Hydrological and Hydraulic Analysis of Wanggar River Flow

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Abstract. Rivers are one of the natural resources to be utilized for human life, including the provision of irrigation water, raw water, industry, transportation and others. Rivers can cause problems if the flow exceeds the capacity of the river. Therefore, in this study, hydrological and hydraulic analysis was carried out on the Wanggar River to determine the hydraulic capacity and the possibility of flooding. This research has two important parts, namely hydrological analysis and hydraulic analysis. Hydrological analysis has two sub-sections, namely the planned rainfall and discharge analysis. The planned rainfall is calculated by various distribution methods, namely Gumbel, Normal, Log Normal, and Log Pearson III distributions. Furthermore, testing was carried out using the statistical parameter method, Chi Square and Smirnov-Kolommogrov. The calculation results show that the frequency analysis that passes the three tests is Log Pearson III. The results of the Pearson Log III were then calculated using the ITB-1, ITB-2, Snyder and Nakayasu methods. Then the result of the discharge plan is chosen which is closest to the Creager graph. The calculation result of 100 year flood discharge is 2,169 m3/s. Hydraulic analysis is carried out by finding the velocity of the critical shear stress and the critical shear stress. The critical shear velocity obtained by the Scobey method is 0.93 m/s and the critical shear stress is obtained by the Shield method of 9.49 N/m2.

Keywords: *frequency analysis; Fortier-Scobey; Shield; Wanggar River.*

1 Introduction

Wanggar is a permanent river that flows water throughout the year, the length of the main river is ± 60 km and the area of the watershed (DAS) is about 1,178 km2. The direction of the flow is from the south to the north across the Wanggar area and empties into Sarera Bay. The central part of the Wanggar River watershed downstream is the administrative area of the Wanggar District, while the middle part towards the downstream includes the administrative area of Uwapa District, Nabire Regency, Papua Province.

In recent years, the Wanggar river has not only functioned as the main drainage channel and water source in the Wanggar plain but has also become a threat of flooding and erosion almost every year. Losses due to water damage are nominally quite large if properly recorded. A rough estimate made by the District of Wanggar on the flood incident in 2010 was Rp. 1,910,155,000.00 and the cessation of community economic activities. To prevent this from happening, it is necessary to analyze the hydrology and hydraulics of the Wanggar river, as a first step to determine the capacity of the river. Therefore, this research was conducted to study the hydrological and hydraulic characteristics of the Wanggar watershed.

2 Material and Methods

2.1 Frequency Analysis

There are 5 methods that can be used to perform frequency analysis calculations, namely the Normal Distribution method, Log Normal, Pearson III, Log Pearson III, and Gumbel reported by Chow, *et al.* in [1]. The formula used to complete the calculation with the Gumbel Method is as follows:

$$x_T = \bar{x} + K_T S \tag{1}$$

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + ln\left[ln\left(\frac{T_r}{T_r-1}\right)\right]\right\} \tag{2}$$

The Normal and Log Normal methods have distinctive properties, namely the asymmetric value (skewness) is almost equal to zero (Cs = 0) with kurtosis = 3. The Normal method uses equation (3) and the Normal Log Method (4) with the following calculation formula:

$$x_T = \bar{x} + K_T S \tag{3}$$

$$\log x_T = \overline{\log x} + K_T S_{logx} \tag{4}$$

$$K_T = z = w - \frac{2,515517 + 0,802853w + 0,010328w^2}{1 + 1,432788w + 0,189269w^2 + 0,001308w^3} \tag{5}$$

$$w = \left[ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} \ (0 < p \leq 0.5);$$

$$w = \left[ln\left(\frac{1}{1-p^2}\right)\right]^{\frac{1}{2}} (0.5 < p < 1)$$

(6)

The Pearson III method uses equation (7) and the Log Pearson III method (8) with the following calculation formula:

$$X_T = \bar{x} + K_T S$$

(7)

$$\log x_T = \overline{\log x} + K_T S_{logx}$$

(8)

$$w = \left[\ln\frac{1}{p^2}\right]^{\frac{1}{2}} \ (0 < p \leq 0{,}5\ )$$

(9)

$$z = w - \frac{2{,}515517 + 0{,}802853w + 0{,}010328w^2}{1 + 1{,}432788w + 0{,}189269w^2 + 0{,}001308w^3}$$

