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Application of Eco-Drainage Concepts to Mitigate Flood Problems on Jalan Panjang Jiwo, Surabaya

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ABSTRACT: Rapid population growth in Surabaya has been accompanied by various environmental challenges, one of which was flooding on Jalan Panjang Jiwo. In addition to high rainfall intensity, the city's flat topography and its location in the downstream area of the Brantas Watershed contributed to the occurrence of flooding. Land conversion into built-up areas also led to a reduction in natural infiltration areas, resulting in increased surface runoff. Furthermore, the suboptimal performance of the existing drainage system made it unable to adequately convey rainwater discharge during periods of high rainfall intensity. This study aimed to examine the potential application of the eco-drainage concept through the injection well method as an alternative flood control measure in the Jalan Panjang Jiwo area. Injection wells were selected because this design was intended to support the infiltration process by allowing rainwater to pass through impermeable or low-permeability topsoil layers. Unlike natural infiltration systems, which relied solely on surface soil permeability, injection wells enabled water to penetrate these layers and reach more permeable soil strata below. Therefore, this method was considered effective for application in urban areas dominated by built-up surfaces with limited green open spaces. The analysis was conducted using hydrological and hydraulic approaches, supported by modeling with EPA SWMM 5.2. Through a trial-and-error process involving calculation and design evaluation, an optimal injection well design with a diameter of 3.25 meters and a depth of 25 meters was obtained. Based on flood discharge estimates under existing channel conditions, a total of six injection wells were required to accommodate surface runoff. The results of this study were expected to serve as technical recommendations for the development of sustainable urban drainage systems, particularly in flat areas with high runoff levels such as Surabaya.

KEYWORDS: Urban flood; eco-drainage; injection well; Surabaya

1. Introduction

Urban flooding has become a persistent challenge in rapidly growing cities, particularly where drainage infrastructure has not kept pace with land-use change. In Surabaya, many drainage channels were originally designed with capacities that are no longer sufficient to accommodate the increasing runoff generated by accelerated urban development [1]. As a result, flooding events have become more frequent, especially in highly urbanized areas such as Jalan Panjang

Jiwo, where environmental conditions and anthropogenic pressures interact to exacerbate flood risk.

The physical characteristics of Surabaya contribute significantly to its vulnerability. The city is predominantly flat, with elevations ranging from 3 to 6 m above sea level and average land slopes below 3% [2]. These conditions reduce flow velocities and prolong runoff concentration times, increasing the likelihood of surface inundation [3]. In addition, Surabaya is located in the downstream section of the Brantas River Basin, causing it to receive cumulative inflows from upstream catchments in the form of river discharge and surface runoff [4]. Flood risk is therefore amplified when intense local rainfall coincides with elevated upstream flows that exceed the capacity of the urban drainage system.

Land-use transformation has further intensified these challenges. The Panjang Jiwo Sub-district has a population density of 10,198 people/km², reflecting intense urban activity. Rapid conversion of land into commercial, industrial, office, and high-density residential areas has substantially reduced natural infiltration zones [5]. The expansion of impervious surfaces limits infiltration and accelerates surface runoff, resulting in higher peak discharges and shorter runoff response times [6]. Previous studies have demonstrated that such land-cover changes significantly increase runoff volumes while reducing baseflow contributions. These findings align with flood vulnerability assessments that classify the Tenggilis Mejoyo District, where Jalan Panjang Jiwo is located, as highly prone to flooding.

Collectively, these factors indicate that conventional drainage systems alone are no longer adequate to manage urban flooding in Surabaya. Flood mitigation strategies must therefore move beyond end-of-pipe solutions and incorporate sustainable drainage concepts that address runoff at its source [7]. Sustainable Urban Drainage Systems (SUDS), particularly eco-drainage approaches, have been widely recognized for their ability to mimic natural hydrological processes through infiltration, storage, and flow attenuation, thereby reducing peak runoff and alleviating pressure on existing drainage networks [8].

However, the application of surface-based SUDS in densely built urban areas such as Jalan Panjang Jiwo is constrained by limited open space, extensive impervious cover, and low soil permeability. Under these conditions, injection wells represent a viable eco-drainage alternative, as they allow stormwater to bypass low-permeability surface layers and infiltrate deeper, more permeable strata. This method has been shown to effectively reduce surface runoff and mitigate localized flooding in highly urbanized environments. Despite their potential, the broader implementation of eco-drainage solutions in Surabaya remains limited due to insufficient regulatory support, budgetary constraints, low public awareness, and inadequate integration into urban planning frameworks [9].

To address these gaps, this study evaluates the application of eco-drainage through injection wells as a flood mitigation strategy for the Jalan Panjang Jiwo area. Hydrological and hydraulic analyses were conducted and simulated using the EPA Storm Water Management Model (SWMM) version 5.2, a widely used dynamic modeling tool for urban rainfall–runoff processes and drainage network performance assessment [10]. The results of this study are expected to provide technical evidence and practical recommendations to support the development of sustainable urban drainage systems in flat, densely urbanized areas such as Surabaya.

2. Materials and Methods

2.1.Study location.

This study was conducted in the drainage system along Jalan Panjang Jiwo, located in the Tenggilis Mejoyo District, Surabaya City, Indonesia. The study area was selected due to its high vulnerability to flooding, as evidenced by recurrent inundation events reported by the local community, field observations, and documentation in local media sources. The drainage corridor represents a densely urbanized environment with limited infiltration capacity and frequent drainage overflows during high-intensity rainfall events. The geographical location and spatial extent of the study area are illustrated in Figure 1, which shows the position of Jalan Panjang Jiwo within the urban drainage network of Surabaya.

