http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 10 No 4 2025

RESEARCH ARTICLE

Integrating Hydrological Modeling and Pavement Evaluation to Analyze the Impact of Drainage Performance on Road Infrastructure

Ida Farida [1,*], Muhammad Habil Khadafi [1], Alan Wijaya[1]

[1] *Civil engineering Department, Institut Teknologi Garut, Jl. Mayor Syamsu no. 1 Jayaraga Tarogong Kidul Garut Indonesia.*

* Corresponding author : idafarida@itg.ac.id
Tel.:+81-1212986; fax: +262-232773
Received: Aug 20, 2025; Accepted: Dec 19, 2025.
DOI: 10.25299/jgeet.2025.10.4.24641

Abstract

The drainage channel along Gatot Subroto Road in Karangpawitan District, Garut Regency, extends about 1,580 meters in an open rectangular form with varying cross-sectional dimensions. Reports from the Public Works and Spatial Planning Agency (UPT PUPR) indicate frequent overflow and partial malfunction, mainly due to additional inflow from residential drainage and undersized sections. These conditions contribute to recurrent flooding, disruption of community activities, and accelerated pavement deterioration. This study aims to quantify design flood discharge, assess the hydraulic capacity of the existing system, evaluate pavement condition influenced by runoff, and recommend redesigned channel dimensions using hydrological hydraulic analysis with the SWMM model. A quantitative approach was applied, integrating rainfall frequency analysis, hydraulic evaluation, and Pavement Condition Index (PCI) surveys. The results show that under a 2 year return period, most segments performed adequately, whereas at 5 and 10 year periods several sections exceeded their capacity. PCI surveys yielded an average value of 58.66, categorized as "Fair," with critical segments falling into failure due to uncontrolled runoff. After redesign, channel performance improved substantially, with Max/Full Flow ratios consistently below 1 across all segments and return periods. The findings confirm a direct relationship between drainage performance and pavement deterioration. Integrating SWMM based modeling with PCI analysis provides a robust framework for diagnosing deficiencies and formulating technical recommendations. These results are consistent with previous studies, emphasizing that drainage adequacy and pavement condition must be addressed together to improve resilience and extend the service life of urban road infrastructure.

Keywords: Drainage, Pavement Condition Index, Runoff, SWMM

1. Introduction

Road infrastructure plays a crucial role in supporting economic growth, mobility, and public safety. However, its service life is often shortened due to drainage deficiencies, which accelerate pavement deterioration (Gibran & Badriani. 2024). Despite extensive research on urban flooding, few studies have explicitly integrated hydrological hydraulic modeling with pavement condition assessment.

In many Indonesian cities, drainage channels are typically open and rely on gravity to convey runoff. Their management, however, remains fragmented, often leading to partial interventions that reduce effectiveness. An effective drainage system requires integrated planning, construction, operation, and maintenance, supported by institutional frameworks, adequate funding, and active community participation (Putri, Hidayah & Ma'ruf. 2023). Flooding occurs when rainfall intensity, watershed characteristics, and climatic factors generate discharges that exceed channel capacity. This situation is further exacerbated by household waste disposal, sedimentation, and a lack of public awareness regarding proper maintenance of drainage facilities (Schwarz et al., 2012; Whitman & Yeboah-Forso, 2015; Feng, Zhang & Bourke, 2021).

The drainage channel along Gatot Subroto Road in Karangpawitan District, Garut Regency, is an open rectangular system with a total length of approximately 1,580 meters and varying cross-sectional dimensions. According to the Public Works and Spatial Planning Agency (UPT PUPR) of Garut, the channel frequently overflows, and several segments no longer function effectively. This is mainly due to additional inflow from residential drainage and undersized channel dimensions, which cause ponding on the road surface, disrupt community activities, and accelerate pavement deterioration (Pratama, Sumiharni & Febrina, 2023).

An innovative approach in sustainable drainage systems is the use of pervious concrete as a water filter in decentralized water treatment (Yogafanny et al., 2024). Due to its high porosity and permeability, pervious concrete has considerable potential to improve water quality in residential areas (Yogafanny et al., 2024). In addition, the vetiver system, designed for slope stabilization and water conservation, can be implemented in landslide-prone areas as part of sustainable drainage planning. Its effectiveness in reducing slope instability, which is commonly observed in steep residential terrains, has been emphasized (Ciawi et al., 2023). Furthermore, understanding aquifer models is essential for analyzing the interaction between surface drainage and potential ground movements that may compromise the integrity of drainage channels. Aquifer models can help predict the likelihood of ground movement, which could threaten the stability of drainage systems in specific areas (Agung et al., 2025).