(10)

$$K_T = z + (z^2 - 1)k + \frac{1}{3}(z^3 - 6z)k^2 - (z^2 - 1)k^3 + zk^4 + \frac{1}{3}k^5 \qquad (11)$$

$$k = \frac{Cs}{6}$$

(12)

2.2 Plan Discharge Analysis

The design flood discharge can be obtained by various methods. The unit hydrograph method is one of the empirical methods used when the observation discharge data is not available in sufficient quantity. The unit hydrograph method is determined based on research so that a correlation relationship can be made between rain and watershed characteristics on flooding. There are many methods for calculating the synthetic discharge, but in this study only the ITB-1, ITB-2, Nakayasu and Snyder methods were used reported by SNI in [3]. The following debit formula is used.

<u>ITB-1 Discharge</u>

$Q(t) = \{t\ exp(1-t)\}^{\alpha C_p}$(t > 0 s/d ∞)
α = 3.700 (13)

ITB-2 Discharge
Curve Up:

$Q(t) = t^{\alpha}$
(0 ≤ t ≤ 1)
α = 2.400
(14)

Curve Down:

$Q(t) = exp\left(1 - t^{\beta C_p}\right)$ (t > 1 s/d ∞)
β = 0.880
(15)

Nakayasu Discharge
Curve Up Equation ($0 \leq t \leq T_p$)

$$Q_a = Q_p \left(\frac{t}{\mathrm{Tp}}\right)^{2,4}$$

1st Curve Down Equation ($T_p \leq t \leq T_p + T_{0.3}$)

$$Q_{d1} = Q_p\ x\ 0{,}3^{\left(\frac{t-Tp}{\mathrm{T}0{,}3}\right)} \quad (17)$$

2nd Curve Down Equation ($T_p + T_{0.3} \leq t \leq T_p + 1{,}5T_{0.3}$)

$$Q_{d1} = Q_p\ x\ 0{,}3^{\left(\frac{t-Tp+0{,}5\mathrm{T}0{,}3}{1{,}5\ \mathrm{T}0{,}3}\right)} \quad (18)$$

3rd Curve Down Equation ($T_p + 1{,}5T_{0.3} \leq t$)

$$Q_{d1} = Q_p\ x\ 0{,}3^{\left(\frac{t-Tp+1{,}5\mathrm{T}0{,}3}{2\ \mathrm{T}0{,}3}\right)} \quad (19)$$

Snyder Discharge

$$Q(t) = Q_p \, x \, 10^{-a\left(\frac{(1-t)^2}{t}\right)} \tag{20}$$

2.3 Hydraulic Analysis

According to Breuser & Raudkivi (1991), dimensional analysis is used to determine several dimensionless parameters and is defined in the form of an incipient motion diagram. Through the Shield graph, by knowing the Reynolds number (Re) grain or grain diameter (d), then the value of the critical shear stress (τc) can be known. When the bed shear stress is above the critical value, the sediment grain moves, or in other words:

- $\tau o < \tau c$ the grain doesn't move
- $\tau o = \tau c$ the basic grain starts to move
- $\tau o > \tau c$ the basic grain moves

In 1936 a Russian paper published the values of the maximum allowable velocity based on grain size, where appropriate grinding of incohesive materials would occur according to various grain sizes and various types of cohesive soils reported by Chow in [2]. This method is called Fortier-Scobey.

3 Result and Discussion

3.1 Frequency Analysis

In this sub-chapter, the results of the study for hydrological studies in the form of daily rainfall data from the Kalibumi SP2 Rain Post, Wanggar Rain Post, Lagare Rain Post and Kalibumi Rain Post will be discussed. The rain station takes the maximum daily rain every year from 2000-2018. However, due to data limitations, some of the rain stations experienced empty rain data. Therefore, it is necessary to calibrate using Giovanni satellite rainfall data.