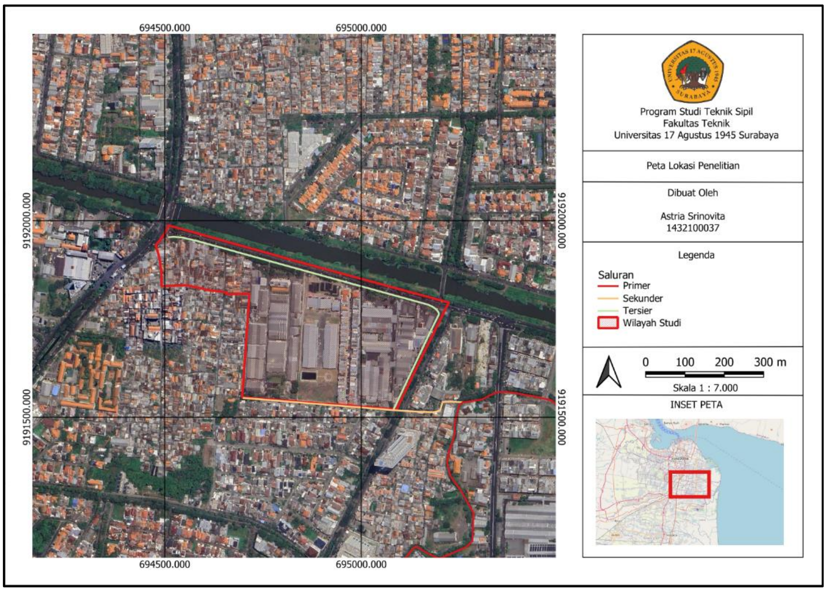

Figure 1. Study location of the Jalan Panjang Jiwo drainage system.

2.2. Data collection.

The analysis was supported by both hydrological and spatial datasets relevant to urban flood assessment and drainage performance evaluation. Rainfall data consisted of ten years of daily precipitation records (2015–2024) obtained from three representative rainfall stations, namely Wonorejo, Wonokromo, and Gunungsari, which adequately capture the spatial variability of rainfall in the study area. Spatial data included the drainage network map of the Wonorejo Drainage Sub-System and a land-use map of Panjang Jiwo Village, which were used to delineate catchment characteristics and assess surface runoff behavior. In addition, geometric data on existing drainage channels, including channel width, depth, slope, and material condition, were collected through field surveys and secondary records. These datasets formed the basis for hydrological analysis, hydraulic modeling, and evaluation of flood mitigation measures.

2.3. Data analysis.

The analytical framework of this study comprised a sequence of interconnected steps, integrating hydrological analysis, hydraulic simulation, and design evaluation. Rainfall data were first processed to determine design rainfall characteristics, which were subsequently used to estimate surface runoff under existing land-use and drainage conditions. Hydraulic performance of the drainage network was then evaluated through modeling using EPA SWMM 5.2, allowing simulation of flow depth, discharge, and potential flooding locations. Based on the simulation results, alternative mitigation scenarios using eco-drainage injection wells were assessed through an iterative trial-and-error process to identify an optimal configuration capable of reducing surface runoff and improving drainage performance. The overall methodological workflow applied in this study is summarized schematically in Figure 2, which illustrates the sequence of data input, analysis, modeling, and evaluation stages.

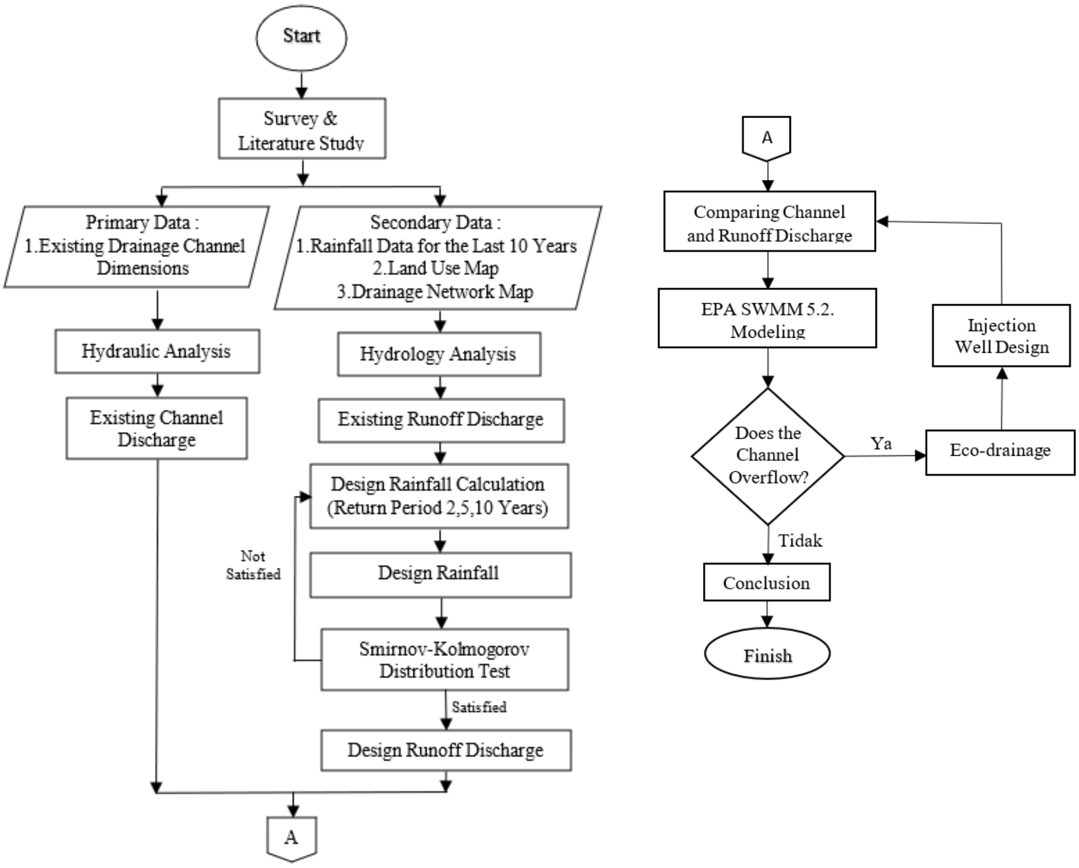

Figure 2. Research flowchart illustrating the methodological framework of the study.