Previous studies have highlighted similar issues in various regions. Twelve drainage channels in Kelapa Gading were unable to accommodate runoff, mainly due to external factors such as sedimentation, waste accumulation, and road contour (Meijer et al., 2023). Channels in Bojonegoro were frequently inundated due to sedimentation and vegetation growth (Sari, M. Zainul Ikhwan & Nur Rahmawati, 2024), while in Mustika Tigaraksa housing, channel dimensions needed adjustment to match the design discharge (Yazdan et al., 2022). Inadequate drainage caused surface runoff on Wirun Palur Road, reducing its Pavement Condition Index (PCI) to a poor category (Ji et al., 2021). SWMM-based simulations identified insufficient capacity in flood-prone residential areas of Batam (Akter, Datta & Shaharia, 2024). These studies confirm the importance of drainage systems, but most have focused either on channel capacity or pavement condition separately.

Comparative analysis confirms that inadequate drainage significantly lowers PCI values (Ji et al., 2021). Moreover, the correlation observed in this study emphasizes that both hydraulic performance and pavement serviceability need to be evaluated together (Abegaz et al., 2024).

This study addresses this gap by integrating hydraulic modeling with pavement evaluation. The novelty lies in combining EPA SWMM simulations with PCI surveys to quantify the relationship between drainage performance and pavement deterioration. Using Gatot Subroto Road as a case study, the research aims to: (1) estimate design flood discharge; (2) evaluate the hydraulic capacity of the existing channels; (3) assess pavement condition using PCI analysis; and (4) propose redesigned channel dimensions to improve performance under different return periods.

2. Research Methodology

2.1 Study Location

The research was conducted on a 734 meter section of Gatot Subroto Road in Karangpawitan District, Garut Regency, West Java, Indonesia. This section was selected because the drainage channel frequently experiences overflow and contributes to pavement deterioration, making it a representative case for analyzing the interaction between drainage performance and road condition. The research location is shown in Figure 1.

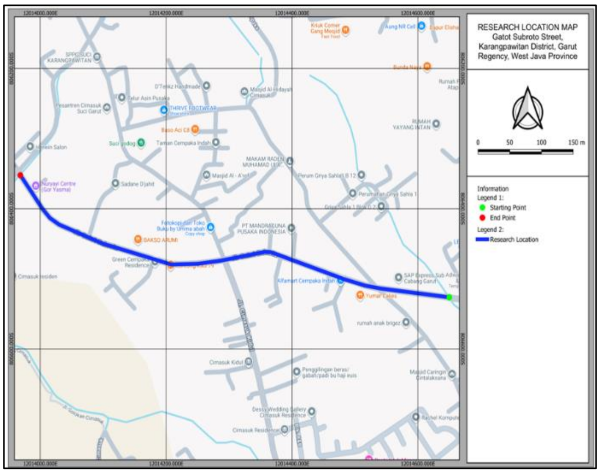

Fig 1. Research Location Map

2.2 Research Flow

The research was structured in several stages. The first stage involved problem identification and a review of relevant literature to establish the theoretical framework. The second stage consisted of data collection through field surveys and secondary sources.

The third stage focused on hydrological and hydraulic analysis, followed by simulation using the storm water management model (SWMM) and pavement evaluation with the Pavement Condition Index (PCI) method. The final stage was the interpretation of results to provide recommendations for drainage improvement and pavement protection. Research flow diagram is shown in figure 2. Comparative analysis confirms that inadequate drainage significantly lowers PCI values (Ji et al., 2021). Furthermore, the correlation observed in this study reinforces that hydraulic performance and pavement serviceability must be evaluated jointly (Abegaz et al., 2024).