After calibrating this rain data, the planned rain was calculated using the Gumber, Normal, Log Normal, Pearson III and Log Pearson III methods for return periods of 2, 5, 10, 25, 50 and 100 years. Then the results of the calculation of the frequency analysis were tested using the Chi-Square, Smirnov-Kolomogorov and Statistical Parameters methods. The results of the statistical parameter test show that the accepted frequency analysis is the Pearson III log method, because the Pearson III log does not have statistical parameter requirements. The results of the chi-square test of Log Pearson III show the chi-square value of Log Pearson III above the critical chi-square, namely $x^2 < x_{cr}^2$ (2.158 < 7.815), so that Log Pearson III passes the chi-square test. The results of the Smirnov-Kolomogorov test show that the Pearson III Log also passed the test. Rainfall obtained from Log

Pearson III was 94.3 mm, 107.6 mm, 115.5 mm, 124.3 mm, 130.42 mm, 136.2 mm, and 141.7 mm for the 2nd rain return period, 5, 10, 25, 50, 100, and 200 years (Table 1).

3.2 Plan Discharge Analysis

The results of Google Earth imaging show that the soil type in the Wanggar watershed is 99% forest with loamy soil characteristics and the like so that the flow coefficient value is 0.3. So it was determined that the runoff coefficient of the Wanggar watershed was 0.3. In the calculation of flood discharge, the first thing that is calculated is the effective rain for each return period and the distribution of rain. Calculation of effective rain and rain distribution are shown in Table 2.

The results of the calculation of effective rain and rain distribution are used to calculate synthetic rain. Synthetic rain in this calculation uses the ITB-1, ITB-2, Nakayasu and Snyder methods. The discharge calculation shows that the HSS ITB-2 method has the highest peak discharge compared to other methods (Figure 1). This discharge calculation also shows that the HSS ITB-1 method has the lowest peak discharge compared to other methods. The results of this discharge calculation are then tested using the Creager test to determine the discharge value to be taken. The results of the plot on the Creager curve obtained a maximum discharge value of $Q_{200year}$ on an area of 1178 km^2 of 2,256 m^3/s. From this it can be seen that the synthetic HSS that is closest to the $Q_{200year}$ Creager is the ITB-2 HSS. Therefore, HSS ITB-2 was chosen as the flood discharge. These results indicate that the flood discharge is 1,504 m^3/s, 1,716 m^3/s, 1,840 m^3/s, 1,981 m^3/s, 2,078 m^3/s, 2,169 m^3/s and 2,256 m^3/s for the rain return period 2, 5, 10 , 25, 50, 100 and 200 years (Figure 2).

3.3 Hydraulics Analysis

The maximum allowable flow velocity was obtained by finding the percentage of soil that passed the sieve test (D50=9.78 mm) at each test point and then plotted it on a soil size distribution graph. Thus, the average soil grain size can be obtained at each test point (Figure 3). Furthermore, each average soil grain size data is plotted on a graph of the maximum allowable velocity for non-cohesive soils according to Fortier & Scobey. Based on the graph, it is estimated that flow velocity above 3.1 kd or 0.93 m/s will result in erosion.

The concept that the shear force acting on the flow is considered to have the most role in the movement of sediment grains. As a result of the flow of water, the flow forces acting on the sediment grains arise. These forces have a tendency to

move/drag sediment grains. In coarse sediment grains (sand and rock), the force against these flow forces is a function of the weight of the sediment grains. In fine sediment grains containing silt or clay fractions which tend to be cohesive, the force against flow forces is due to cohesion rather than the weight of the sediment grains. Cohesion of fine sediment grains is a complex phenomenon; The effect of cohesion varies and depends on the mineral content. The data shows the average temperature at the wanggar is 27^0C, the average slope of the river is 0.002 and the viscosity is 1.3 x 10^{-6}.
Obtained:

$$y = \frac{d}{v}\sqrt{0.1\ x\ \left(\frac{\rho s}{\rho} - 1\right) g\ d}$$

$$y = \frac{9{,}78\ x\ 10^{-3}}{1{,}3\ x\ 10^{-6}}\sqrt{0.1\ x\ \left(\frac{2650}{1000} - 1\right) x\ 9{,}81\ x\ 9{,}78\ x\ 10^{-3}}$$

$$y = 939$$

Then the value of y is plotted with a shield diagram, obtained a feasible F* value of 0.06, then the critical shear stress is calculated.

