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# Evaluation and Revitalization of the Drainage System at the Ngabul Intersection in Tahunan District, Jepara Regency

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**Abstract**

This study aims to evaluate and redesign the drainage system at the Ngabul intersection area in Tahunan District, Jepara, which frequently experiences flooding during periods of intense rainfall. The increasing traffic activity and inadequate drainage capacity have contributed to recurring inundation that disrupts transportation activities and reduces road service performance. This study employed field surveys, hydrological analysis, hydraulic analysis, and numerical simulation using the HEC-RAS software to evaluate the existing drainage condition and determine an appropriate drainage redesign. Primary data included field observations, channel geometry measurements, and elevation surveys, while secondary data consisted of rainfall data collected over a 10-year period. Hydrological analysis was conducted using the Log Pearson Type III distribution method to estimate design rainfall intensity and flood discharge. The results showed that the existing drainage channels had an average discharge capacity of 4.98 $m^3/s$, while the maximum discharge obtained from the HEC-RAS simulation reached 10.84 $m^3/s$, indicating that the existing drainage system was unable to accommodate future runoff discharge. Therefore, a redesigned drainage channel using a rectangular U-ditch section with dimensions of 1.6 m width and 2.0 m depth was proposed as an effective solution to reduce flooding in the study area. The proposed drainage improvement is expected to enhance flood control performance, improve road functionality, and support safer transportation conditions in the Ngabul intersection area.

*Keywords:* Drainage system; flood control; hydrological analysis; hydraulic analysis; HEC-RAS; urban drainage; U-ditch design.

## 1. Introduction

Road infrastructure plays a crucial role in supporting economic activities, social interaction, and regional mobility[1,2]. However, inadequate supporting infrastructure, particularly drainage systems, can significantly reduce road performance and create severe transportation problems such as flooding and traffic disruption. The Ngabul intersection road section in Tahunan District, Jepara, serves as an important transportation corridor connecting the Ngabul and Ngasem areas. In recent years, the road has experienced increasing traffic volume due to traffic diversion policies implemented by the local government to improve accessibility to the new Ngabul market area. However, the increased traffic demand has not been accompanied by adequate drainage infrastructure improvements. Flooding frequently occurs in the Ngabul intersection area, especially during periods of high rainfall intensity. The inundation can occur within a short duration of rainfall and significantly disrupt transportation activities and road accessibility. One of the primary causes of flooding in urban areas is the insufficient capacity and poor performance of drainage systems[3,4]. Ineffective drainage conditions can lead to prolonged water ponding, which weakens pavement structures, accelerates road deterioration, and increases the risk of traffic accidents.

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In addition, sedimentation and waste accumulation within drainage channels further reduce hydraulic performance and limit the capacity of the drainage network. Previous studies have emphasized the importance of proper drainage system planning and hydraulic evaluation in reducing urban flood risks and improving infrastructure resilience[5,6]. Therefore, an effective evaluation and revitalization of the drainage system are required to mitigate flooding problems in the study area. This study aims to evaluate the hydraulic performance of the existing drainage channels, analyze flood discharge characteristics using hydrological methods, and develop an improved drainage design using hydraulic simulation with the HEC-RAS model[7]. The contribution of this study lies in providing a technical recommendation for sustainable urban drainage improvement to reduce flooding risk, improve transportation safety, and enhance infrastructure reliability in the Ngabul intersection area.

## 2. Material and Methods

### 2.1. Research Object and Data Collection

This study was conducted at the Ngabul intersection area located in Tahunan District, Jepara. The study focused on evaluating and redesigning the existing roadside drainage system to address recurring flood problems in the area. Data collection consisted of both primary and secondary data acquisition. Primary data were collected through direct field surveys and observations, including measurements of existing drainage channel dimensions, channel elevations, flow conditions, and surrounding environmental characteristics. Field investigations were also conducted to identify drainage conditions, sediment accumulation, and potential hydraulic obstructions within the drainage system. Secondary data included rainfall records obtained from related agencies for a 10-year observation period from 2014 to 2023. These rainfall data were used for hydrological analysis and design rainfall estimation. Additional supporting data related to drainage planning standards and previous studies were also collected to support the analysis process.