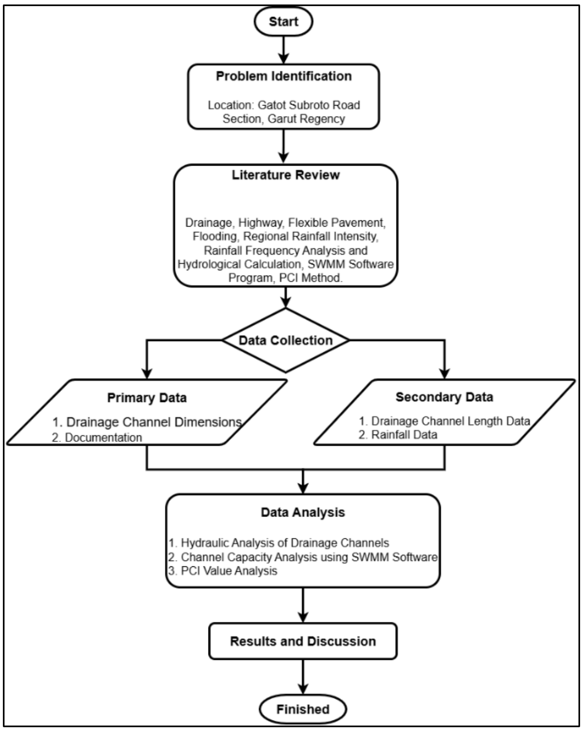

Fig 2. Research Flow Diagram

2.3 Data Collection

Two types of data were used: primary and secondary. Primary data included field measurements of channel cross sections, road width, and visual documentation of drainage and pavement conditions. Pavement condition surveys were also carried out to record distress types and severity in accordance with the ASTM D6433-07 standard (Systems & Management, 2011).

Secondary data were obtained from the Department of Water Resources and UPT PUPR Garut, including daily rainfall records from Tarogong Station (2014 - 2023) and technical information on road and drainage infrastructure. These datasets were combined to support both the hydrological analysis and the pavement evaluation.

The main data used in this study are summarized in Table 1, including data type, description, and source.

Table 1. Summary of Research Data

Data Type	Description	Source/Method
Rainfall Data	Daily rainfall 2014 - 2023	Tarogong Station (BMKG)
Channel Data	Length, cross sections, dimensions	Field survey & UPT
Road Data	Pavement width, surface condition	Field survey
PCI Survey	Distress type, severity, area	Field survey (Systems & Management, 2011)

2.4 Data Processing and Analysis

Once all data were collected, the following stages of analysis were conducted:

a. Hydrological Analysis
Rainfall data were processed using statistical distribution methods, namely Normal, Log Normal, Gumbel, and Log Pearson III. The best fit was determined using Chi Square and Smirnov Kolmogorov tests (Bhuyian & Kalyanapu, 2018). Design rainfall intensity was calculated and used in the Rational Method to estimate design flood discharge based on catchment characteristics and runoff coefficients.

b. Hydraulic Analysis
The hydraulic capacity of the existing channel was analyzed using Manning's equation to determine velocity and discharge capacity. Results were compared with design discharges to identify undersized segments (Yang et al., 2020). Field measurements supported this analysis by verifying dimensions and identifying structural issues affecting flow.

c. Pavement Condition Survey
The classification of pavement condition provides a quantitative basis for relating drainage performance to pavement deterioration (Meissonnier & Dejoux, 2016). Pavement condition was assessed using the PCI method in accordance with ASTM D6433-07. Surveys were conducted at 25 meter intervals. Distress type, severity, and affected area were recorded for each segment. PCI values ranged from 0 (Failed) to 100 (Excellent). The PCI results were then compared with channel performance to examine correlations between inadequate drainage and pavement deterioration. This step provided a quantitative assessment of the impact of runoff on road conditions.

d. Hydraulic Modeling with SWMM
This study applied the Storm Water Management Model (SWMM) to evaluate runoff dynamics and drainage performance under 2, 5, and 10 year return periods, reflecting both standard design practices in Indonesia and medium-term resilience considerations (Irvine, Chua & Eikass, 2014; Hutchins et al., 2020; Dangar, Asoka & Mishra, 2021; Pratama et al., 2023). The model utilized rainfall intensity, catchment characteristics, and cross-sectional channel data as inputs, while the simulations generated parameters including flow rate, water depth, velocity, and conveyance capacity (Yang et al., 2020). Calibration was carried out by comparing simulated results with field observations, ensuring consistency between model outputs and empirical data within acceptable error margins (Akter et al., 2024). Channel performance was then interpreted using the Max/Full Flow ratio, where values below 1 indicated adequate capacity, while ratios equal to or exceeding 1 denoted segments prone to overflow. This approach enabled the identification of critical bottlenecks and provided a robust foundation for proposing redesign strategies.