$$F^* = \frac{\tau_c}{(\gamma_s - \gamma_w)\ x\ D} = 0.06$$

$$\tau_c = F^*\ x\ (\gamma_s - \gamma_w)\ x\ D$$

$$\tau_c = 0.06\ x\ (2650 - 1000)\ x\ 9{,}78\ x\ 10^{-3}$$

$$\tau_c = 9{,}49\ \text{N/m}^2$$

4 Figures and Tables

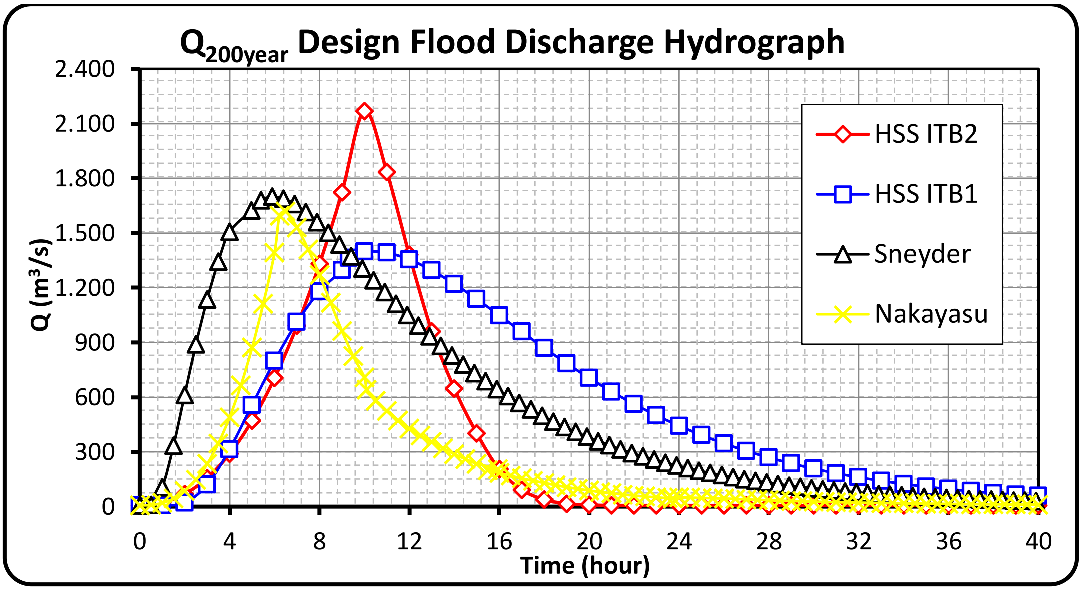

Figure 1 Figure 1 Discharge Comparison of Each HSS

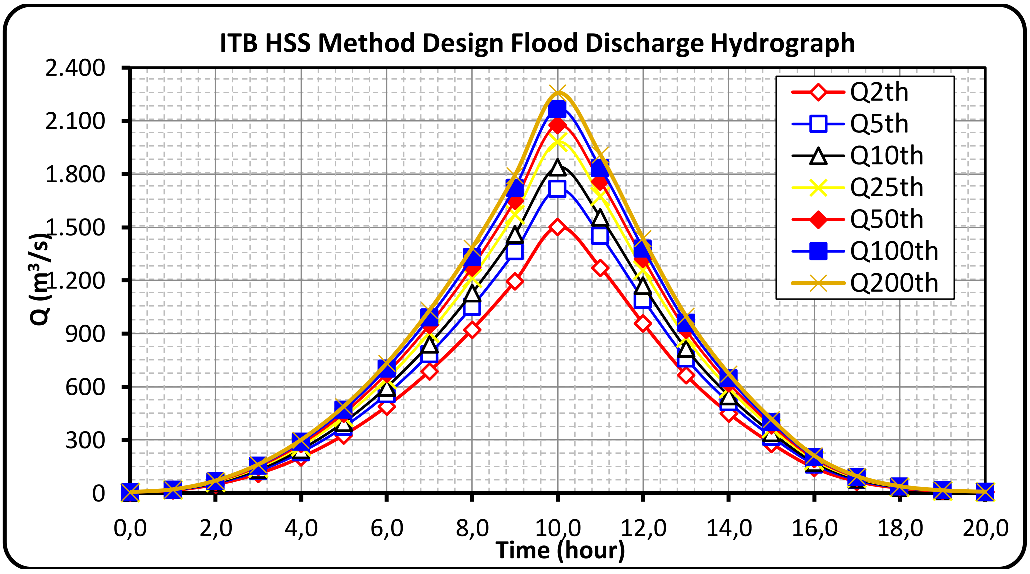

Figure 2 Figure 2 ITB-2 HSS Calculation Results

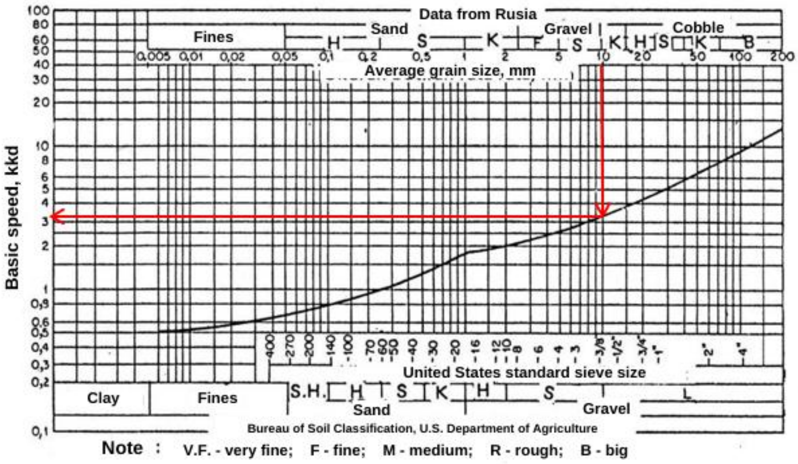

Figure 3 Fortier-Scobey Critical Speed Determination

Table 1 Table 1 Frequency Analysis Calculation Result

Return Period	Normal (mm)	Log Normal (mm)	Gumbel (mm)	Pearson (mm)	Log Pearson (mm)
2	95.4	94.3	93.2	94.3	94.3
5	108.0	107.5	109.2	107.6	107.6
10	114.6	115.2	119.8	115.5	115.5
25	121.0	123.2	133.1	124.3	124.3
50	126.1	129.9	143.0	130.4	130.4
100	130.3	135.7	152.9	136.2	136.2
200	134.0	141.1	162.7	141.7	141.7
1000	141.7	152.9	185.4	153.8	153.8

Table 2 Table 2 Effective Rain and Rain Distribution Log Pearson III

Return Period (year)	Effective Rain (mm)	Rain Distribution Ratio (%)					
		55	15	11	7	7	5
		Distribution of Rainfall (mm)					
