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Original Article

# Peak Flood Discharge Analysis of the Gajah Wong Sub-Watershed, Indonesia

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**ABSTRACT**
Every year, during high rainfall, the Gajah Wong River overflows and inundates residential areas. The largest flood events on the Gajah Wong River occurred in early 2016 and mid-2016, this disaster caused the Gajah Wong River embankment to collapse, as a result the floods continued to overflow and enter residents' settlements as high as 2 meters. This is because the capacity of the river exceeds the peak discharge. This study aims to calculate the peak discharge using the rational method by utilizing data on daily maximum rainfall in the range from 2001 to 2021. The results of the study show that there was an increase in the inundation area for each flood return period. The peak flood discharge in the Gajah Wong River Segment using the rational method respectively for return floods of 2, 5, 10, 25 and 50 years is 61.41 $m^3$/second, 98.94 $m^3$/second, 123.79 $m^3$/second , 155.18 $m^3$/second and 178.46 $m^3$/second.

**KEYWORDS**
*Flood;*
*Hec-RAS;*
*Gajah Wong.*

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## INTRODUCTION

One of the water resource management units that is often used is watershed, which is divided into upstream, middle and downstream parts. Watershed has a function as a unit and resource management. The strategic role of watershed as a planning and resource management unit can be seen when watershed cannot function optimally as a medium for regulating water management and guaranteeing water quality (Suprayogi & Werdiningsih, 2014). In addition, watershed encompass the regulation of water management and the provision of ecosystem services. Functions of watershed include the accommodation and storage of rainfall, as well as the management of water resources. Furthermore, watershed can provide benefits in the form of resources to accommodate the activities of living things in it.

The components that affect the characteristics of the watershed include soil type, land use, topography, slope and slope length. The biophysical characteristics of the watershed respond to rainfall with the size of evapotranspiration, infiltration, percolation, surface flow, groundwater content, and runoff (Asdak, 2014). If one of the watershed components is disturbed, the watershed work system will not be in accordance with its function, In the event that one of the watershed components is disturbed, the watershed work system will be out of accordance with its function. This will result in detrimental impacts. One of the impacts that occurs due to the disruption of the function of the watershed components is flooding. Flooding is a phenomenon of overflowing water flow that occurs due to the inability of the river channel or drainage to accommodate the flow discharge. According to Purnama, et al., (2013) stated that the characteristics of floods and the impacts caused in a watershed are influenced by interrelated factors including climate factors, watershed characteristics, and the socio-economic conditions of the community in the watershed.

Gajah Wong Sub-watershed is located in an urban area covering Sleman Regency, Yogyakarta City, and Bantul Regency. In this study, the Gajah Wong River segment located in Umbulharjo District always experiences flooding every year. As demonstrated in the research conducted by Ardiansyah and Sumunar (2020), the flood vulnerability interval is predominantly influenced by the Gajah Wong sub-watershed zones, extending from the upstream to the downstream zones. On an annual basis, during periods of high rainfall, the Gajah Wong River experiences a phenomenon of inundation, affecting residential areas in the vicinity. Consequently, it is imperative to undertake a study concerning the peak discharge of the Gajah Wong River segment in Yogyakarta, with the objective of mitigating the risk posed by flooding resulting from high rainfall.

The novelty in this study is the determination of peak flood discharge carried out along the riverbanks of the Gajah Wong Sub-watershed segment which is a residential area in urban areas. This analysis is formulated from hydrological parameters to predict peak flood discharge in river segments included in the research area using the rational method. The selection of this method was predicated on its alignment with the characteristics of the study area, which encompasses a sub-watershed area of less than 50 $km^2$. According to Chow (in Kodoatie, 2013), the rational method is a viable approach for flood mitigation planning in urban areas.

# METHOD

Gajah Wong as one of the urban sub-watershed has problems caused by the high percentage of built-up land in the upstream part of the watershed which should function as a catchment area. The presence of built-up land that is impermeable in the catchment area results in a reduction of the infiltration process during precipitation events. Conversely, rainwater is converted into substantial amounts of surface runoff. Floods are frequently precipitated by substantial precipitation in the upstream segment of the river basin, resulting in substantial surface runoff that exceeds the capacity of the river channels in the middle and downstream segments. The overflow of the river flow then inundates the area around the river (Sari, 2025).

On an annual basis, during periods of high rainfall, the Gajah Wong River will overflow and inundate residential areas. The most significant flood events in the Gajah Wong River occurred in early and mid-2016. This disaster precipitated the failure of the river embankment, resulting in the inundation of residential areas with floodwaters reaching a height of 2 meters. In addition, on March 18, 2021, there was a flood due to heavy rain in Umbulharjo District, which is an area located on the banks of the Gajah Wong River, at least 50 families suffered losses due to the flood disaster that occurred (Tribun Jogja). The latest data from Regional disaster management planning agency of Yogyakarta stated that there was a flood overflowing the Gajah Wong River in Umbulharjo District on October 2-3, 2022 which was caused by high rainfall intensity which caused a lot of houses to be affected by the flood and in March 2023, there was another flood in residential areas around Gajah Wong Park reaching a height of 1 meter.

**Research Location**

The research was conducted in the Gajah Wong Sub-watershed segment located in Umbulharjo District, Yogyakarta, Special Region of Yogyakarta Province. The Gajah Wong Sub-watershed was chosen as the research location because it is located in an urban area dominated by residential areas. The Gajah Wong River segment in the Umbulharjo district frequently floods due to river overflow. The length of the river at the research location is 1.008 meters and the watershed area is 3.726,85 hectares.