The methodology integrates hydrological analysis, hydraulic evaluation, pavement condition survey, and hydraulic simulation. This framework provides a systematic approach for identifying drainage deficiencies, quantifying their impact on pavement performance, and developing technical recommendations for channel redesign

3. Results and Discussion

3.1 Regional Rainfall

The analysis of maximum daily rainfall over a 10 year period (2014 - 2023) at Tarogong Station revealed substantial variability, with the highest recorded rainfall of 501.5 mm in 2014 and the lowest of 281 mm in 2023 (Table 2). The mean value of 391.45 mm with a standard deviation of 69.07 mm reflects a moderately stable trend, but also indicates the presence of extreme rainfall events that significantly influence runoff generation. Such variability underlines the necessity of using long term datasets to reduce uncertainties in hydrological modeling.

This finding is directly linked to the first research objective estimating design flood discharge as accurate rainfall characterization is the foundation for all subsequent hydraulic and pavement analyses. The results of this study confirm that rainfall extremes are a primary factor aggravating drainage failures and pavement deterioration, consistent with findings that urban growth coupled with climate variability increases the intensity of rainfall-driven flooding (Feng et al., 2021).

Table 2. Summary of Maximum Daily Average Rainfall.

No	Year	Max Rainfall (mm)
1	2014	501.5
2	2015	281.5
3	2016	448
4	2017	390
5	2018	438
6	2019	415.5
7	2020	373
8	2021	404
9	2022	382
10	2023	281
Average ($\bar{X}$)		391.45
Standard Deviation (Sd)		69.07

3.2 Frequency Analysis

The frequency analysis of rainfall using four probability distributions (Normal, Log Normal, Gumbel, and Log Pearson Type III) produced increasing rainfall estimates with longer return periods (Table 3). The Gumbel distribution yielded the highest rainfall values, with 521.71 mm for a 10 year return period, compared to 491.39 mm from Log Pearson Type III.

Table 3. Recapitulation of Rainfall Frequency Analysis.

Recapitulation				
Return Period (years)	Probability Distribution			
	Normal (mm)	Log Normal (mm)	Gumbel (mm)	Log Pearson Type III (mm)
1	2	3	4	5
2	391.45	385.57	384.71	384.05
5	449.47	451.29	467.14	450.83
10	479.86	490.08	521.71	491.39

This outcome fulfills the first research objective by providing a robust rainfall basis for discharge calculation. Conservative estimates from the Gumbel distribution are particularly useful for urban drainage planning, ensuring that extreme events are accounted for in system design. Gumbel has been shown to be reliable for drainage capacity studies, particularly in areas prone to flood risks, and is therefore adopted in this study to maintain both statistical rigor and practical safety (Ahmad et al., 2024).

3.3 Goodness of Fit Test

To determine the most appropriate probability distribution for estimating design rainfall, two goodness of fit tests were applied: the Chi Square test (Table 4) and the Kolmogorov Smirnov (K-S) test (Table 5). These statistical tests are essential to verify whether theoretical distributions adequately represent the observed rainfall data, thus ensuring the reliability of subsequent discharge calculations.

Table 4. Summary of Chi Square Goodness of Fit Test

No	Probability Distribution	χ^2 Calculated	χ^2 Critical	Conclusion
1	Normal	5	5.991	Accepted
2	Gumbel	2	5.991	Accepted
3	Log Normal	5	5.991	Accepted
4	Log Pearson Type III	5	5.991	Accepted

Table 3 shows that all four tested distributions Normal, Gumbel, Log Normal, and Log Pearson Type III produced Chi-Square (χ^2) values lower than the critical threshold of 5.991 at a 5% significance level. This indicates that, statistically, none of the distributions can be rejected based on the Chi-Square criterion. In other words, the observed rainfall data can reasonably be represented by all four distributions. However, although Chi-Square results suggest equal acceptability, this test alone does not guarantee that the distributions capture the overall shape of the empirical data accurately.