3. Results and Discussion

3.1. Hydrological analysis.

3.1.1. Regional rainfall.

Regional rainfall was estimated using the Arithmetic Method, which was considered appropriate due to the relatively flat topography of the study area, the fairly uniform rainfall distribution, and the close proximity of the rainfall stations to the catchment. Under these conditions, each rainfall station was assumed to contribute equally to the average rainfall, making the arithmetic method sufficiently representative for catchment-scale hydrological analysis [11]. The results of the regional rainfall calculation for the period 2015–2024 are presented in Table 1.

Table 1. Regional rainfall in the study area (2015–2024)

Year	R Region (mm)
2015	80.67
2016	107.67
2017	118.67
2018	81
2019	72
2020	100.67
2021	88.5
2022	66.67
2023	105.33
2024	123
∑	**944.2**
Average	**94.42**

As shown in Table 1, regional rainfall exhibited notable interannual variability, with values fluctuating throughout the observation period. This pattern is consistent with the climatic characteristics of East Java, which are influenced by large-scale climate phenomena such as El Niño and La Niña [12]. In this study, these variations were treated as natural hydrometeorological fluctuations and were directly used as inputs for subsequent hydrological analysis, without further assessment of long-term climate anomalies..

3.1.2. Catchment area characteristics.

Catchment delineation was carried out through spatial digitization of the drainage area contributing runoff to the Jalan Panjang Jiwo drainage system. The resulting land-use classification revealed that the catchment was dominated by built-up areas, particularly industrial land use. The distribution of land-use types and their respective areas is summarized in Table 2. The industrial land use accounted for the largest proportion of the catchment area. This dominance of impervious surfaces substantially reduced infiltration capacity and increased surface runoff generation, thereby exerting significant pressure on the existing drainage system.

Table 1. Catchment area classification.

No	Land Use	Area (Km^2)
1	Road/pavement	0.016
2	Industry	0.148
3	Residential	0.018
Total		**0.182**

3.1.3. Runoff Coefficient

Given the heterogeneous land-use composition of the catchment, a composite runoff coefficient was calculated based on the weighted contribution of each land-use type. The composite coefficient was determined using the area-weighted method, expressed as the ratio of the sum of individual runoff coefficients multiplied by their respective areas to the total catchment area. The resulting composite runoff coefficient was calculated as 0.78. This high runoff coefficient reflects the highly urbanized nature of the study area and is consistent with previous findings in tropical urban catchments dominated by industrial and commercial land uses, where runoff coefficient values typically exceed 0.70 [13−15]. The predominance of impervious surfaces limits soil infiltration and causes a large proportion of rainfall to be converted directly into surface runoff, increasing the hydraulic load on the drainage network. Consequently, the composite runoff coefficient highlights the strong influence of land-use change on the hydrological response of the catchment [6].

$$C = \frac{\Sigma\, C_i\,.A_i}{\Sigma A_i}$$

$$C = \frac{C_{Road}\,.A_{Road} + C_{Industry}\,.A_{Industry} + C_{Residential}\,.A_{Residential}}{Total\ Catchment\ Area}$$

$$C = \frac{(0.95\ x\ 0.016)+(0.8\ x\ 0.148)+(0.5\ x\ 0.018)}{0.182}$$

$$C = 0.78$$

3.1.4. Time of concentration.

The time of concentration represents the travel time required for runoff to flow from the hydraulically most distant point of the catchment to the outlet [16, 17]Click or tap here to enter text.. In this study, the time of concentration was estimated using the Kirpich equation, which is commonly applied to small catchments with clearly defined flow paths [18]. This method has been widely used in both natural and urban watersheds where runoff is dominated by surface and channel flow [19]. Considering the relatively short drainage length and simple flow configuration of the study area, the Kirpich formula was deemed appropriate. The calculated time of concentration was 58.71 minutes, equivalent to approximately 0.98 hours. This relatively short concentration time indicates a rapid hydrological response to rainfall events, which contributes to the high flood susceptibility of the area.

$$tc = 0.0195\ x\ L^{0{,}77}\ x\ S^{-0{,}385}$$

$$tc = 0.0195\ x\ 981^{0{,}77}\ x\ 0.00089^{-0{,}385}$$

$$tc = 0.0195\ x\ 201.7\ x\ 14.96$$

$$tc = 58.71\ \text{minutes} = 0.98\ \text{hours}$$

*3.1.5. Rainfall intensity***.**

Rainfall intensity was estimated using the Mononobe formula, which is suitable for regions where only maximum daily rainfall data are available [20]. This method is widely applied in hydrological studies in Indonesia to convert daily rainfall values into short-duration rainfall intensities corresponding to the time of concentration. Based on the average regional rainfall and the calculated concentration time, the rainfall intensity was determined to be 33.52 mm/h.

$$I = \frac{R24}{24}\left(\frac{24}{tc}\right)^{\frac{2}{3}} = \frac{94.42}{24}\left(\frac{24}{0.98}\right)^{\frac{2}{3}} = 33.52\ \text{mm/hour}$$

3.1.6. Existing runoff discharge.

The existing peak runoff discharge was calculated using the Rational Method, which is appropriate for small drainage areas with relatively uniform rainfall intensity and concentration times of less than one hour [21]. This discharge value reflects the combined effect of high rainfall intensity, short concentration time, and a high composite runoff coefficient. Under such conditions, the existing drainage system is highly susceptible to capacity exceedance during intense rainfall events, underscoring the need for alternative or complementary flood mitigation measures

Q = 0.278 x C x I x A = 0.278 x 0.78 x 33.08 x 0.182 = 1.31 m^3/s

3.2. Hydraulic analysis.

Hydraulic analysis was conducted to evaluate the capacity of the existing drainage system and its ability to convey runoff generated during design rainfall events. This analysis includes channel geometry assessment, flow characteristics, probability-based design rainfall determination, runoff discharge estimation, and numerical simulation using EPA SWMM 5.2.

