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Analysis of Peak Flood Discharge in Small-Scale River Flow Area (Case Study in the Akelaka Watershed)

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ABSTRACT

Purpose: Flood discharge is a critical component in reducing the impact of flooding in a given location. An analytical technique based on a watershed's morphometric properties is a method for those without a gauge, particularly in small-scale watersheds.

Design/methodology/approach: The synthetic unit hydrograph (HSS) approach is used in this study to analyze flood output. This study was conducted in the Akelaka watershed, a sub-watershed of Tayawi. This analysis relies on spatial and attributes data. A spatial study of watershed morphometric properties was obtained by integrating digital elevation model (DEM) data into geographic information system-based applications (GIS). Meanwhile, using rainfall data from 2019 to 2021, a statistical approach is used to calculate the design rainfall intensity, which is then used as an input variable in the HSS analysis.

Findings: The findings of hydrographic analysis using Nakayasu HSS demonstrate that the peak flood time (Tp) is 2.8 hours with a maximum flood discharge (Qp) of 56.636 m3/s, 76, 987 m3/s, 88,091 m3/s, and 101,279 m3/s for return periods of two years, five years, ten years, and 25 years.

Paper type: Research paper

Keyword: *Akelaka, Flood Discharge, Small Watershed, Synthetic Unit Hydrograph*

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I. INTRODUCTION

A watershed is an area bordered by ridges of hills where water that falls in the area is routed to bodies of water via a network of rivers (Asdak, 2002). The amount of runoff that occurs is strongly influenced by several factors, including 1) meteorological factors such as precipitation intensity, duration, and distribution, temperature, humidity, solar radiation, wind speed, and air pressure; 2) watershed factors such as shape, slope, geology, soil type, vegetation, and drainage network; and 3) human factors in the watershed system (Seyhan, 1990). Thus, human activities in a watershed's ecosystem significantly impact the volume of the surface runoff contribution that causes floods in the watershed's lowlands.

The watershed comprises numerous sub-watersheds that feed into the main river system. Natural resource management must begin at the sub-watershed size as the starting point for all hydrological processes (V.V., 1993). As a result, the sub-watershed plays an essential role in a watershed's hydrological properties. Differences in genetic features that make up each sub-watershed will affect the runoff volume. As a result, attempts to manage a watershed must begin with the sub-watershed, particularly the most critical (Karale et al., 1977).

Rainfall has increased in intensity and amplitude due to global climate change (Rejekiningrum, 2014). Furthermore, land conversion due to population growth is a component that contributes to an increase in surface runoff in a given area. It causes diverse hydrometeorological disasters in different places, such as floods and

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landslides. According to BNPB data, flood occurrences will continue to dominate natural catastrophe events in Indonesia in 2022, accounting for 42.82% of all events. As a result, understanding hydrological behavior, particularly runoff discharge in a watershed, becomes essential as a foundation for flood management to mitigate the impact.

The Akelaka watershed is a sub-watershed of the Tayawi watershed, which is administratively located in Tidore Islands City's South Oba District (Figure 1). The floods in South Oba District in 2017 from April to December caused significant material damage. As seen in Figure 1, it inundated 1,243 dwellings in Koli Village, Kosa Village, Trans SP I Area, Trans SP 2 Area, and the Kahoho Irrigation Area, spanning an area of 650 acres. The inundation height caused by the Akelaka river overflow ranged between 0.4 m and 0.7 m, as indicated in Figure 2. Flood difficulties in the Akelaka Watershed are caused by a combination of factors, including high rainfall intensity, morphometric conditions of the watershed and river, and changes in land use owing to illegal logging.

The analysis of flood discharge in a watershed will provide critical information for flood control. However, a recurring issue is the scarcity of flood monitoring stations, particularly in small-scale watersheds. As a result, several ways of dividing the watershed or transferring data are used to estimate the building of flood and peak flow hydrographs. Approaching the morphometric properties of the watershed is one strategy for obtaining flood discharge hydrographs in locations lacking gauges. This technique is also known as a synthetic unit hydrograph (HSS).