Table 4, on the other hand, presents the results of the K-S test, which evaluates the maximum deviation (D value) between the empirical and theoretical cumulative distribution functions. The results demonstrate that the Normal (0.1261), Gumbel (0.1705), and Log Normal (0.1571) distributions all yielded D values below the critical value of 0.41, meaning they were acceptable. In contrast, the Log Pearson Type III distribution produced a D value of 0.8244, far exceeding the critical threshold, and was therefore statistically rejected. This discrepancy highlights the greater sensitivity of the K-S test in detecting mismatches in data distribution patterns, especially in the tails where extreme values occur.

Table 5. Kolmogorov Smirnov Test

No	Probability Distribution	D Calculated	D Critical	Conclusion
1	Normal	0.1261	0.41	Accepted
2	Gumbel	0.1705	0.41	Accepted
3	Log Normal	0.1571	0.41	Accepted
4	Log Pearson III	0.8244	0.41	Rejected

Based on the combined results of both tests, the Gumbel distribution was selected as the most appropriate for further analysis. This decision was grounded on three considerations: (1) it satisfied both the Chi Square and K-S criteria, (2) it produced conservative rainfall estimates compared to the other distributions, and (3) it has been widely validated in previous hydrological studies as suitable for modeling extreme events (Ahmad et al., 2024). By adopting Gumbel, the study ensures that the design rainfall input is not only statistically representative but also conservative, thereby minimizing the risk of underestimating design discharges.

This step directly supports the first research objective by strengthening the accuracy and robustness of rainfall inputs used in hydrological and hydraulic analyses. The careful selection of a statistically validated distribution is critical to prevent underdesign in urban drainage systems (Pratama et al., 2023). Thus, the choice of Gumbel in this study increases the reliability of discharge estimates and provides a solid foundation for evaluating drainage channel capacity and proposing redesign solutions.

3.4 Time of Concentration

The time of concentration (Tc) for the study catchment was calculated at 169.5 minutes, equivalent to 2.82 hours. Tc defines the hydrological response time of the watershed, or the duration required for runoff from the most distant point of the catchment to reach the outlet. This parameter is critical for determining the rainfall intensity used in design discharge estimation. The relatively long Tc indicates a slower runoff response, which can be attributed to the mixed topography and semi-urban land cover conditions along Gatot Subroto Road.

In relation to the research objectives, the determination of Tc provides site-specific hydrological input that improves the reliability of flood discharge estimation. Compared with studies in denser urban areas such as Kelapa Gading (Meijer et al., 2023). where Tc values were much shorter due to steep slopes and impervious surfaces, the longer Tc in this study highlights the need for localized calibration. Relying on generalized values could lead to significant errors in drainage planning, either by underestimating peak discharges or by overdesigning channels, thus underscoring the importance of using field-based Tc in drainage evaluation.

3.5 Rainfall Intensity

Rainfall intensity analysis was carried out using the Mononobe method based on the Gumbel distribution. The results are presented in Table 6 for storm durations ranging from 1 to 24 hours, and in Table 7 for the specific duration corresponding to the time of concentration (Tc = 2.82 hours). These two sets of results provide both a general understanding of intensity-duration-frequency (IDF) characteristics and a site-specific design parameter for discharge estimation.

Table 6. Rainfall Intensity Calculation Results for 24-Hour Duration

T (Hour)	Return Period (Years)		
	2	5	10
1	133.37	161.95	180.87
2	84.02	102.02	113.94
3	64.12	77.86	86.95
4	52.93	64.27	71.78
...	...	...	...
23	16.49	20.02	22.36
24	16.03	19.46	21.74
Max	133.37	161.95	180.87

Table 7. Calculated Rainfall Intensity Based on Tc Value

T (Hours)	Return Period (Years)		
	2	5	10
2.825	66.739	81.040	90.507

Table 6 illustrates the calculated rainfall intensities for 2, 5, and 10 year return periods across different durations. As expected, the analysis revealed an inverse relationship between duration and intensity: shorter storms produced significantly higher intensities, while longer durations resulted in lower intensities. For instance, 1 hour rainfall intensities ranged from 133.37 mm/h (2 year) to 180.87 mm/h (10 year), whereas 24 hour intensities decreased to only 16.03 - 21.74 mm/h. This pattern confirms a well established hydrological principle that concentrated rainfall over short periods generates more intense runoff. The result is consistent with previous findings that reported similar IDF patterns in Tangerang, highlighting that storm duration plays a critical role in determining the peak discharge capacity of drainage systems (Yazdan et al., 2022).