3.2.1. Existing drainage channel characteristics.

Field surveys indicate that the existing drainage channels along Jalan Panjang Jiwo have an average width of 1.02 m and a depth of 0.835 m. These dimensions are significantly smaller than those specified in the 2018 Surabaya Drainage Master Plan, which recommends channel dimensions of 3.0 m in width and 1.5 m in depth. This discrepancy suggests that the existing channels have limited hydraulic capacity and may be unable to safely convey flow during high-intensity rainfall events.

3.2.2. Channel slope.

The channel slope was calculated based on the difference between upstream and downstream elevations divided by the total channel length. The resulting slope value is expressed as:

$$S = \frac{\text{Downstream elevation} - \text{Upstream elevation}}{Channel\ lenght} = \frac{1.47-0.6}{986} = 0.00088 = 0.088\%$$

This relatively mild slope reflects the flat topography of the study area and contributes to reduced flow velocity.

3.2.3. Hydraulic radius.

The hydraulic radius was calculated using the ratio of the wetted area to the wetted perimeter for a rectangular channel section. Based on the measured channel dimensions, the hydraulic radius was obtained as 0.3169 m.

$$R = \frac{Wetted\ area}{Wetted\ perimeter} = \frac{b\ x\ h}{b+2h} = \frac{1.02\ x\ 0.835}{1.02+2(0.835)} = \frac{0.852}{2.69} = 0.3169$$

3.2.4. Flow velocity.

Flow velocity was estimated using the Manning equation with a roughness coefficient of 0.012, which represents concrete-lined channels. The calculated average flow velocity is 1.15 m/s, indicating moderate flow conditions within the drainage channel.

$$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} = \frac{1}{0.012} (0.3169)^{\frac{2}{3}} (0.00089)^{\frac{1}{2}} = \frac{1}{0.012} (0.465)\ (0.02983) = 1.15\ \text{m/s}$$

3.2.5. Existing channel capacity.

The channel discharge capacity was determined by multiplying the flow velocity by the wetted cross-sectional area. The calculated channel capacity is 0.98 m^3/s. When compared with the design runoff discharge, this value confirms that the existing channel is undersized and prone to overflow during peak rainfall events.

Q_S = V A = 1.15 x (1.02 x 0.835) = 1.15 x 0.852 = 0.98 m^3/det

3.3. Design rainfall analysis.

Design rainfall estimation was performed using statistical frequency analysis to obtain rainfall values corresponding to selected return periods.

3.3.1. Probability distribution selection.

Several probability distributions were evaluated using statistical parameters including coefficient of variation (Cv), skewness (Cs), and kurtosis (Ck) [22]. The results of this evaluation are summarized in Table 3, which shows that the Normal, Log Normal, and Gumbel distributions do not satisfy the required criteria. The Log Pearson Type III distribution meets all statistical requirements and was therefore selected for further analysis [23].

Table 3 presents the determination of the most suitable probability distribution for rainfall analysis.

No	Distribution	Requirement	Computed Value	Remark
1	Normal	Cs = 0	0,01	Does not meet
		Ck = 3	1,37	Does not meet
2	Log Normal	Cs = 3Cv + Cv^3	0,63	Does not meet
		Ck = Cv^8 + $6Cv^6$ + 15 Cv^4 + 16 Cv^2 +3	3,71	Does not meet
3	Gumbel	Cs = 1,14	0,01	Does not meet
		Ck = 5,4	1,37	Does not meet
4	Log Pearson	Other than the values above		Meets the requirement

3.3.2. Log Pearson type III parameter calculation.

The parameters of the Log Pearson Type III distribution were calculated using logarithmic transformation of annual rainfall data. The computation of the mean, standard deviation, and skewness coefficient is presented in Table 4. These parameters form the basis for determining design rainfall values for different return periods.

Table 4. Calculation of Log Pearson type III distribution parameters.

Year	Rainfall, R (mm)	Log Xi	(Log Xi − Log X̄)²	(Log Xi − Log X̄)³
2015	80.67	1.907	0.00177	−0.00007
2016	107.67	2.032	0.00694	0.00058
2017	118.67	2.074	0.01576	0.00198
2018	81.00	1.908	0.00162	−0.00007
2019	72.00	1.857	0.00836	−0.00076
2020	100.67	2.003	0.00293	0.00016
2021	88.50	1.947	0.00000	0.00000
2022	66.67	1.824	0.01559	−0.00195
2023	105.33	2.023	0.00544	0.00040
2024	123.00	2.090	0.01992	0.00281
Total	944.20	19.665	0.07834	0.00308
Mean	94.42	1.97		
Standard Deviation		0.09		
Skewness Coefficient (Cs)		0.53		

3.3.3. Design rainfall estimation.

Using the derived statistical parameters, design rainfall values for 2-, 5-, and 10-year return periods were calculated. The resulting design rainfall depths are presented in Table 5.