**Figure 1. Location of the study**

### 2.2. Data Analysis Procedure

Hydrological analysis was conducted to determine the design rainfall characteristics and estimate the flood discharge within the study area. Historical rainfall data collected over a 10-year observation period were first analyzed statistically to identify the most appropriate probability distribution model for rainfall frequency analysis. Several statistical parameters, including the coefficient of skewness and rainfall distribution characteristics, were evaluated to assess the suitability of the rainfall data distribution. Based on the analysis results, the Log Pearson Type III distribution method was selected as the most appropriate approach for estimating design rainfall values for various return periods. Following the rainfall frequency analysis, rainfall intensity values were calculated to represent the relationship between rainfall depth and rainfall duration for the selected return periods. The calculated rainfall intensity values were then used to estimate the design flood discharge using the Rational Method, which considers rainfall intensity, runoff coefficient, and catchment area characteristics. The runoff coefficient was determined based on land use conditions and surface characteristics within the drainage catchment area. This hydrological analysis provided the basis for evaluating the hydraulic capacity requirements of the drainage system under peak runoff conditions.

Hydraulic analysis was subsequently performed to evaluate the performance and capacity of the existing drainage channels. The analysis utilized Manning's equation to calculate flow velocity and discharge capacity within the drainage channels. Several hydraulic parameters were analyzed, including channel cross-sectional area, wetted perimeter, hydraulic radius, channel slope, flow velocity, and discharge capacity. Field survey data on channel geometry and elevation profiles were incorporated into the hydraulic calculations to accurately represent existing site conditions.

In addition to manual hydraulic calculations, numerical simulations were conducted using the HEC-RAS software to evaluate flow behavior and water surface profiles along the drainage network. The simulation was used to assess whether the existing drainage channels were capable of accommodating the calculated runoff discharge under maximum rainfall conditions. The HEC-RAS model also enabled the identification of critical sections where overflow and insufficient channel capacity occurred. Based on the hydraulic simulation results, alternative drainage channel dimensions were developed to improve the hydraulic performance of the drainage system and mitigate flooding problems in the study area. The redesigned drainage channels were evaluated to ensure that the proposed dimensions could safely convey the projected flood discharge while maintaining stable flow conditions. The final drainage design was intended to provide a more reliable and sustainable drainage system capable of reducing flood risks and improving overall infrastructure performance in the study area.

## 3. Results and Discussion

### 3.1. Analysis Data

The hydrological analysis indicated that the Log Pearson Type III distribution was the most appropriate method for rainfall frequency analysis based on the statistical distribution evaluation. The calculated design rainfall values for return periods of 2, 5, 10, and 20 years were 258.04 mm, 282.22 mm, 291.80 mm, and 299.84 mm, respectively. The rainfall intensity analysis produced significant runoff potential within the study area. Using the Rational Method, the design flood discharge was calculated as 0.060 m³/s. Hydraulic analysis of the existing drainage channels showed varying discharge capacities along the study area. The average channel discharge capacity was approximately 4.98 m³/s, with the highest discharge occurring at STA 500. However, the hydraulic simulation results using the HEC-RAS software indicated that the maximum runoff discharge could reach 10.84 m³/s, exceeding the capacity of the existing drainage system. Based on the hydraulic evaluation and simulation results, the existing drainage channels were considered inadequate to accommodate future flood discharge conditions. Therefore, a redesigned drainage system using a rectangular U-ditch channel with dimensions of 1.6 m width and 2.0 m depth was proposed. The redesigned channel demonstrated sufficient hydraulic capacity to safely convey the calculated runoff discharge based on the HEC-RAS simulation results. Table 1 presents the statistical parameters of annual maximum rainfall data analyzed using the Log Pearson Type III distribution method. The rainfall data from 2014 to 2023 were transformed into logarithmic values to evaluate statistical characteristics required for frequency analysis. Several statistical parameters were calculated, including the deviation from the mean logarithmic rainfall value, squared deviations, cubic deviations, and quartic deviations. These parameters were used to determine statistical properties such as variance, skewness, and kurtosis, which are essential for evaluating the suitability of the Log Pearson Type III distribution for rainfall frequency analysis. The analysis results indicate that the average logarithmic rainfall value was 2.4. The calculated statistical parameters demonstrate that the rainfall data exhibited skewed distribution characteristics, making the Log Pearson Type III method appropriate for estimating design rainfall values in this study. These results were subsequently used as the basis for determining rainfall intensity and designing flood discharge in the hydraulic analysis of the drainage system.