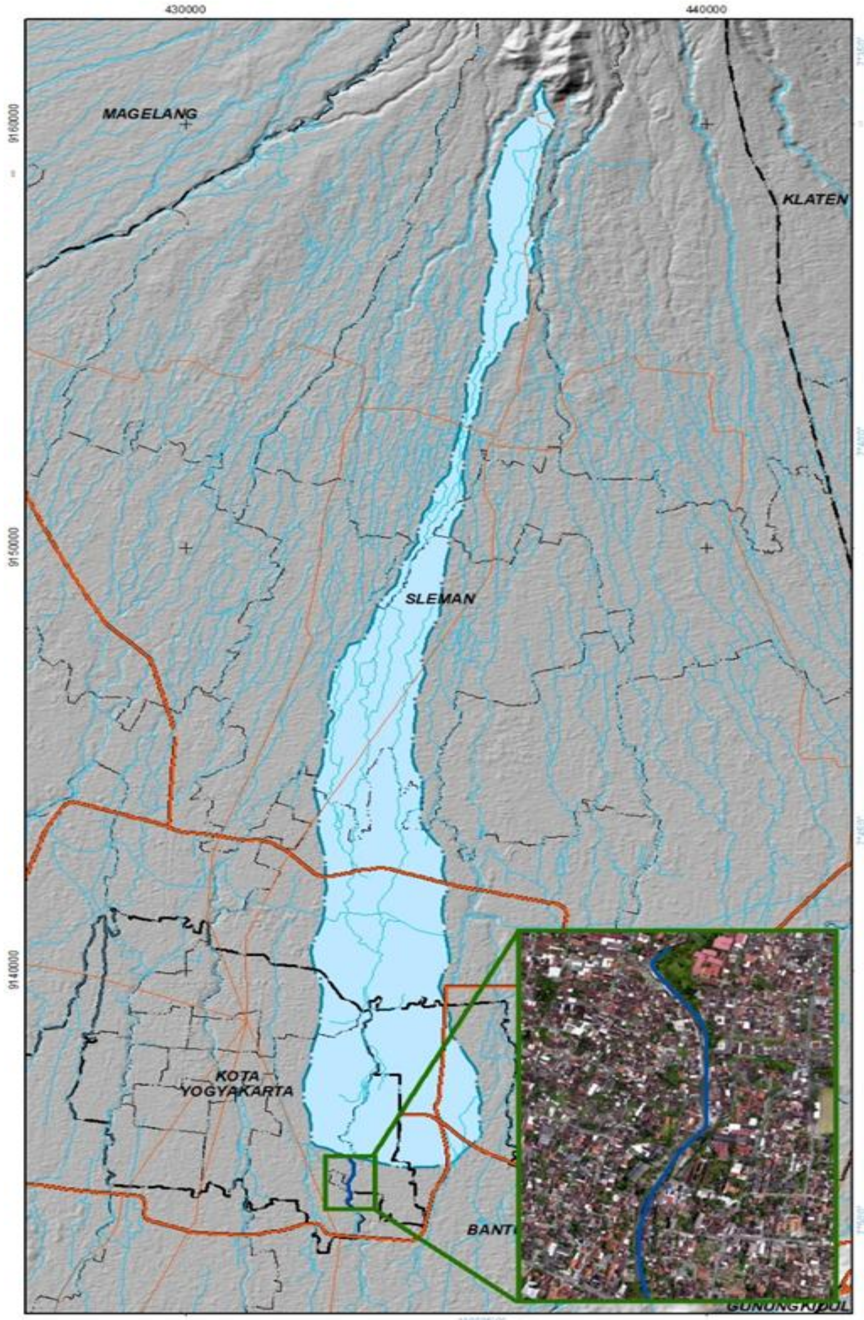


**Figure 1.** Research Location Map

**Research Approach**

The calculation of peak discharge in this study was carried out using the rational method. The rational method is used to calculate the maximum discharge in a small watershed, a watershed is considered small if it has an area of 50 km$^2$ (Hadisusanto, 2010). This method was chosen because it is in accordance with the characteristics of the study area with a watershed area of <50 km$^2$. The assumptions used in the rational method are as follows:

1. Floods are caused by a long period of uniform rainfall intensity.
2. The discharge rate will gradually increase until it is constant from the farthest point to the watershed outlet.
3. The duration of rainfall and the time required for discharge from the farthest point to the watershed outlet are equal to the concentration time.

The variables used to calculate flooding using the Rational Method are the flow coefficient, the rainfall intensity, and the watershed area. Meanwhile, the parameters used to estimate surface runoff conditions according to the Cook method include: (1) slope gradient, (2) vegetation cover, (3) soil infiltration (soil type), and (4) surface water accumulation (river flow patterns and density).

**Research Procedures**

In general, this research was conducted in several stages, as shown in Figure 2.