Table 2. Design rainfall.

Return Period	$\overline{Log\ X}$	Sd x K_{TR}	Log X	Design Rainfall (mm)
2 Years	1.967	-0.0081	1.9658	92.42
5 Years	1.967	0.1105	1.9768	94.80
10 Years	1.967	0.1815	1.9835	96.26

3.3.4. Goodness-of-Fit test.

The suitability of the selected distribution was verified using the Smirnov–Kolmogorov goodness-of-fit test [24]. The calculated maximum deviation (Dmax) is 0.202, which is lower than the critical value of 0.409 for a 5% significance level and 10 data points. The detailed test results are presented in Table 6, confirming that the Log Pearson Type III distribution adequately represents the rainfall data [25].

Table 3. Smirnov Kolmogorov test**.**

No	Log Xi	P (Xi)	P (x <)	F (t)	P' (x)	P' (X<)	D
1	2.090	0,091	0,909	1,8274	0,111	0,889	0,020
2	2.074	0,182	0,818	0,7985	0,222	0,778	0,040
3	2.032	0,273	0,727	0,6342	0,333	0,667	0,061
4	2.023	0,364	0,636	0,5749	0,444	0,556	0,081
5	2.003	0,455	0,545	0,3979	0,556	0,444	0,101
6	1.947	0,545	0,455	-0,5142	0,667	0,333	0,121
7	1.908	0,636	0,364	-0,6006	0,778	0,222	0,141
8	1.907	0,727	0,273	-0,7020	0,889	0,111	0,162
9	1.857	0,818	0,182	-0,9900	1,000	0,000	0,182
10	1.824	0,909	0,091	-1,4262	1,111	-0,111	0,202

3.4. Design runoff discharge.

Runoff discharge for the selected return periods was calculated using the Rational Method, considering rainfall intensity, runoff coefficient, and catchment area. The resulting design discharges are summarized in Table 7. The 10-year return period runoff discharge of 1.35 m^3/s was selected for hydraulic modeling, as it represents a critical design condition.

Table 4. Design runoff discharge.

Return Period	Xt (mm)	tc (hours)	I (mm/hr)	C	A (km^2)	Q (m^3/s)
2 Years	92.42	0,98	32,81	0,78	0,182	1,30
5 Years	94.80	0,98	33,66	0,78	0,182	1,33
10 Years	96.26	0,98	34,18	0,78	0,182	1,35

3.5. EPA SWMM 5.2 simulation of existing conditions.

Hydraulic modeling was conducted using EPA SWMM 5.2 to simulate the behavior of the existing drainage network under the 10-year design rainfall. The drainage network configuration used in the simulation is illustrated in Figure 3.

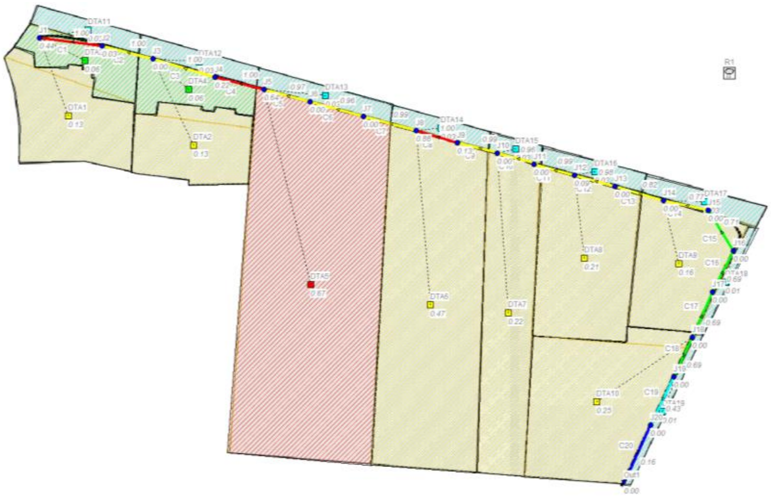

Figure 3. Drainage network modeling on Jalan Panjang Jiwo.

The simulation results indicate continuity errors of −0.46% for surface runoff and 0.01% for flow routing, which are within the acceptable tolerance limit of 10%. Several channel segments experienced overflow conditions, particularly in upstream and midstream areas. A summary of flooding conditions at each junction is presented in Table 8.

Table 5 Existing channel conditions based on EPA SWMM 5.2 simulation results.

Junction	STA	Total Flood Volume (m^3)	Description
J1	0+000	6.143	Overflowing
J2	0+050	0.131	Overflowing
J3	0+100	0	Does not overflow
J4	0+150	1.917	Overflowing
J5	0+200	3.316	Overflowing
J6	0+250	0	Does not overflow
J7	0+300	0.002	Overflowing
J8	0+350	4.034	Overflowing
J9	0+400	0.292	Overflowing
J10	0+450	0	Does not overflow
J11	0+500	0	Does not overflow
J12	0+550	0.193	Overflowing
J13	0+600	0	Does not overflow
J14	0+650	0	Does not overflow
J15	0+700	0	Does not overflow
J16	0+750	0	Does not overflow
J17	0+800	0	Does not overflow
J18	0+850	0	Does not overflow
J19	0+900	0	Does not overflow
J20	0+950	0	Does not overflow
Out1	0+986	0	Does not overflow

To better visualize hydraulic performance, the longitudinal profile of the drainage channel is shown in Figure 4, illustrating the relationship between channel bed elevation, water surface elevation, and channel capacity. Although the modeling results show good performance, this study still has limitations. Model calibration was limited due to the lack of measured discharge data, so that several parameters, such as the channel roughness coefficient, were determined based on assumptions and literature. In addition, the use of synthetic rainfall hyetographs does not fully represent actual rainfall variations, so the simulation results need to be interpreted with caution.