2	28.1	15.5	4.2	3.1	2.0	2.0	1.4
5	32.1	17.6	4.8	3.5	2.2	2.2	1.6
10	34.4	18.9	5.2	3.8	2.4	2.4	1.7
25	37.0	20.4	5.6	4.1	2.6	2.6	1.9
50	38.9	21.4	5.8	4.3	2.7	2.7	1.9
100	40.6	22.3	6.1	4.5	2.8	2.8	2.0
200	42.2	23.2	6.3	4.6	3.0	3.0	2.1
1000	45.8	25.2	6.9	5.0	3.2	3.2	2.3

5 Conclusion

- The result of synthetic HSS in the Wanggar watershed that is closest to Creager's Q200 is HSS ITB-2. Therefore, HSS ITB-2 was chosen as the flood discharge. These results indicate that the flood discharge is 1504 m3/s, 1716 m3/s, 1840 m3/s, 1981 m^3/s, 2078 m3/s, 2169 m3/s and 2256 m3/s for the rain return period 2, 5, 10, 25, 50, 100 and 200 years (Figure 2).

- Based on the Fortier & Scobey chart, the Wanggar River is estimated to have a flow velocity above 3.1 kkd or 0.93 m/s which will result in erosion of the channel bottom.

- The average temperature at the Wanggar is 27^0C, the average slope of the river is 0.002 and the viscosity is 1.3 x 10^{-6}indicating the critical stress value of the Wanggar River is 9.49 N/m^2.

References

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