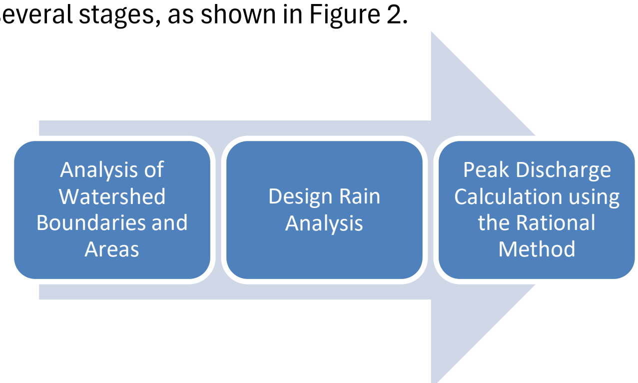


**Figure 2.** Research Procedure

**Data Collection Instruments**

The data needed to conduct a study on the calculation of peak flood discharge in the Gajah Wong River is the annual maximum rainfall data from 2001 to 2021, this rainfall data is secondary data from the Public Works, Housing, Energy and Mineral Resources Service of the Special Region of Yogyakarta Province.

**Data analysis**

1. Analysis of Watershed Boundaries and Areas

The Gajah Wong Sub-watershed boundary was obtained from the boundary determined by the Public Works, Housing, Energy and Mineral Resources agency of the Special Region of Yogyakarta Province, and the watershed area was obtained from calculating geometry using ArcGIS software.

2. Design Rain Analysis

The design rainfall analysis was carried out by combining the processing of daily rainfall data and concentration time. The daily rainfall data used was in the form of daily maximum rainfall intensity for several years (2001-2021) obtained from rainfall stations around the Gajah Wong River, including the Angin-Angin, Beran, Bronggag, Gemawang, Karang Ploso, Prumpung stations. The steps for calculating design rainfall are as follows:

a) Determine the maximum daily rainfall in a certain year at each rainfall station covering the study area.

b) Determine the area of influence of each rainfall station using the Thiessen polygon method.

$$P=(P_1A_1+P_2A_2+\cdots..P_nA_n)/(A_1+A_2+\cdots..A_n) \quad ............(1)$$

Notes:
P is the rainfall intensity at the rain gauge station and A is the area of the Thiessen polygon. 1, 2, and n are symbols for the calculated rainfall station.

c) The rainfall value selected each year is then used to calculate the design rainfall with the following steps:

1) Sort the average maximum daily rainfall data from largest to smallest.
2) Determine the statistical parameters of the sorted data, namely: mean (x), standard deviation (S), coefficient of variation (Cv), coefficient of skewness, dan coefficient of kurtosis (Ck).
3) Determine the appropriate type of distribution based on existing statistical parameters. There are four types of frequencies that are often used in hydrology, namely:
   - Normal Distribution. The normal distribution is also called the Gaussian distribution (Soewarno, 1995). The normal probability density function is normal if Cs ≈ 0; Ck ≈ 3.
   - Log Normal Distribution. Log Normal distribution is the result of transformation of normal distribution, namely by changing the value of the X variate into the logarithmic value of the X variate (Soewarno, 1995). Determining the estimated distribution according to its parameters is Cs ≈ 3; Cv > 0.
   - Gumbel Distribution. Gumbel distribution is used for maximum data analysis, for example for flood frequency analysis (Soewarno, 1995). Gumbel distribution has a difference coefficient (Coeffisient of skewness) or CS ≈ 1,139 and kurtosis coefficient (Coeficient Curtosis) or Ck < 4,002.
   - Pearson Log Distribution Type III. This distribution is widely used in hydrological

analysis, especially in the analysis of maximum and minimum data with extreme values. Included in this distribution if Cs ≈ 0; Ck > 4 s.d 6

4) Conduct tests with Chi-Square and Smirnov-Kolmogorov to determine whether the selected distribution type is appropriate.
5) Calculating the design rainfall for return periods of 2.5, 10, 25 and 50 years based on the selected distribution type, which is expressed by the following simple formula:

$$XT = Xr + KT\,S \qquad (2)$$

Information:
XT : design rainfall with a return period of T years
Xr : average magnitude
S : standard deviation
KT : frequency factor for a return period of T years

6) Calculate the design rainfall into rainfall intensity using the Mononobe equation.

3. Rational Method

The variables used in the rational method are flow coefficient (C), rainfall intensity (I), and watershed area (A). The rational method equation is as follows:

$$Q = 0{,}278 . C . I . A \qquad (3)$$

Information :
C = Flow coefficient
I = Rain intensity (mm/hour)
A = Watershed area ($km^2$) (Asdak, 2014)

a) Flow Coefficient

The flow coefficient is a metric used to indicate whether a watershed has undergone disturbance. The physical condition of the watershed affects the process of rainwater becoming surface flow that can change rain into flow discharge (Seyhan, 1977). The size of the C value depends on the permeability and the ability of the soil to hold water. A large C value indicates that a lot of rainwater becomes runoff. Information on land use, land slope, soil type, and flow density is then used to calculate the flow coefficient value using the Cook's method. The weight of each parameter is presented in table 1. The results are used to determine the flow coefficient value. The calculation of the flow coefficient using the weighted average method from the unit area value of the overlapping results is carried out with the equation

$$C = ((CaxLa)+(CbxLb)+\cdots+(CnxLn))/(La+Lb+\cdots+Ln) \qquad (4)$$

Information :
Cn = Flow coefficient at the nth unit (%)
Ln = Area of the nth area (ha)
C = Total flow coefficient (%)