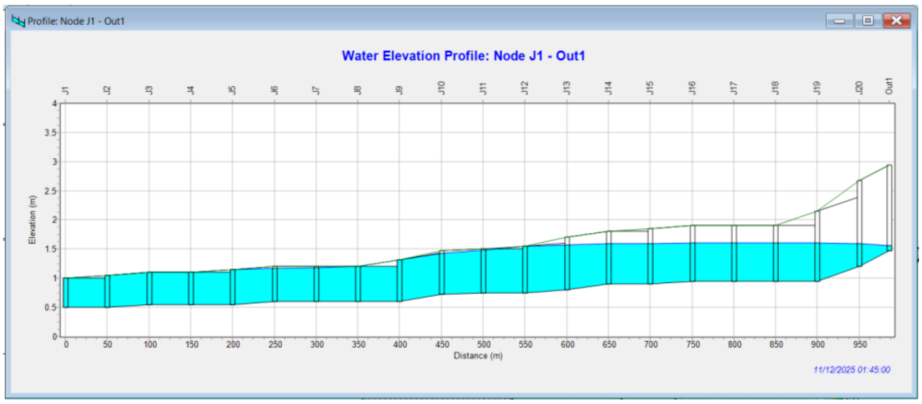

Figure 4. Existing profile of the Panjang Jiwo drainage channel.

3.6. Injection well eco-drainage application

Injection wells were proposed as an eco-drainage solution to manage excess runoff that exceeds the capacity of existing channels during extreme rainfall events.

3.6.1. Flood discharge and runoff volume.

The flooding discharge was calculated as the difference between design runoff discharge and existing channel capacity, resulting in a surplus flow of 0.37 m³/s. This corresponds to a runoff volume of 1332 m³ per hour that must be managed through infiltration.

$$Q_{Flooding} = Q_{design} - Q_{channel} = 1.35\ m^3/s - 0.98\ m^3/s = 0.37\ m^3/s$$

$$V_{Runoff} = Q_{Flooding}\ x\ t = 0.37\ m^3/s\ x\ 3600\ s = 1332\ m^3/hr$$

3.6.2. Injection well design dimensions.

Injection wells were designed with a depth of 25 m to allow rainwater to penetrate impermeable surface layers and reach more permeable subsurface soil layers. Several design trials with different well diameters were evaluated. The design parameters for each trial are presented in Table 9. In the context of densely populated urban areas such as Jalan Panjang Jiwo, the effectiveness of shallow infiltration systems is often hampered by soil heterogeneity, impervious layers, and potential blockages due to sedimentation [26]. The variability of these soil properties causes the infiltration rate to be uneven and difficult to predict naturally. Therefore, this study does not rely on natural infiltration as the main mechanism, but instead uses a pumping system to force rainwater into more permeable deep soil layers. This approach is in line with eco-drainage practices as part of Sustainable Urban Drainage Systems (SUDS), which aim to reduce runoff at the source and lower the burden on conventional drainage systems, especially in urban areas with high levels of soil impermeability [7].

Table 6. Planned injection well dimensions.

Design Parameter	Trial 1	Trial 2	Trial 3	Trial 4
Diameter (d)	2.5 m	3 m	3.25 m	3.5 m
Depth (L)	25 m	25 m	25 m	25 m
Pumps efficiency (η)	70%	70%	70%	70%
Buffer time (t)	60 s	60 s	60 s	60 s

3.6.3. Injection well capacity and quantity.

The total capacity of each injection well configuration was calculated by combining well storage volume and short-term buffer volume. Based on these calculations, the required number of injection wells for each trial was determined. The summary of results, including required pump power, is presented in Table 10.

$$V_{total} = V_{well} + V_{storage} = (\pi r^2 L) + (Q_{Flooding}\ x\ 60\ s) = 122.66 + 22.2 = 144.86\ \text{m}^3$$

$$n = \frac{V_{Runoff}}{V_{total}} = \frac{1332\ m3}{144.86\ m3} = 9.20 \approx 10 \text{ injection wells}$$

$$Q_{Well} = \frac{Qflooding}{n} = \frac{0.37\ m3/s}{10} = 0.037\ \text{m}^3/\text{s}$$

$$P = \frac{\rho\ x\ g\ x\ Qwell\ x\ H}{\eta} = \frac{1000\ x\ 9.81\ x\ 0.037\ x\ 27}{0.7} = 14\ \text{KW}$$

Table 7. Summary of injection well calculations.

Parameter Design	Trial 1	Trial 2	Trial 3	Trial 4
Diameter (d)	2.5 m	3 m	3.25 m	3.5 m
Depth (L)	25 m	25 m	25 m	25 m
V_{well}(m^3)	122.66	176.63	207.29	240.41
Wetwell volume (m^3)	22.2	22.2	22.2	22.2
Number of Injection wells	10	7	6	5
Q_{well}(m^3/hour)	0.037	0.053	0.062	0.074
Pump power (KW)	14	20	23.33	28

The initial simulation was conducted using the Trial 4 scenario, which represents the most economical alternative with the fewest injection wells. In this scenario, five injection wells were installed at segments with the highest runoff accumulation (J1, J4, J5, J8, and J9) to reduce flow loads at critical points. In the EPA SWMM model, the storage basin was represented as a storage unit, while the injection wells were modeled as outfall nodes. The simulation results indicate that, although runoff volumes decreased, segments J2 and J12 still experienced overflow, suggesting that the number of injection wells in the Trial 4 scenario was insufficient to reduce flow loads below the capacity of the existing drainage channels.

