, infiltration, and delayed outlet response	The bioretention system retained 9–100% of runoff volume, with an average annual efficiency of 65% during one hydrological year	[49]
Brasília / Paranoá Lake basin, Brazil	Undersized urban drainage system with severe flooding every 2–3 years	Detention ponds / storage-based grey-green control	Temporary storage and controlled release to reduce downstream peak flow	After simulation of 13 detention-pond alternatives, a downstream pond reduced peak flow by 10–30%; combined distributed ponds achieved 30–60% peak-flow reduction; some ponds could be reduced to 70% of original size or by 20% without losing damping efficiency	[41]

4. Conclusion

This study demonstrates that the drainage system along Rela–Sutomo Road operates under critical hydraulic overload conditions due to the combined influence of rainfall runoff, increasing domestic wastewater discharge, and sediment accumulation. The total discharge reaches 24.46 m^3/s, while the existing channel capacity is only 1.31 m^3/s, with sedimentation reducing effective capacity by up to 30%, resulting in system failure and high flood risk. The integrated analysis confirms that drainage performance is controlled by multiple interacting factors rather than a single dominant variable. However, this study has several limitations. The analysis is based on a limited number of observation segments and assumes uniform flow conditions along the channel. Rainfall data and projection methods introduce uncertainty in long-term estimation, while wastewater discharge is derived from standard assumptions rather than continuous field monitoring. The study also does not include detailed hydraulic modeling or dynamic simulation of flow interaction during extreme storm events. Future research should incorporate high-resolution hydrodynamic modeling, continuous monitoring of wastewater discharge, and real-time sediment transport analysis to improve accuracy. The implementation of smart drainage systems, separation of sewer and stormwater networks, and integration of green infrastructure should also be explored to enhance system resilience under increasing urban pressure.

References

[1] S. Maruapey, R. J. Betaubun, and J. C. Jakob, "Evaluasi saluran drainase jalan wolter monginsidi passo kecamatan Baguala kota Ambon," *KOLONI*, vol. 3, no. 1, pp. 116–122, Feb. 2024, doi: 10.31004/koloni.v3i1.600.

[2] A. Widiastomo, R. Wigati, B. A. Priyambodho, S. Subekti, and N. P. Purnaditya, "Analisis dan evaluasi kapasitas sistem drainase di perumahan dasana indah Kabupaten Tangerang," *Fondasi J. Tek. Sipil*, vol. 11, no. 2, p. 254, Nov. 2022, doi: 10.36055/fondasi.v11i2.17024.

[3] L. Lindawati, P. Irawan, and R. Nursani, "Evaluasi sistem drainase dalam upaya penggulangan banjir di Jalan A.H. Nasution Kota Tasikmalaya menggunakan program EPA SWMM 5.1," *J. Siliwangi Seri Sains dan Teknol.*, vol. 7, no. 2, pp. 41–51, 2021, doi: https://doi.org/10.37058/jssainstek.v7i2.4027.

[4] S. Aqsha and D. S. Harahap, "Evaluasi sistem drainase di kawasan pemukiman penduduk di Jalan Air Bersih, Kelurahan Sudirejo I, Kecamatan Medan Kota," *J. Tek. Sipil*, vol. 1, no. 1, pp. 73–77, 2022.

[5] H. Kurniawan, A. Khamid, D. D. Apriliano, and W. Diantoro, "Evaluasi dan rencana pengembangan sistem drainase di Kota Tegal (studi kasus di Kecamatan Tegal Barat)," *Era Sains J. Penelit. Sains, Keteknikan dan Inform.*, vol. 1, no. 2, pp. 1–11, 2023, [Online]. Available: https://jurnal.eraliterasi.com/index.php/erasains/article/view/105/91

[6] M. J. Saragih, "Developing The Perspective of Preservice Mathematics Teachers Through Early Field Experience," in *Proceedings of International Conference on Research in Education and Science*, K. M., O. O.T., and C. M.L., Eds., Pelita Harapan University, Indonesia: The International Society for Technology Education and Science, 2023, pp. 1254–1263.

[7] A. A. Perkasa, E. Wardhani, and A. Z. Irmansyah, "Evaluasi sistem drainase di Pasar Bancong Kelurahan Sukatani Kabupaten Bekasi," *J. Serambi Eng.*, vol. 9, no. 3, pp. 9294–9300, 2024.