**Table 1.** Weight Values of Cook's Method Parameters and Data Acquisition Techniques

| No | Parameter | Criteria | Value Category | Score | Data Analysis Techniques |
|---|---|---|---|---|---|
| 1 | Slope | 1. >30%<br>2. 10-30%<br>3. 5-10%<br>4. 0-5% | 1. Steep<br>2. Hilly<br>3. Wavy<br>4. Relatively Flat | 40<br>30<br>20<br>10 | Data analysis SRTM |
| 2 | Vegetation Cover | 1. Low Density Vegetation<br>2. Medium Density Vegetation<br>3. Sparse Density Vegetation<br>4. Hardened Surface Settlement | 1. Low<br>2. Medium<br>3. High<br>4. Very High | 5<br>10<br>15<br>20 | Secondary Data (Land-Use Data Processing, 2021) |
| 3 | Soil Infiltration (Soil Type) | 1. Rough Texture<br>2. Loamy Texture<br>3. Smooth Texture<br>4. Clay Texture | 1. Extreme<br>2. Fast<br>3. Moderate<br>4. Slow | 5<br>10<br>15<br>20 | Land Map |
| 4 | Surface Embankment (Flow Pattern and River Channel Density) | 1. Always Flooded<br>2. Surface Depressions, Lakes and Swamps Found<br>3. Quite Good Drainage System<br>4. Draining Too Fast | 1. High<br>2. Normal<br>3. Low<br>4. Negligible | 5<br>10<br>15<br>20 | Satellite imagery is interpreted with the aid of flow pattern maps from RBI and landform maps. |

Source: Chow, 1988

Meanwhile, the formula used to calculate flow density or river flow is as follows:

$Dd = \frac{L}{A}$ ..........................................................(5)

Information:
Dd = Flow Density ($Km/Km^2$)
L = River Length (Km)
A = Sub-watershed area ($Km^2$)

The flow density values for each class can be observed in the following table.

**Table 2.** Flow Density Values in Each Class

| Flow Density ($km/km^2$) | Condition | Classification |
|---|---|---|
| >5 | Strong drainage, steep channels, no ponding | Negligible |
| 2-5 | Good to moderate management, no lakes | Slight |
| 1-2 | Good to moderate management, 2 percent of the area is flooded | Moderate |
| <1 | Poor management, lots of puddles | High |

Source: Ismail (2009)

b) Design Rainfall Intensity

Rainfall intensity can be calculated using the Mononobe formula:

$I = \frac{R24}{24} \times \frac{24}{tc^{2/3}}$ ..........................................................(5)

Information:

R = maximum rainfall (mm)
tc = concentration time (hours)

c) Concentration Time (Tc)

Concentration time Tc (time of concentration) is the travel time required by water from the furthest place (upstream of the watershed) to the water flow observation point (outlet) (Asdak, 2010). Concentration time is calculated using the formula developed by Kirpich, which can be formulated as follows:

$Tc = x = \frac{0,06628.\ L0,77}{S^{0,385}}$ ............................................(6)

Information:
Tc = concentration time (hours)
L = length of main river (km)
S = slope of main river (m)

d) Concentration Time (Tc)

Concentration time Tc (time of concentration) is the travel time required by water from the furthest place (upstream of the watershed) to the water flow observation point (outlet) (Asdak, 2010). Concentration time is calculated using the formula developed by Kirpich, which can be formulated as follows:

$Tc = 0,06628.\ L^{0,77}\ S^{-0,385}$ .........................................(7)

Description:
Tc = concentration time (hours)
L = length of main river (km)
S = slope of main river (m)

e) Drainage Channel Design for River Embankment

Wet cross section to accommodate maximum discharge.

Trapezoidal Channel

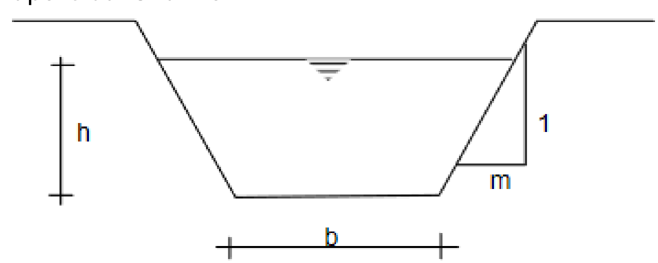


**Figure 3.** Trapezoidal Channel

Rectangular Channel

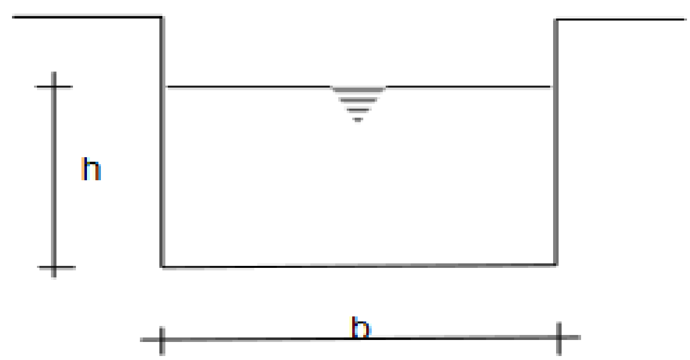


**Figure 4.** Rectangular Shape Channel

The formula used for trapezoidal channels:

Ae = $(b+m.h)h$ ................................................(8)
P = $b + 2h\sqrt{(1+m^2)}$ ......................................(9)
$R = \frac{Ae}{P}$ ................................................ (10)

The formula used for rectangular channels:

Ae = b.h ..........................................................(11)

$R = \frac{Ae}{P}$ ..........................................................(12)

P = b + 2h ..........................................................(13)

Information:

b = Channel width (m)
h = Water depth (m)
m = Comparison of embankment slope
R = Hydraulic radius (m)
P = Wet channel cross-section (m)
Ae = Wet cross-section area ($m^2$)

f) Average Flow Velocity

The average flow velocity is the process of water flowing through the drainage from the inlet to the outlet which is taken per unit time (m/second). Determining the average velocity in calculating the channel dimensions using the Manning formula:

$V = \frac{1}{n}(R)^{\frac{2}{3}}(i)^{\frac{1}{2}}$ ..................................................(14)

Information:

Q : Water discharge in the channel ($m^3$/sec)
V : Water velocity in the channel (m/sec)
n : Wall roughness coefficient
R : Hydraulic radius (m)
i : Channel bottom slope
A : Wet cross-sectional area ($m^2$)

# RESULTS AND DISCUSSION

## 1. Morphometry of Gajah Wong Sub-watershed

According to Soewarno (2014), the morphometry of a watershed is calculated using several parameters, including area, length, width, slope, order, and river density. The size of the watershed dictates the area of the water catchment area, thereby influencing the total volume of outflow from within the watershed (Indarto, 2010). Pramono et al. (2010) explained that the river morphometry parameters used to estimate flood discharge using the rational method are area, flow length, and river slope.

The Gajah Wong watershed has a main river length of 31.409 km with an average river slope of 0,066%. The rivers in the Gajah Wong watershed are classified as perennial rivers, which means they flow throughout the year.

**Table 3.** Morphometric Data of Gajah Wong Sub-watershed

| No | River Characteristics | Value |
|---|---|---|
| 1. | Wet Cross-sectional Area of Channel (Ae) | 14,5 $m^2$ |
| 2. | Channel Wet Circumference (P) | 16.708 m |
| 3. | Hydraulic Radius (R) | 0,8678 m |
| 4. | Manning Coefficient (Plastered River Stone) | 0,02-0,025 |
| 5. | Water Speed in Channels | 8,91 m/sec |
| 6. | Channel Discharge Capacity | 106,97 $m^3$/sec |

Source: Field Observation and Data Processing

## 2. Regional Rain

Regional rainfall calculations were carried out using the Thiessen Polygon method. This method was chosen based on the uneven rainfall measurement points and the relatively low topographical conditions. The study utilizes five rainfall measurement points as interpolation points. Each point generates its own coverage area. Based on the interpolation results, the coverage area of point 1 is 1,55 $km^2$, point 2 is 17,84 $km^2$, point 3 is 4,77 $km^2$, point 4 is 9,42 $km^2$, and point 5 is 3,67 $km^2$. The calculation of regional rainfall using the Thiessen Polygon in the Gajah Wong sub-watershed from 2001-2021 is as follows (Figure 5).

Daily rainfall in Gajah Wong Sub-watershed ranges from 23,91 mm/day – 170,55 mm/day. The maximum daily rainfall in 2017 was much higher than in other years, this is because in 2017 there was a cyclone Cempaka so that Yogyakarta was affected by extreme rain (T. Kurniawan, 2017).

Frequency analysis calculations are performed on maximum daily rainfall data. Frequency analysis is used to determine the type of probability distribution that is appropriate for calculating design rainfall. The design rainfall then becomes the basis for calculating design rainfall intensity. The results of frequency analysis calculations using the normal and gumbel distribution methods show that the coefficient of variation (cv) is 0.53, the skewness coefficient (cs) is 0.97, and the kurtosis coefficient (ck) is 0.52.

The suitability test was then conducted on the design rainfall data. The suitability test was conducted to determine the suitability of the sample data frequency distribution with the calculation results. The suitability test was conducted using Chi-Square and Smirnov-Kolmogorov. Table 4 shows the results of the Chi-Square and Smirnov-Kolmogorov suitability tests.