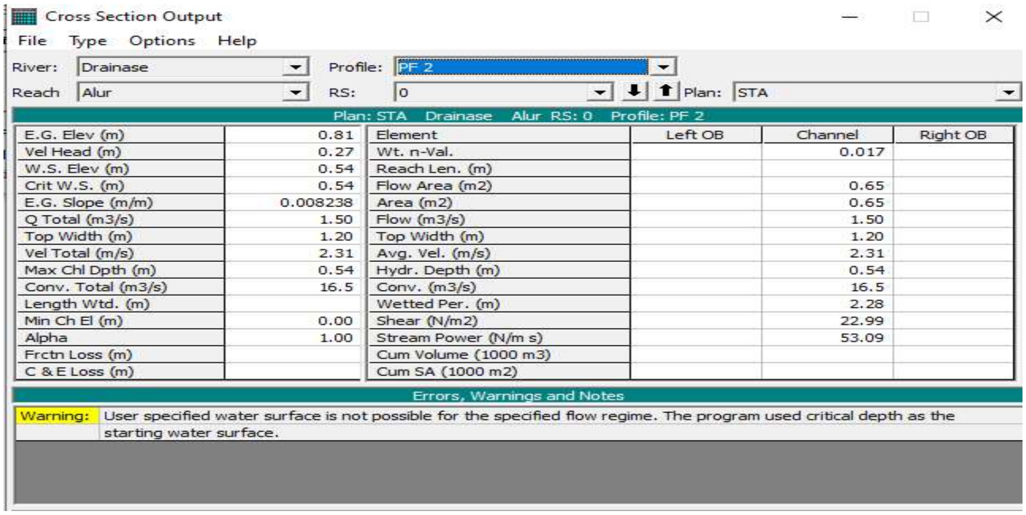
**Table 1. Statistical Parameters of Rainfall Data Using the Log Pearson Type III Method**

| No | Tahun | Xi | Log xi | (log xi-log) | (log xi- log $\bar{x}$)$^2$ | (log xi- log $\bar{x}$)$^3$ | (log xi- log $\bar{x}$)$^4$ |
|---|---|---|---|---|---|---|---|
| 1 | 2014 | 280.6 | 24.480.877 | 0.048088 | 0.002312 | 0.0001112 | 5.35E-06 |
| 2 | 2015 | 304 | 24.828.736 | 0.082874 | 0.006868 | 0.00056918 | 4.72E-05 |
| 3 | 2016 | 246 | 23.909.351 | -0.00906 | 8.22E-05 | -7,45E-04 | 6.75E-09 |
| 4 | 2017 | 269 | 24.297.523 | 0.029752 | 0.000885 | 2,63E-01 | 7.84E-07 |
| 5 | 2018 | 231 | 2.363.612 | -0.03639 | 0.001324 | -4,82E-02 | 1.75E-06 |
| 6 | 2019 | 229 | 23.598.355 | -0.04016 | 0.001613 | -6,48E-02 | 2.60E-06 |
| 7 | 2020 | 180 | 22.552.725 | -0.14473 | 0.020946 | -0.003015 | 0.000439 |
| 8 | 2021 | 303 | 24.814.426 | 0.081443 | 0.006633 | 0.0005402 | 4.40E-05 |
| 9 | 2022 | 266.6 | 24.258.601 | 0.02586 | 0.000669 | 1,73E-01 | 4.47E-07 |
| 10 | 2023 | 251 | 23.996.737 | -0.00033 | 1.06E-07 | -3,47E-08 | 1.13E-14 |
| | **Total** | | **24.037.345** | **0.037345** | **0.041333** | **-0.001881** | **0.0005408** |
| | **Average** | | **2.4** | | | | |

The statistical analysis of rainfall data was conducted to determine the most appropriate probability distribution method for rainfall frequency analysis. Several statistical parameters were calculated from the logarithmic transformation of rainfall data, including the standard deviation, coefficient of skewness, coefficient of kurtosis, and coefficient of variation. These statistical parameters were used to evaluate the distribution characteristics of the rainfall data and to identify the probability distribution that best represents the observed rainfall pattern. The standard deviation value was calculated using the logarithmic rainfall deviation data and produced a value of S=0.06S = 0.06S=0.06. The coefficient of skewness was obtained as Cs=−1.15, indicating that the rainfall data distribution exhibited negative skewness. Furthermore, the coefficient of kurtosis value was calculated as Ck=4.5, while the coefficient of variation was obtained as Cv=0.025. These statistical indicators demonstrate that the rainfall data did not follow a normal distribution pattern and therefore required a more appropriate probabilistic distribution approach for hydrological analysis. To determine the most suitable distribution method, the calculated statistical parameters were compared with the requirements of several probability distribution models, including the Gumbel distribution, Log Pearson Type III distribution, and Normal distribution. The evaluation results showed that the Gumbel and Normal distributions did not satisfy the required skewness criteria, whereas the Log Pearson Type III distribution fulfilled the statistical requirements with a skewness coefficient value less than 1.0. Therefore, the Log Pearson Type III distribution was selected as the most appropriate method for rainfall frequency analysis in this study. The selected Log Pearson Type III distribution was subsequently used to estimate design rainfall values for different return periods, which were then applied in the calculation of rainfall intensity and design flood discharge for the drainage system analysis.