Table 7 presents rainfall intensities specifically calculated for Tc = 2.82 hours, the critical storm duration for the study catchment. The results yielded intensities of 66.739 mm/h (2 year), 81.040 mm/h (5 year), and 90.507 mm/h (10 year). These values constitute the critical inputs for the Rational Method, directly linking rainfall characteristics to the design flood discharge. Compared to generalized assumptions often applied in conventional practice, these locally calibrated intensities provide a more realistic representation of the catchment's hydrological response. Accurate determination of rainfall intensity is fundamental for estimating flood discharge and evaluating drainage capacity (Yoga Pratama & Munandar, 2023).

By synthesizing the outcomes of Table 6 and Table 7, this study achieves two important objectives. First, the IDF analysis (Table 6) establishes a comprehensive understanding of rainfall variability across different storm durations. Second, the site-specific intensity values (Table 7) ensure that design flood discharge estimation is based on the actual hydrological response of the catchment. These findings align with previous observations highlighting the sensitivity of discharge estimation to rainfall intensity selection, while also strengthening the primary research objective of providing reliable hydrological parameters for drainage capacity evaluation and redesign (Widyasari & Meigawati, 2024).

3.6 Design Flood Discharge

The distribution of design flood discharges along the right-side drainage channel shows a consistent increase across the 2, 5, and 10 year return periods. Peak flow values were concentrated in several critical segments, particularly at 12 - 13, 21 - 22, and 28 - 29, indicating potential hydraulic bottlenecks that are highly vulnerable to overflow. These findings emphasize the importance of segment specific analysis in identifying priority areas for redesign (Figure 3).

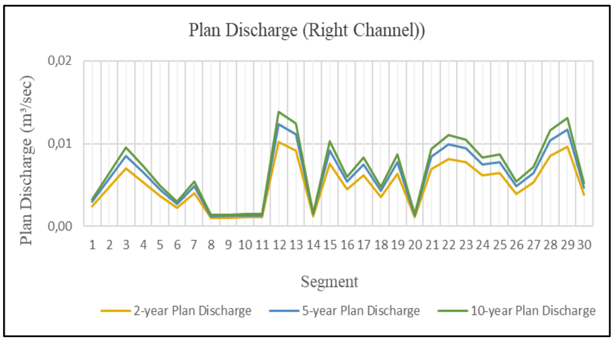

Fig 3. Design Discharge Graph (Right-Side Channel)

On the left side drainage channel, the discharge distribution also increased with longer return periods, though the concentration of flow was most evident at segments 1, 11, 20, and 28. These segments exhibited significantly higher flow rates compared to surrounding sections, suggesting localized weaknesses within the channel system that could compromise its overall performance during extreme rainfall events (Figure 4).

Taken together, the analysis of both channels reveals that drainage performance is not uniform, but instead heavily influenced by localized flow concentrations. This directly addresses the research objective of identifying critical drainage segments and confirms earlier findings that drainage system failures are typically localized rather than system-wide (Widyasari & Meigawati, 2024). Targeting redesign efforts at these vulnerable segments offers a more effective and resource-efficient strategy for improving overall system resilience.

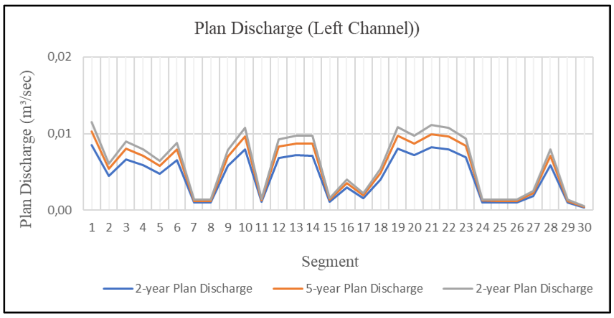

Fig 4. Design Discharge Graph (Left Side Channel)

3.7 Drainage Channel Capacity

The hydraulic assessment of the existing drainage network demonstrated significant performance deficiencies. Average flow velocities were extremely low, reaching only 0.008 m/s, which is far below the threshold required for effective stormwater conveyance. Such low velocities not only indicate insufficient channel gradients but also increase the likelihood of sediment deposition, further reducing flow capacity. In terms of discharge, many segments particularly along the right side channel were unable to accommodate even the 2 year design flows, confirming that the cross-sections are undersized and hydraulically inadequate.