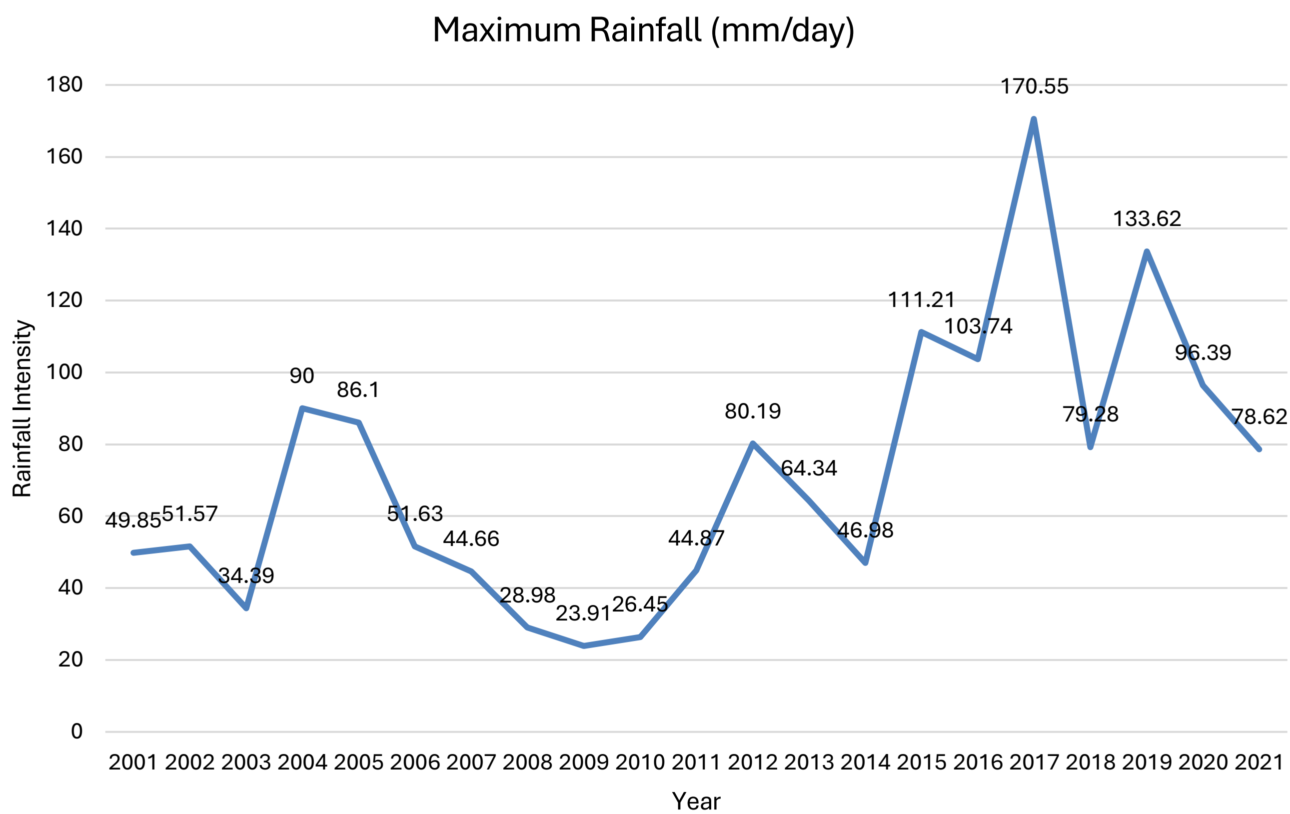


**Figure 5.** Graph of Maximum Rainfall in Gajah Wong Sub-Watershed
Source: Results of Research Data Processing in 2023

The results of the goodness-of-fit test show that the Chi count and D count values are smaller than the Chi critical and D critical. Based on the results of the calculation of several statistical parameters, it was concluded that all types of distributions are acceptable. Therefore, the total rainfall value using the Gumbel distribution is higher than other types of distributions, so the type of distribution used to calculate the design rainfall is the Gumbel distribution.

**Table 5.** Design Rainfall at Each Return Period

| Return Period | Rainfall Intensity (mm) |
|---|---|
| 2 | 65,43 |
| 5 | 105,41 |
| 10 | 131,89 |
| 25 | 165,33 |
| 50 | 190,14 |

Source: Research Data Processing Results (2023)

Design rainfall value shows that the longer the time in the return period, the higher the rainfall intensity. This happens because the longer the return period indicates a smaller probability of occurrence. The return periods of 2, 5, 10, 25 and 50 years have a probability of occurrence of 50 percent, 20 percent, 10 percent, 4 percent and 2 percent. This means that in the 2-year return period, the probability of 65,43 mm of rain each year is 50 percent, the 5-year return period has a probability of 105,41 mm of rain of 20 percent, the 10-year return period has a probability of 131,89 mm of rain of 10 percent, the 25-year return period has a probability of 165,33 mm of rain of 4 percent, and the 50-year return period has a probability of 190,14 mm of rain of 2 percent.

**Table 4.** Chi-Square and Smirnov Kolmogorov Goodness of Fit Tests

| Frequency Distribution Analysis | | | | |
|---|---|---|---|---|
| **Tr (Year)** | **Normal** | **Gumbel** | **Log Normal** | **Log Pearson Tipe III** |
| 50 | 147.55 | 190.14 | 185.32 | 139.36 |
| 25 | 136.34 | 165.33 | 157.91 | 130.21 |
| 10 | 119.67 | 131.89 | 124.45 | 114.54 |
| 5 | 102.99 | 105.41 | 98.08 | 98.71 |
| 2 | 71.30 | 65.43 | 62.37 | 68.14 |
| **Total** | 736.91 | **872.98** | 846.90 | 697.71 |
| **Distribution Suitability Test** | | | | |
| **Chi-Square Test** | | | | |
| **Chi Count** | 5.5714286 | 1.57142857 | 4.42857 | 7.285714 |
| **Critical Chi** | 7.8150 | 7.815 | 7.815 | 7.815 |
| ***Conclusion*** | ***Accepted*** | ***Accepted*** | ***Accepted*** | ***Accepted*** |
| **Uji Smirnov Kolmogorov** | | | | |
| **Chi Count** | 0.22 | 0.22 | 0.18 | 0.18 |
| **Critical Chi** | 0.286 | 0.286 | 0.286 | 0.286 |
| ***Conclusion*** | ***Accepted*** | ***Accepted*** | ***Accepted*** | ***Accepted*** |

Source: Results of Research Data Processing 2023

### 3. Surface Flow Coefficient

The surface runoff coefficient is a comparison of the volume of water flowing on the surface during rainfall with the total volume of rainfall during a certain period. The calculation of the flow coefficient is needed to determine the amount of water flowing due to a rainfall event. In addition, the coefficient also indicates the impact of the natural geomorphological conditions of an area. According to Che, et al (2018), the flow coefficient can also be used to compare the response of each different landform in transforming rainfall into surface runoff.