A goodness-of-fit analysis was conducted using the Chi-Square test to evaluate the suitability of the selected probability distribution for rainfall frequency analysis. The test compared the observed rainfall values with the expected values obtained from the selected distribution model. The calculation results produced a Chi-Square value of 49.43. Based on the statistical evaluation with a significance level of 5% and degrees of freedom equal to 9, the calculated critical value was 16.919. The comparison between the calculated and critical values indicated that the selected Log Pearson Type III distribution was considered acceptable for representing the rainfall characteristics in the study area. Therefore, the distribution was deemed suitable for further hydrological analysis and design rainfall estimation. Following the distribution analysis, rainfall intensity analysis was performed to determine the rainfall intensity characteristics within a specific duration. Rainfall intensity represents the depth of rainfall occurring over a certain period of time, where shorter rainfall durations generally produce higher rainfall intensities. The analysis was conducted using daily rainfall data, which were subsequently converted into rainfall intensity values using the Mononobe equation. The calculation results showed that rainfall intensity values varied annually according to the recorded rainfall depth. The highest rainfall intensity was observed in 2015 with a value of 6.874 mm/hour, while the lowest intensity occurred in 2020 with a value of 4.070 mm/hour. The total calculated rainfall intensity from the observation period reached 56.984 mm/hour. These rainfall intensity values were then used as input parameters for estimating the design flood discharge in the drainage analysis.

The design flood discharge analysis was carried out using the Rational Method, which is commonly applied for estimating runoff discharge in drainage system planning. Several hydrological and hydraulic parameters were considered in the calculation, including the drainage catchment area, drainage channel length, channel slope, runoff coefficient, and concentration time. The drainage catchment area in the study area was calculated as 0.55 hectares, while the drainage channel length was approximately 500 m with a channel slope of 0.007%. The concentration time was calculated using an empirical equation and resulted in a value of 15.77 minutes. Based on land-use characteristics in the study area, a runoff coefficient value of 0.7 was adopted to represent the runoff condition of the drainage catchment. Using the Rational Method equation, the maximum design flood discharge was calculated as 0.060 $m^3/s$. This calculated discharge value was subsequently used as the basis for evaluating the hydraulic performance of the existing drainage channels and for designing the proposed drainage system improvements to mitigate flooding in the study area. The design flood discharge was calculated using the Rational Method, which is widely applied in drainage system planning to estimate peak runoff discharge from a catchment area. In this study, the runoff coefficient was selected as 0.7 to represent the runoff characteristics of the asphalt-paved road surface within the study area. This coefficient reflects the relatively low infiltration capacity of paved surfaces, which causes a significant portion of rainfall to become surface runoff. The calculation incorporated the runoff coefficient, rainfall intensity, and drainage catchment area parameters. Using a rainfall intensity value of 56.98 mm/hour and a drainage area of 0.55 hectares, the maximum design flood discharge was calculated using the Rational Method equation, Qmax= 0.060 m3/s. The calculation result indicates that the maximum design flood discharge in the study area was 0.060 $m^3/s$. This discharge value was subsequently used as the basis for evaluating the hydraulic capacity of the existing drainage system and for determining the required dimensions of the proposed drainage channel. Figure 2 describes the output of cross sectional of drainage design.