[8] Y. Sibagariang and P. A. E. Saputra, "Analisis drainase di daerah rawan banjir dan dampaknya di Kecamatan Medan Baru Kota Medan," *JUITECH J. Ilm. Fak. Tek. Univ. Qual.*,

vol. 5, no. 1, pp. 66–80, 2021, doi: http://dx.doi.org/10.36764/ju.v5i1.538.

[9] E. Wardhani and A. Rufina, "Evaluasi saluran drainase di Kecamatan Bogor Selatan," *J. Reka Lingkung.*, vol. 10, no. 2, pp. 113–124, Jun. 2022.

[10] E. Prawati, "Analisis sistem drainase akibat curah hujan yang tinggi (studi kasus ruas Jalan Krakatau–Jalan Tawes, Kota Metro)," *TAPAK (Teknologi Apl. Konstr. J. Tek. Sipil*, 2021, [Online]. Available: https://www.academia.edu/download/97064567/1020.pdf

[11] T. E. Saragi, E. O. Zai, and H. F. Siregar, "Studi evaluasi kinerja saluran drainase pada Jalan Perumnas Simalingkar Kota Medan dalam mengatasi debit puncak air," *J. Constr.*, vol. 2, no. 2, pp. 56–70, 2023.

[12] M. Amrulloh, W. Yunarni Widiarti, and G. Halik, "Evaluasi kinerja sistem drainase jalan kaliurang kecamatan Sumbersari kabupaten Jember," *J. Tek. Pengair.*, vol. 12, no. 2, pp. 81–91, Dec. 2021, doi: 10.21776/ub.pengairan.2021.012.02.01.

[13] T. E. Saragi, Y. R. Saragi, E. O. Zai, and M. Harefa, "Analisis dan perencanaan sistem drainase Jalan Pelita 1 Kecamatan Medan Perjuangan Kota Medan," *J. Visi Eksakta*, vol. 2, no. 1, pp. 97–110, 2021.

[14] N. I. Ibrahim, P. T. Berhitu, and F. Puturuhu, "Evaluasi sistem drainase dalam upaya penanggulangan banjir (studi kasus kelurahan Honipopu kota Ambon)," *J. Geogr. Geogr. dan Pengajarannya*, vol. 20, no. 2, pp. 131–143, Dec. 2022.

[15] G. Al Rasyid, D. M. Sidabutar, W. Prayogo, Y. Yolanda, R. Simanjuntak, and R. Harahap, "Evaluasi kapasitas saluran drainase dalam menampung limpasan hujan dan limbah cair domestik di Jalan Sukarela Timur–Jalan Surya Haji Tembung, Percut Sei Tuan, Indonesia," *J. Ilmu Tek. Sipil Indones.*, vol. 2, no. 1, pp. 73–81, 2026, doi: https://doi.org/10.70134/jitesna.v2i1.1375.

[16] Joy Eklesia Pasaribu, Hansen Anugrah Malau, and Wisnu Prayogo, "Evaluasi kapasitas saluran drainase dalam menampung limpasan hujan dan limbah cair domestik pada ruas jalan Tuamang–jalan Rakyat di kota Medan," *J. Stud. dan Apl. Tek. Sipil*, vol. 2, no. 1, pp. 11–19, Feb. 2026, doi: 10.64123/jsats.v2.i1.2.

[17] W. Prayogo *et al.*, "Evaluation of an urban drainage system in a Big City," *J. Tek. Pertan. Lampung (Journal Agric. Eng.*, vol. 12, no. 4, p. 1036, Dec. 2023, doi: 10.23960/jtep-l.v12i4.1036-1052.

[18] H. Pasaribu, "Comprehensive evaluation of drainage channels along selected roads in Medan City, North Sumatra," *JST (Jurnal Sains dan Teknol.*, vol. 12, no. 1, Mar. 2023, doi: 10.23887/jstundiksha.v12i1.52487.

[19] I. A. Daulay, R. Mahadewi, C. H., Simanjuntak, W. Prayogo, and R. Harahap, "Evaluasi kapasitas saluran drainase di Kecamatan Medan Kota dan Medan Denai," *J. Ilmu Tek. Sipil Indones.*, vol. 2, no. 2, pp. 1–6, 2026, doi: https://doi.org/10.70134/jitesna.v2i2.1384.

[20] L. G. E. B. Ginting, R. Simanjuntak, W. Prayogo, and R. Harahap, "Analisis sedimentasi pada saluran drainase di Kecamatan Medan Johor, Kota Medan," *J. Ilmu Tek. Sipil Indones.*, vol. 2, no. 2, pp. 34–40, 2026, doi: https://doi.org/10.70134/jitesna.v2i2.1390.