The flow coefficient value is between 0 and 1. The higher the surface runoff, the greater the flow coefficient, or closer to 1, indicating that the area has poor ability to store and drain rainfall that falls below the surface. The results of the flow coefficient calculation in the Gajah Wong Sub-watershed can be seen in Table 6.

The determination of the flow coefficient is carried out using the Cook method. This method is based on four variables (topography, vegetation cover, soil infiltration and surface storage). The calculation of surface storage is performed using the flow density approach. Each characteristic is assigned a distinct weight. In the context of land use, specifically in the form of built-up land, the infiltration area is constrained. Rainfall that accumulates in areas characterized by built-up land has been observed to result in an augmentation of the surface flow rate. This will also affect the value of the maximum peak discharge. The flow coefficient value for all characteristics is then calculated compositely so that the flow coefficient for the Gajah Wong Sub-watershed is 0.57.

### 4. Peak Flood Discharge

Peak discharge shows how much water passes through a cross-section of each channel in each unit of time and the capacity if the channel is unable to accommodate the flood discharge, then a flood occurs. The results of the peak discharge calculation using the rational method are presented in Figure 6. The calculation of peak discharge with a return period of 2, 5, 10, 25 and 50 years is carried out with the assumption that the parameters or characteristics of the watershed are relatively the same or do not change. The flow coefficient value used for all return periods is the same. The rainfall intensity and area of the Sub-watershed used are also the same as in the previous calculation

**Table 6.** Study Area Flow Coefficient

| Watershed characteristics | Characteristics that Generate Flow | | | | Weight x Area | Area ($Km^2$) | C | |
|---|---|---|---|---|---|---|---|---|
| | Extreme (100) | High (75) | Moderate (50) | Low (25) | | | Cn | Ct |
| **Topography** | Steep (>40%) | Hilly (10-40%) | Undulating (5-10%) | Flat (0-5%) | 5,50 | 33,24 | 0,17 | 0,57 |
| **Weight** | 0,4 | 0,3 | 0,2 | 0,1 | | | | |
| **Area ($Km^2$)** | 0,007 | 5,126 | 11,504 | 16,602 | | | | |
| **Soil Infiltration** | Rocks covered with a thin layer of soil | Clay | Sandy Loam, Dusty Loam, Loam, Clay Loam | Sand, Gnarled Sand | 3,36 | | 0,10 | |
| **Weight** | 0,2 | 0,15 | 0,1 | 0,05 | | | | |
| **Area ($Km^2$)** | 0 | 0 | 31,025 | 2,214 | | | | |
| **Cover Vegetation** | Residential, vacant land | Irrigated rice fields, rain-fed rice fields, and dry fields | Mixed gardens, less dense forests | Dense Forest | 5,27 | | 0,16 | |
| **Weight** | 0,2 | 0,15 | 0,1 | 0,05 | | | | |
| **Area ($Km^2$)** | 18,545 | 1,927 | 12,742 | 0,024 | | | | |
| **Surface Deposits** | Negligible, strong drainage, steep channels, no lakes | Little, good management, no lakes | Moderate, good-moderate management, 2% of the area is lakes | Substantial, less regulation, many lakes | 4,98 | | 0,15 | |
| **Weight** | 0,2 | 0,15 | 0,1 | 0,05 | | | | |
| **Area ($Km^2$)** | 0 | 33,22 | 0,018 | 0 | | | | |

Source: Research Data Processing Results (2023)