Cross Section Output

River: Drainase Profile: PF 2

Reach: Alur RS: 0 Plan: STA

Plan: STA Drainase Alur RS: 0 Profile: PF 2

| | | Element | Left OB | Channel | Right OB |
|---|---|---|---|---|---|
| E.G. Elev (m) | 0.81 | Wt. n-Val. | | 0.017 | |
| Vel Head (m) | 0.27 | Reach Len. (m) | | | |
| W.S. Elev (m) | 0.54 | Flow Area (m2) | | 0.65 | |
| Crit W.S. (m) | 0.54 | Area (m2) | | 0.65 | |
| E.G. Slope (m/m) | 0.008238 | Flow (m3/s) | | 1.50 | |
| Q Total (m3/s) | 1.50 | Top Width (m) | | 1.20 | |
| Top Width (m) | 1.20 | Avg. Vel. (m/s) | | 2.31 | |
| Vel Total (m/s) | 2.31 | Hydr. Depth (m) | | 0.54 | |
| Max Chl Dpth (m) | 0.54 | Conv. (m3/s) | | 16.5 | |
| Conv. Total (m3/s) | 16.5 | Wetted Per. (m) | | 2.28 | |
| Length Wtd. (m) | | Shear (N/m2) | | 22.99 | |
| Min Ch El (m) | 0.00 | Stream Power (N/m s) | | 53.09 | |
| Alpha | 1.00 | Cum Volume (1000 m3) | | | |
| Frctn Loss (m) | | Cum SA (1000 m2) | | | |
| C & E Loss (m) | | | | | |

Errors, Warnings and Notes

Warning: User specified water surface is not possible for the specified flow regime. The program used critical depth as the starting water surface.

**Figure 2. Result of cross sectional analysis**

The hydraulic simulation results generated using the HEC-RAS model illustrate the water surface profile along the drainage channel in the study area. The simulation was conducted to evaluate the hydraulic behavior of the existing drainage system under the calculated design flood discharge conditions. The water surface profile analysis provides an overview of flow elevation changes along the drainage channel and identifies sections that may experience insufficient flow capacity or potential overflow conditions. The simulation results indicate that the water surface elevation gradually increased along the drainage channel alignment following the variation in channel geometry and bed elevation. The computed water surface profile remained close to the channel boundary throughout the flow path, indicating that the existing drainage channel was operating near its hydraulic capacity limit during peak runoff conditions. Several channel sections showed reduced freeboard between the water surface and channel boundary, suggesting a potential risk of overflow during extreme rainfall events. The hydraulic profile analysis also demonstrates the influence of channel slope and channel geometry on flow behavior within the drainage system. Variations in channel elevation contributed to changes in flow depth and water surface gradients along the drainage alignment. Based on these findings, improvements to the drainage channel dimensions were considered necessary to enhance hydraulic performance and ensure that the drainage system could safely convey the projected runoff discharge without causing inundation in the surrounding area. Figure 3 describes the profile dimensions the study case.