The second simulation employed the Trial 3 scenario, which included six injection wells located at segments J1, J2, J4, J5, J8, and J12 to further enhance infiltration capacity and reduce channel flow loads. The simulation produced continuity error values of −0.46% for surface runoff and 0.00% for flow routing, both of which are well within the acceptable tolerance limit of 10%. The implementation of six injection wells significantly improved the hydraulic performance of the drainage system, as evidenced by the elimination of overflow in eight segments that had previously experienced flooding. These results confirm that the incorporation of injection wells is effective in reducing flow loads at critical locations and enhancing drainage capacity under the design rainfall conditions. Figure 5 illustrates the spatial distribution of the six injection wells within the drainage network.

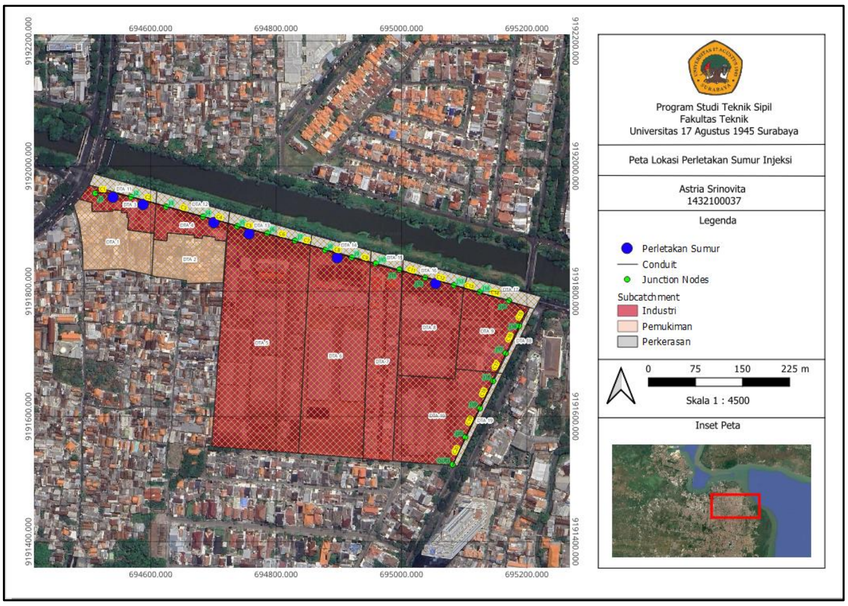

Figure 5. Map of injection well locations.

4. Conclusions

This study demonstrated that the application of the eco-drainage concept through drainage system modeling using EPA SWMM was able to provide a comprehensive assessment of the hydrological and hydraulic performance of the urban drainage network along Jalan Panjang Jiwo, Surabaya. The simulation results indicated that the existing drainage network was not capable of accommodating the planned 10-year return period rainfall, as evidenced by overflow occurring in several channel segments. The implementation of injection wells as part of the eco-drainage system proved to be effective in reducing runoff and increasing system capacity, particularly in the scenario involving six injection wells, under which all channel segments operated without overflow. The findings indicated that injection wells were a viable solution for densely populated urban areas characterized by limited open space and predominantly impervious surfaces. This approach was consistent with the principles of Sustainable Urban Drainage Systems (SUDS), which emphasize source control and on-site runoff management to reduce the burden on conventional drainage infrastructure. However, this study had several limitations, including the absence of detailed soil property characterization, the exclusion of clogging mechanisms, and the lack of evaluation of the long-term performance of injection well systems. Therefore, further research was recommended to incorporate detailed soil characteristic analyses, long-term monitoring of injection well performance, and comprehensive evaluation of system operation and maintenance requirements. In addition, future studies should investigate the integration of injection wells with other eco-drainage elements, such as bioretention systems or detention storage, to develop a more adaptive and sustainable urban runoff management network. With adequate policy support, technical standards, and active stakeholder participation, the implementation of eco-drainage was expected to become an important strategy for urban flood mitigation in major cities across Indonesia.

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Competing Interest

The authors declare that they have no known competing

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

Astria Srinovita and Faradlillah Saves contributed equally to this work. Both authors were involved in conceptualization, methodology, data collection, data analysis, visualization, and writing.

References

[1] Nurhayati, D.E.; Caroline, J.; Kusumaningrum, D. (2022). Study of inundation management on tertiary drainage channels in Keputih Tegal Surabaya City. *Journal of Civil Engineering, Planning, and Design*, *1*, 45–49. https://doi.org/10.31284/j.jcepd.2022.v1i1.3053.

[2] Agustina, N.A.; Supartono; Prasita, V.D. (2023). Rob flood as impact of sea level rise around Kenjeran Beach Tourism Surabaya. *IOP Conference Series: Earth and Environmental Science*, *1273*, 012084. http://doi/org/10.1088/1755-1315/1273/1/012084.

[3] Guo, K.; Guan, M.; Yu, D. (2021). Urban surface water flood modelling: A comprehensive review of current models and future challenges. *Hydrology and Earth System Sciences*, *25*, 2843–2874. http://doi/org/10.5194/hess-25-2843-2021.

[4] Agonafir, C.; Lakhankar, T.; Khanbilvardi, R.; Krakauer, N.; Radell, D.; Devineni, N. (2023). A review of recent advances in urban flood research. *Water Security*, *19*, 100141. http://doi/org/10.1016/j.wasec.2023.100141.

[5] Öztürk, Ş.; Yılmaz, K.; Dinçer, A.E.; Kalpakcı, V. (2024). Effect of urbanization on surface runoff and performance of green roofs and permeable pavement for mitigating urban floods. *Natural Hazards*, *120*, 12375–12399. http://doi/org/10.1007/s11069-024-06688-w.