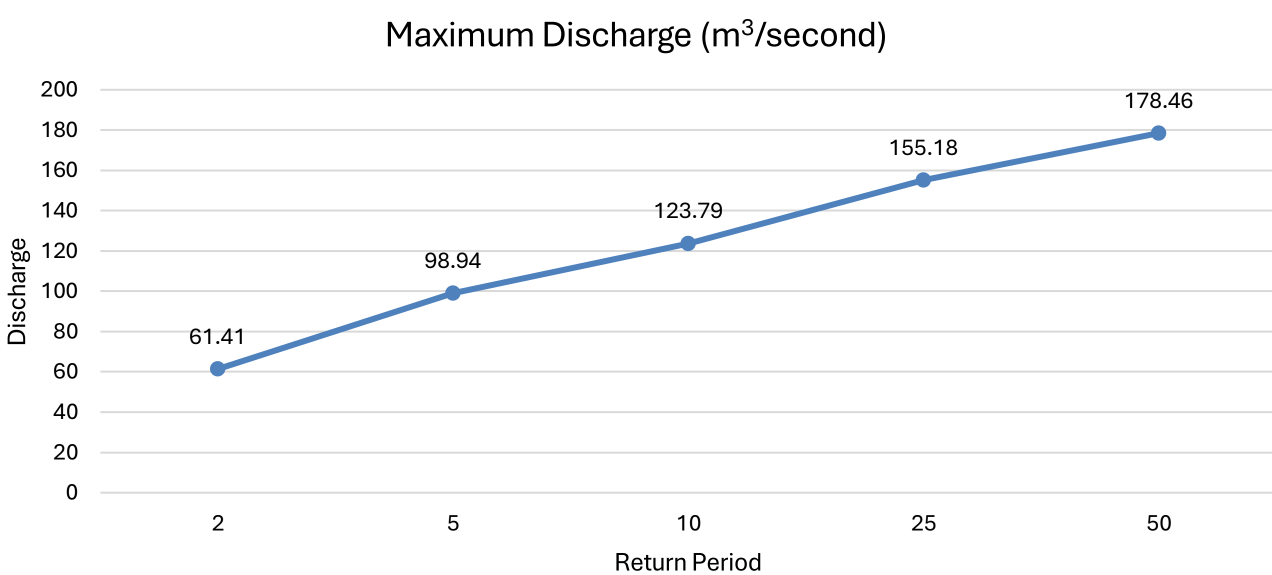


**Figure 6.** Peak Discharge of Gajah Wong Sub-watershed
Source: Results of Research Data Processing in 2023

Furthermore, the design rainfall data is combined with the concentration time to obtain a design rainfall intensity value that is evenly distributed throughout the Sub-watershed. The concentration time is the time required for water to flow from the furthest point to the observation point in the Gajah Wong sub-watershed of around 2.74 hours, with a watershed flow coefficient of 0.57. The peak discharge value of the Gajah Wong sub-watershed in various return periods is presented in (Figure 6).

Based on the graph in Figure 6, it shows that the results of the peak discharge calculation of the Gajah Wong Sub-watershed have an increasing pattern during the return period. The peak discharge in the Gajah Wong Sub-watershed is 61,41 $m^3$/second at a return period of 2 years, 98,94 $m^3$/second at a return period of 5 years, 123,79 $m^3$/second at a return period of 10 years, 155,18 $m^3$/second at a return period of 25 years and 178,46 $m^3$/second at a return period of 50 years. The maximum flood discharge at the return periods of 2 and 50 years exhibit a substantial discrepancy. This phenomenon transpires due to the substantial disparity in the design rainfall values at both return periods, which aligns with the principles of probability. The magnitude of the design rainfall value exerts a considerable influence on the magnitude of the peak discharge.

**5. Evaluation of River Embankment Capacity in the Study Area**

In the field of flood management, a common structural mitigation measure is the construction of river embankments.

**Table 7.** Capacity of the Embankment Channel in the Study Area

| No | River Characteristics | |
|---|---|---|
| 1. | Height of Embankment | 3 m |
| 2. | Wet Cross-sectional Area of Channel (Ae) | 14.5 $m^2$ |
| 3. | Channel Wet Circumference (P) | 16,708 m |
| 4. | Hydraulic Radius (R) | 0,8678 m |
| 5. | Manning Coefficient (Plastered River Stone) | 0.02-0.025 |
| 6. | The Velocity of Water in Channels | 8,91 m/det |
| 7. | Channel Discharge Capacity | 106,97 $m^3$/det |

Source: Data Processing, 2023

The height of the embankment in the river segment of the research area is 3 meters. To evaluate the height of the river embankment, data on concentration time and river slope are needed. Concentration time is the time required for river water to flow from upstream to reach the inlet segment in the research area. While the concentration time of the Gajah Wong Sub-watershed river flow is 2.74 hours (2 hours 44 minutes). With a river slope of 3.8 percent.

The 3-meter high embankment indicates that the channel discharge capacity is 106.97 $m^3$/sec. In instances where the peak discharge exceeds the capacity of the channel, the river is unable to accommodate the excess flow, resulting in flooding due to river overflow.

**Table 8.** Comparison of Planned Discharge with Channel Capacity with Embankment Height

| Period Time | Peak Discharge ($m^3$/det) | Channel Discharge Capacity ($m^3$/second) | Information |
|---|---|---|---|
| 2 | 61,41 | 106,97 | No flood |
| 5 | 98,94 | 106,97 | No flood |
| 10 | 123,79 | 106,97 | Flood |
| 25 | 155,18 | 106,97 | Flood |
| 50 | 178,46 | 106,97 | Flood |

Source: Data Processing (2023)

As indicated in Table 8, the height of the embankment, which is 3 meters, is inadequate to fully accommodate the peak discharge. The river embankment with a height of 3 meters can only accommodate flood inundation at a return period of 2 and 5 years. While for a return period of 10, 25 and 50 years, an embankment with a height above 3 meters is required.

## CONCLUSION

The maximum flood discharge in the Gajah Wong River Segment, as determined using the rational method for floods with return periods of 2, 5, 10, 25, and 50 years, was 61.41 $m^3$/second, 98.94 $m^3$/second, 123.79 $m^3$/second, 155.18 $m^3$/second, and 178.46 $m^3$/second, respectively. Peak discharge is a critical factor in flood evaluation because it quantifies the volume of water that passes through a specific channel cross-section per unit of time. In instances where a channel is incapable of accommodating the flood discharge, a flood is likely to ensue. The results of the river embankment evaluation indicated that the 3-meter embankment height proved to be inadequate in fully accommodating the flood. Therefore, to mitigate flooding caused by the overflow of the Gajah Wong River, it is necessary to increase the height of the embankment along the river segment in the study area. Subsequent research endeavors are anticipated to elucidate the flood inundation model, which is predicated on peak discharge data. This study is imperative for the consideration of flood mitigation measures within the Gajah Wong Sub-Watershed segment.

**Conflict of Interest** The author declares that he has no conflict of interest relevant to this research.



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