[21] T. S. T. Sinaga, A. W. Jaya, R. Simanjuntak, W. Prayogo, and R. Harahap, "Geometric characteristics and sedimentation analysis of urban drainage channels in Alumunium Raya," *J. Ilmu Tek. Sipil Indones.*, vol. 2, no. 2, pp. 13–18, 2026, doi: https://doi.org/10.70134/jitesna.v2i2.1386.

[22] R. D. Puspita, G. D. Silaban, W. Prayogo, R. Simanjuntak, R. Harahap, and Y. Yolanda, "Analisis sistem drainase dalam mengurangi genangan air Kota Medan Kecamatan

Percut Sei Tuan," *J. Ilmu Tek. Sipil Indones.*, vol. 2, no. 2, pp. 19–24, 2026, doi: https://doi.org/10.70134/jitesna.v2i2.1387.

[23] W. Najwa, R. Simanjuntak, K. D. S. Gulo, W. Prayogo, and R. Harahap, "Analisis kapasitas saluran drainase berdasarkan analisis curah hujan di Jalan Rahayu Pasar VII Tembung," *J. Ilmu Tek. Sipil Indones.*, vol. 2, no. 2, pp. 25–33, 2026, doi: https://doi.org/10.70134/jitesna.v2i2.1388.

[24] Y. A. Simaremare, A. Sihole, R. Simanjuntak, W. Prayogo, and R. Harahap, "Evaluasi kinerja sistem drainase menggunakan metode rasional dan persamaan Manning pada koridor Jalan Suluh–Jalan Pembangunan III Kota Medan," *J. Ilmu Tek. Sipil Indones.*, vol. 2, no. 2, pp. 7–12, 2026, doi: https://doi.org/10.70134/jitesna.v2i2.1385.

[25] H. S. V. Pasaribu, H. S. Marbun, Nur Sakinah, N. Panjaitan, Nur Novilina Arifianingsih, and Wisnu Prayogo, "Evaluation of an urban drainage channel system on Tuamang Road, Medan," *Int. J. Archit. Urban.*, vol. 6, no. 2, pp. 221–232, Sep. 2022, doi: 10.32734/ijau.v6i2.9693.

[26] F. Damara, D. P. Tinambunan, S. M. G. Hasibuan, R. Mulyana, M. Fadila, and A. Zulfikar, "Evaluation of drainage channel on Meteorological Road, Laut Dendang Village, Deli Serdang Regency," *J. Sustain. Infrastruct.*, vol. 1, no. 2, 2022, [Online]. Available: https://pdfs.semanticscholar.org/09ff/1018af0241d8bfc495f23e5c860808118e4e.pdf

[27] U. Nations, "World population prospects 2019: Highlights. United Nations Department of Economic and Social Affairs.

[28] J. E. Cohen, "Human population: The next half century," *Science (80-.).*, vol. 302, no. 5648, pp. 1172–1175, Nov. 2003, doi: 10.1126/science.1088665.

[29] D. Butler, J. W. Davies, and N. Graham, *Urban drainage (4th ed.)*. CRC Press, 2018. doi: https://doi.org/10.1201/9781315274260.

[30] V. T. Chow, D. R. Maidment, and L. . Mays, *Applied hydrology*. McGraw-Hill, 1988. [Online]. Available: https://ponce.sdsu.edu/Applied_Hydrology_Chow_1988.pdf

[31] D. Koutsoyiannis, "Statistics of extremes and estimation of extreme rainfall: I. Theoretical investigation," *Hydrol. Sci. J.*, vol. 49, no. 4, Aug. 2004, doi: 10.1623/hysj.49.4.575.54430.

[32] P. Willems, "Multidecadal oscillatory behaviour of rainfall extremes in Europe," *Clim. Change*, vol. 120, no. 4, pp. 931–944, Oct. 2013, doi: 10.1007/s10584-013-0837-x.

[33] R. G. Allen, L. S. Pereira, D. Raes, and M. Smith, *Crop evapotranspiration: Guidelines for computing crop water requirements*. Rome: Food and Agriculture Organization of the United Nations, 1998.

[34] J. Lu, G. Sun, S. G. McNulty, and D. M. Amatya, "A comparison of six potential evapotranspiration methods for regional use in the Southeastern United States," *J. Am. Water Resour. Assoc.*, vol. 41, no. 3, pp. 621–633, Jun. 2005, doi: 10.1111/j.1752-1688.2005.tb03759.x.