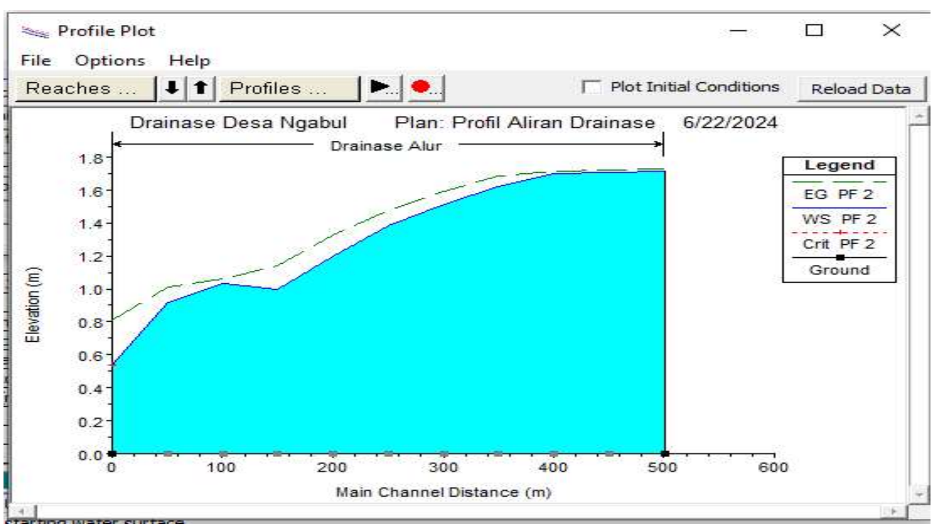



**Figure 3. Profile plot of drainage design**

The final drainage channel design was developed based on the results of the hydrological calculations and hydraulic simulations to ensure adequate capacity for conveying the projected runoff discharge in the study area. The proposed drainage system utilizes a reinforced concrete U-ditch channel with overall dimensions of 1.6 m in width and 2.0 m in depth. As shown in Figure 4, the internal channel width was designed as 1.38 m with reinforced concrete wall sections to provide sufficient structural strength and hydraulic stability during peak flow conditions. The drainage channel structure was designed with reinforced concrete elements to improve durability and resistance against hydraulic pressure and long-term environmental exposure. The channel walls and base slab were equipped with reinforcement bars to enhance structural integrity and minimize the risk of cracking or structural failure. In addition, the channel foundation incorporated a working floor layer and sand bedding layer to improve foundation stability and ensure uniform load distribution to the supporting soil layer. Several drainage outlet openings were also incorporated into the channel design to facilitate effective water flow and improve drainage efficiency. The proposed dimensions were selected to ensure that the drainage channel could safely accommodate the calculated design flood discharge while maintaining adequate freeboard to reduce the risk of overflow during extreme rainfall events.

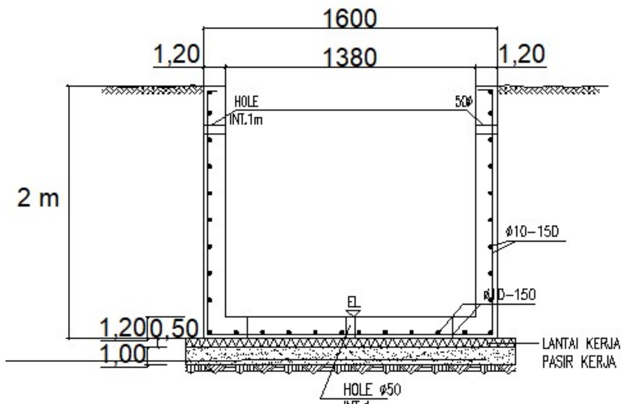



**Figure 4. Dimension of final drainage design**

## 3.2. Discussion

The results demonstrate that the existing drainage system at the Ngabul intersection area is hydraulically insufficient to accommodate increasing runoff discharge during high rainfall events. The limited channel dimensions, combined with sediment accumulation and poor drainage maintenance, have reduced the overall drainage capacity and contributed to recurring flooding problems in the area. These conditions not only disrupt transportation activities but also increase the risk of pavement deterioration and traffic accidents. The application of hydrological and hydraulic analysis, combined with numerical simulation using the HEC-RAS model, provided a comprehensive evaluation of the drainage system performance. The simulation results clearly indicated that the existing drainage channels could not safely convey the projected runoff discharge under future rainfall conditions. Therefore, increasing the drainage channel dimensions became necessary to improve hydraulic capacity and reduce flood risk. The proposed U-ditch drainage design with dimensions of 1.6 m × 2.0 m provides a practical and effective engineering solution for improving drainage performance in the study area. In addition to channel enlargement, regular maintenance activities such as sediment removal and waste cleaning are essential to ensure long-term drainage functionality. Effective drainage management is critical for maintaining road infrastructure performance, minimizing water-related pavement damage, and improving transportation safety and reliability.

# 4. Conclusions

Based on the hydrological and hydraulic analyses conducted in this study, the existing drainage system at the Ngabul intersection area in Jepara was found to be incapable of accommodating the projected runoff discharge during heavy rainfall events. The hydraulic simulation using the HEC-RAS software showed that the maximum runoff discharge exceeded the capacity of the existing drainage channels, resulting in recurring flooding conditions. To address this problem, a redesigned drainage system using a rectangular U-ditch channel with dimensions of 1.6 m width and 2.0 m depth was proposed. The redesigned channel demonstrated sufficient hydraulic performance to safely accommodate the projected runoff discharge. In addition to infrastructure improvement, routine drainage maintenance and sediment removal are necessary to maintain long-term drainage effectiveness. The proposed drainage revitalization is expected to reduce flood occurrence, improve road accessibility, enhance transportation safety, and support sustainable urban infrastructure development in the Ngabul intersection area.

## 5. Declarations

### 5.1. Author Contributions

Conceptualization, D.M.A. and D.R.; methodology, K.U.; software, D.M.A.; validation, D.R., K.U. and D.M.A.; formal analysis, K.U.; investigation, N.H.; resources, N.H.; data curation, A.A.F...; writing—original draft preparation, A.A.F.; writing—review and editing, A.A.F..; visualization, D.R..; supervision, D.R.; project administration, D.M.A. All authors have read and agreed to the published version of the manuscript.

### 5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

### 5.3. Funding

Funding information is not available.

### 5.4. Acknowledgements

The authors would like to express their sincere appreciation to all parties who contributed to the completion of this study.

### 5.5. Conflicts of Interest

The authors declare no conflict of interest.

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