The left side channel, although slightly better in performance, also exhibited several segments with discharges lower than the design requirement, indicating that the system as a whole cannot reliably manage stormwater under current conditions. This evaluation directly fulfills the second research objective by quantifying the hydraulic limitations of the existing channels and highlights the urgency of structural improvements. Similar findings were reported in Bojonegoro (Sari et al., 2024) and in Banyuwangi, where poorly dimensioned and improperly maintained channels accelerated localized flooding risks. The inadequacies observed in this study provide a clear justification for channel redesign, which is further addressed in the subsequent analysis (Gibran & Badriani, 2024).

3.8 Cross-Sectional Analysis with SWMM

The cross sectional capacity of the drainage network was further evaluated using SWMM simulations under different return periods. The results indicate that during the 2 year return period most channel segments performed adequately, although several sections (25 – 29) had already reached their maximum conveyance capacity. Under more severe scenarios corresponding to the 5 and 10 year return periods, additional segments such as 16 and 22 failed to accommodate the simulated discharges, demonstrating that system performance deteriorates substantially as rainfall intensity increases.

These findings reinforce the earlier hydraulic assessment by quantifying the degree of vulnerability in specific segments of the drainage system. The analysis shows that the network is not uniformly deficient but instead constrained by localized cross sectional limitations, which act as bottlenecks under design storm conditions. Such localized weaknesses have also been identified through SWMM-based analysis in Batam, confirming the effectiveness of the model as a diagnostic tool for urban drainage systems (Akter et al., 2024). In the context of this study, the simulation outcomes provide a robust evidence base for determining which sections of the drainage channel must be prioritized for redesign to ensure system reliability across varying hydrological conditions.

3.9 Pavement Condition Index (PCI)

The pavement condition survey produced an overall average PCI score of 58.66, which falls into the "Fair" category. However, the results varied substantially across segments. Critical areas, particularly segments 19, 28, and 29, recorded PCI values as low as 7, placing them in the "Failed" category. These deteriorated segments overlapped with drainage sections identified as hydraulically unsafe, indicating a clear interdependence between inadequate drainage capacity and pavement deterioration.

This finding directly addresses the third research objective, namely establishing the relationship between drainage system performance and pavement serviceability. Comparative analysis confirms that insufficient drainage significantly accelerates PCI decline (Ji et al., 2021). Furthermore, the correlation observed in this study reinforces the need to evaluate hydraulic performance and pavement condition jointly, consistent with international findings (Abegaz et al., 2024).

Nevertheless, some segments maintained moderate to good PCI values despite poor drainage conditions. This anomaly highlights the influence of other factors, such as repetitive traffic loading and material deficiencies (Ahmed et al., 2024). These results underline that while drainage is a primary determinant of pavement performance, integrated assessments incorporating structural and loading factors are essential for accurate diagnosis and sustainable road management.

3.10 Drainage Channel Redesign

The redesign analysis was carried out to address the hydraulic deficiencies previously identified. Table 8 (summary) combines the results of the redesigned cross-sections under 2, 5, and 10 year return periods for both right and left side channels. Meanwhile, Figures 5 and 6 provide visual comparisons of flow conditions before and after redesign.

Table 8. Summary of Redesigned Channel Performance (Right and Left Side)

Segment Group	Critical Segments	Max/Full Flow Ratio (2 year)	Max/Full Flow Ratio (5 year)	Max/Full Flow Ratio (10 year)	Status After Redesign
Right Side	12–13, 21–22, 28–29	< 1.0	< 1.0	< 1.0	Safe
Left Side	1, 11, 28	< 1.0	< 1.0	< 1.0	Safe
Other Segments	All others	< 1.0	< 1.0	< 1.0	Safe

Note: All redesigned sections achieved safe hydraulic performance under 2, 5, and 10 year return periods.

The summarized results demonstrate that all redesigned segments achieved Max/Full Flow ratios below 1, confirming that the new dimensions are adequate to accommodate design discharges across all return periods. Critical segments such as 12-13, 21-22, and 28-29 (right side) as well as segments 1, 11, and 28 (left side), which previously showed severe overflow risk, now operate within safe hydraulic thresholds. This validates the effectiveness of the resizing strategy in eliminating localized bottlenecks. Figures 5 further illustrate the improved hydraulic performance, where flow distribution is more uniform and channel capacity is no longer exceeded under extreme rainfall scenarios.