[35] L. Oudin *et al.*, "Which potential evapotranspiration input for a lumped rainfall–runoff model?," *J. Hydrol.*, vol. 303, no. 1–4, pp. 290–306, Mar. 2005, doi: 10.1016/j.jhydrol.2004.08.026.

[36] R. Ashley, J. Bertrand-Krajewski, T. Hvitved-Jacobsen, and M. Verbanck, "Solids in sewers: Characteristics, effects and control of sewer solids and associated pollutants," *Water Intell. Online*, vol. 4, pp. 9781780402727–9781780402727, Dec. 2015, doi: 10.2166/9781780402727.

[37] W. Sangkaew *et al.*, "Performance of viral and bacterial genetic markers for sewage pollution tracking in tropical Thailand," *Water Res.*, vol. 190, p. 116706, Feb. 2021, doi: 10.1016/j.watres.2020.116706.

[38] F. Tang, Y. Zhou, and Y. Bai, "The effect of mixed forest identity on soil carbon stocks in Pinus massoniana mixed forests," *Sci. Total Environ.*, vol. 907, p. 167889, Jan. 2024, doi: 10.1016/j.scitotenv.2023.167889.

[39] T. Alam, A. Mahmoud, K. D. Jones, J. C. Bezares-Cruz, and J. Guerrero, "A comparison of three types of permeable pavements for urban runoff mitigation in the semi-arid South Texas, U.S.A," *Water*, vol. 11, no. 10, p. 1992, Sep. 2019, doi: 10.3390/w11101992.

[40] Y.-T. Lee, M.-C. Ho, Y.-S. Chiou, and L.-L. Huang, "Assessing the performance of permeable pavement in mitigating flooding in urban areas," *Water*, vol. 15, no. 20, p. 3551, Oct. 2023, doi: 10.3390/w15203551.

[41] F. Pereira Souza, M. E. Leite Costa, and S. Koide, "Hydrological modelling and evaluation of detention ponds to improve urban drainage system and water quality," *Water*, vol. 11, no. 8, p. 1547, Jul. 2019, doi: 10.3390/w11081547.

[42] U. Joshi, J. P. Leitão, and L. Beggiato, "Assessing the effectiveness of decentralized nature-based solutions for combined sewer overflow mitigation," *Water Res.*, vol. 190, no. 116706, 2021.

[43] A. Cavadini, S. Eggimann, and L. Mutzner, "Effectiveness of blue-green infrastructure combinations for combined sewer overflow reduction," *Sci. Total Environ.*, vol. 906, no. 167889, 2024.

[44] A. Mostafaeipour, S. J. Hosseini Dehshiri, S. S. Hosseini Dehshiri, M. Jahangiri, and K. Techato, "A thorough analysis of potential geothermal project locations in Afghanistan," *Sustainability*, vol. 12, no. 20, p. 8397, Oct. 2020, doi: 10.3390/su12208397.

[45] A. Palla, I. Gnecco, and P. La Barbera, "Assessing the hydrologic performance of a green roof retrofitting scenario for a small urban catchment," *Water*, vol. 10, no. 8, p. 1052, Aug. 2018, doi: 10.3390/w10081052.

[46] J. Lönnqvist, M. Viklander, and G. T. Blecken, "Hydrological performance of green roofs in subarctic climate conditions," *J. Hydrol.*, vol. 634, no. 130500, 2025, doi: https://doi.org/10.1016/j.jhydrol.2024.130500.

[47] T. M. Osawa *et al.*, "Hydrological benefits of green roof retrofitting Policies: A case study of an urban watershed in Brazil," *Water*, vol. 17, no. 13, p. 1936, Jun. 2025, doi: 10.3390/w17131936.

[48] J. Y. Lee, H. S. Kim, and J. . Park, "Hydrological performance of permeable pavement under heavy rainfall conditions," *Water*, vol. 15, no. 20, p. 3551, 2023.

[49] M. B. de Macedo, C. A. F. Lago, and E. . Mendiondo, "Stormwater volume reduction through bisoretention systems in a Brazilian subtropical catchment," *J. Environ. Manage.*, vol. 231, pp. 702–701, 2019.

[50] R. Sihite and R. S. Simanjuntak, "Analisis sedimentasi pada saluran drainase Jalan Perjuangan, Medan," Jurnal Teknologi Lingkungan, vol. 4, no. 1, pp. 50–58, Jun. 2026, doi: 10.29408/jtl.v4i1.34549.