[6] Bashar, T.; Uddin, M.Z. (2025). Effects of land use change on surface runoff and infiltration: The case of Dhaka City. *Urban Science*, *9*, 497. http://doi/org/10.3390/urbansci9120497.

[7] Fletcher, T.D.; et al. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, *12*, 525–542. http://doi/org/10.1080/1573062X.2014.916314.

[8] Cotterill, S.; Bracken, L.J. (2020). Assessing the effectiveness of sustainable drainage systems (SuDS): Interventions, impacts and challenges. *Water*, *12*, 3160. http://doi/org/10.3390/w12113160.

[9] Monachese, A.P.; Gómez-Villarino, M.T.; López-Santiago, J.; Sanz, E.; Almeida-Ñauñay, A.F.; Zubelzu, S. (2025). Challenges and innovations in urban drainage systems: Sustainable drainage systems focus. *Water*, *17*, 76. http://doi/org/10.3390/w17010076.

[10] Storm Water Management Model User's Manual (Version 5.2). (accesed on 1 November 2025) Available online: www.epa.gov/water-research.

[11] Lee, J.; Kim, S.; Jun, H. (2018). A study of the influence of the spatial distribution of rain gauge networks on areal average rainfall calculation. *Water*, *10*, 1635. http://doi/org/10.3390/w10111635.

[12] Hasibuan, M.A.; Sidiq, I.A.; Asifin, H.A.Z.; Sa, Q. (2024). Quantifying the relationship between ENSO-induced SST anomalies and rainfall variability in East Java's coastal regions. *Jurnal Geografi*, *21*, 167–178. http://doi/org/10.15294/jg.v21i2.16790.
[13] Teang, L.; Irvine, K.N.; Chua, L.H.C.; Usman, M. (2025). Dynamics of runoff quantity in an urbanizing catchment: Implications for runoff management using nature-based retention wetland. *Hydrology*, *12*, 141. http://doi/org/10.3390/hydrology12060141.
[14] Alivio, M.B.; Radinja, M.; Šraj, M.; Gribovszki, Z.; Bezak, N. (2024). Comparative analysis of event runoff coefficients and curve numbers in contrasting urban environments based on observed rainfall–runoff data. *Journal of Hydrology*, *645*, 132135. http://doi/org/10.1016/j.jhydrol.2024.132135.
[15] Wang, J.; Hu, C.; Ma, B.; Mu, X. (2020). Rapid urbanization impact on the hydrological processes in Zhengzhou, China. *Water*, *12*, 1870. http://doi/org/10.3390/W12071870.
[16] Pramana, Y.H.; Harisuseno, D. (2024). Time of concentration estimated of overland flow. *IOP Conference Series: Earth and Environmental Science*, *1311*, 012004. http://doi/org/10.1088/1755-1315/1311/1/012004.
[17] Osuagwu, J.C.; Agunwamba, J.C.; Nwabunor, C.E. (2019). Verification of time of concentration equation for improved drainage design. *Environmental Management and Sustainable Development*, *8*, 151–162. http://doi/org/10.5296/emsd.v8i2.14902.
[18] Beven, K.J. (2020). A history of the concept of time of concentration. *Hydrology and Earth System Sciences*, *24*, 265–286. http://doi/org/10.5194/hess-2019-588.
[19] Harset, D.; Jayadi, R.; Legono, D. (2022). The influence of two different time of concentration equations on the GIUH-based flood hydrograph estimates of Keduang and Temon sub-watersheds, Indonesia. *Current Applied Science and Technology*, *22*, 1–15. http://doi/org/10.55003/cast.2022.05.22.001.
[20] Hidayati, N.; Soeryamassoeka, S.B.; Herawati, H. (2023). Rainfall analysis for creating intensity–duration–frequency (IDF) curve of Pontianak City. *Jurnal Teknik Sipil*, *23*, 488–506. http://doi/org/10.26418/jts.v23i4.66.
[21] Suheri, A.; Kusmana, C.; Purwanto, M.Y.J.; Setiawan, Y. (2019). The peak runoff model based on existing land use and masterplan in Sentul City area, Bogor. *IOP Conference Series: Earth and Environmental Science*, *399*, 012039. http://doi/org/10.1088/1755-1315/399/1/012039.
[22] Armawan, L.M.A.; Pribadi, A. (2025). Evaluation of the drainage system in Kotabaru Village, West Bekasi, using the EPA SWMM model. *Jurnal Teknik Sipil dan Lingkungan*, *10*, 159–168. http://doi/org/10.29244/jsil.10.1.159-168.
[23] Desvina, A.P.; Novia, S.A.; Zein, M.; Yendra, R.; Hendri, M.; Fudholi, A. (2019). Log Pearson III distribution and Gumbel distribution model for rainfall data in Pekanbaru. *International Journal of Engineering and Advanced Technology*, *9*, 803–807. http://doi/org/10.35940/ijeat.A1411.109119.
[24] Helda, N. (2025). Analysis of flood discharge in the Balangan sub-watershed using HEC-HMS. *Jurnal Teknik Sipil dan Perencanaan*, *27*, 62–72. http://doi/org/10.15294/jtsp.v27i2/21976.
[25] Tri Aditya, M.; Susilo, H. (2025). Analysis of the suitability of frequency distribution of rainfall data and rainfall return period at PT. X, Kutai Kartanegara Regency, East Kalimantan. *World Journal of Sustainable Infrastructure Systems*, *3*, 2038. http://doi/org/10.58812/wsis.v3i05.2038.
[26] Fletcher, T.D.; Vietz, G.; Walsh, C.J. (2014). Protection of stream ecosystems from urban stormwater runoff: The multiple benefits of an ecohydrological approach. *Progress in Physical Geography*, *38*, 543–555. http://doi/org/10.1177/0309133314537671.