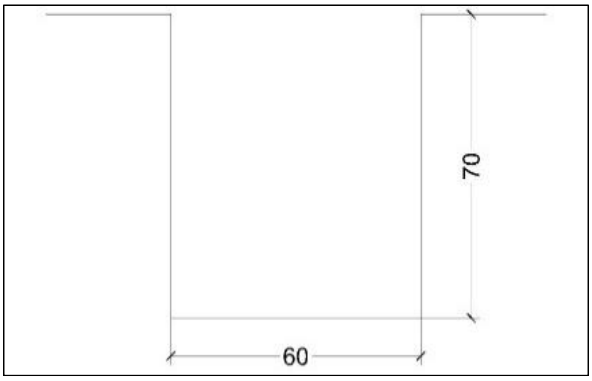

Fig 5. Redesigned Right - Left Channel at Segment 16 and 18

This finding directly addresses the final research objective by providing redesign solutions to enhance system reliability. The redesigned channels effectively mitigate overflow risks while protecting adjacent pavements from accelerated deterioration, thereby extending their service life. These results are consistent with previous studies, which emphasized that resizing validated through SWMM simulations is essential for sustainable flood mitigation (Yoga Pratama & Munandar, 2023). Similar conclusions were also drawn in more recent work highlighting integrated sustainable drainage design approaches (Maglia & Raimondi, 2025). Moreover, the integration of PCI into the redesign evaluation highlights the novelty of this study, demonstrating that improved drainage capacity can simultaneously enhance pavement performance (Abegaz et al., 2024).

This integrated approach also reflects a broader trend in urban drainage research, where the combination of technical modeling and sustainability assessment provides a more comprehensive framework for long term infrastructure planning (Castilla-Rho et al., 2015; Hutchins et al., 2020). In line with this perspective, green infrastructure solutions such as green roofs have been widely recognized for their effectiveness in reducing stormwater runoff while simultaneously delivering multiple environmental benefits (Lee et al., 2019). In addition, recent advances in deep learning for flood susceptibility mapping demonstrate how predictive tools can further strengthen resilient drainage planning (Ma et al., 2019). Complementary to these developments, systematic flood risk analysis methods for hazard mapping are also acknowledged as critical instruments for identifying exposure and supporting informed decision making in flood management (Mudashiru et al., 2021).

4. Conclusion

This study examined the relationship between hydrological characteristics, drainage channel performance, and pavement deterioration along Jalan Gatot

Subroto, Karangpawitan District. The conclusions are summarized as follows:

1. Hydrological findings confirmed that runoff magnitude is primarily governed by catchment size, impervious surface ratio, runoff coefficients, and rainfall intensity, with subcatchments SC29, SC12, SC1, SC10, and SC13 generating the largest discharges.
2. Hydraulic assessment revealed that several drainage segments were unable to accommodate design flows, particularly under 5 and 10 year return periods, indicating critical points vulnerable to flooding.
3. Pavement surveys yielded an average PCI value of 58.66 ("Fair"), with severely deteriorated segments coinciding with deficient drainage capacity, thereby demonstrating a strong link between drainage performance and pavement damage.
4. Redesign analysis showed that modified channel dimensions significantly improved hydraulic capacity, with all sections maintaining Max/Full Flow ratios below 1 for return periods up to 10 years, reducing flood risk and extending pavement service life.
5. Practical recommendations include prioritizing redesign of critical segments, integrating drainage maintenance into road asset management, and adopting combined SWMM-PCI frameworks in urban infrastructure planning.
6. Limitations of this study lie in the reliance on historical rainfall data, without incorporating climate change projections that may influence future runoff patterns. Consequently, further research integrating traffic loading, pavement material properties, and climate modeling is necessary to strengthen understanding of drainage pavement interactions and enhance long term infrastructure resilience.

Acknowledgements

We sincerely thank all those who contributed their constructive feedback to this manuscript. Our appreciation also goes to Institut Teknologi Garut for providing the essential research facilities. We would like to extend special thanks to the ublic Works and Spatial Planning Agency (UPT PUPR) of Garut Regency for their significant help with data collection. Additionally, we are thankful for the financial support provided by ITG. Lastly, we express our deepest gratitude to our families for their continuous encouragement throughout this research journey.

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