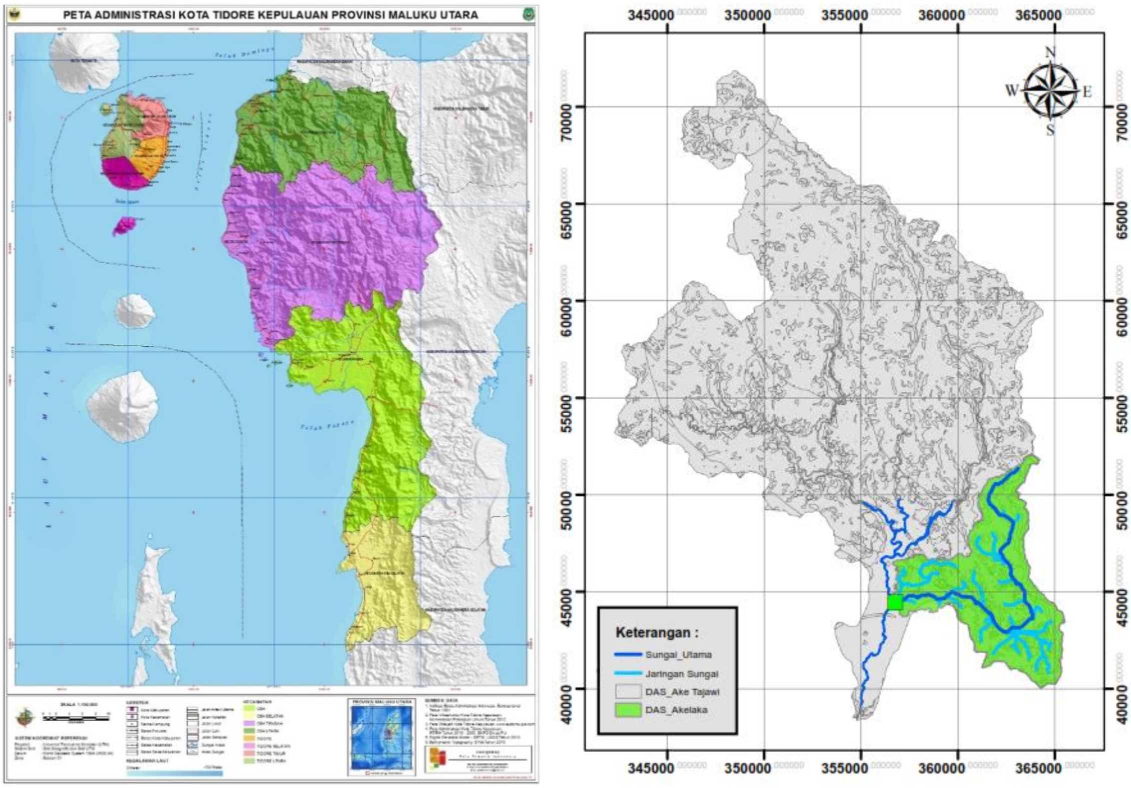

Figure 1. Location of the Akelaka sub-watershed

This study aims to look at the peak flood flow in small-scale watersheds, especially those that don't have hydrological observation stations. This study looks at synthetic unit hydrographs using a watershed morphological approach (HSS). Sub-watershed parameters can be found by putting digital elevation model (DEM) data into geographic information system tools.

II. METHODS

This research is a quantitative study of the Akelaka sub-watershed in North Maluku Province, specifically in the Tidore Islands Regency. The location is chosen based on the frequency of flood events in that area. It is

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undeniable that the Akelaka sub-watershed has experienced land degradation due to changes in land use caused by illicit logging.

DAS morphometric parameters for analyzing hydrology characteristics are obtained by analyzing DEM data from the DEMNAS site. A GIS-based application is used for the delineation and measurement of morphometric parameters.

In this study, hydrological analysis refers to the analysis steps proposed by Triatmodjo (2008). It begins with examining the rainfall distribution utilizing the normal distribution model, normal log, Gumbel, and Pearson type III log. The statistical requirements are met by testing the basic parameters and the suitability of the data for the distribution model using the Chi-Square Test and the Smirnov Kolmogorov Test. Because the available data is simply the maximum daily rainfall (mm/24 hours) in one year of observation, rainfall intensity is computed using the Mononobe equation (Suripin, 2004).

The Nakayasu synthetic hydrograph (HSS Nakayasu) model was used to perform the synthetic hydrograph approach to the design flood discharge analysis. According to Safarina et al. (2011), the Nakayasu approach has a 22% error deviation for the shape of the hydrograph and a 9% error rate for peak flooding. These numbers are the lowest compared to other approaches, such as GAMA 1, Limantara, or Snyder. It was also stated that the Nakayasu approach has an advantage over the Snyder method in that it reveals the time of concentration for peak flooding, which is better under the watershed circumstances in his study (Sarminingsih, 2018).

III. RESULTS AND DISCUSSIONS

A. Morphometric characteristics of the Akelaka sub-watershed

A geographical model can be used to interpret the hydrological properties of a watershed (Loebis, 1993). The spatial analysis findings were acquired by delineating and measuring the morphometric parameters of the Akelaka watershed using the ArcGIS tool, as shown in Figure 2.

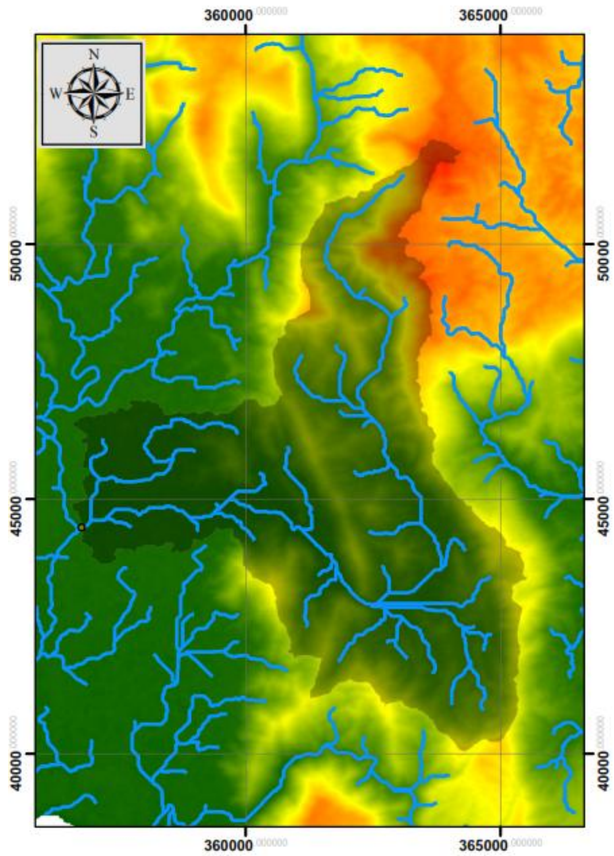

Figure 2. Results of Akelaka Sub-watershed Delineation

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The interpretation of the morphometric parameters is the first step to explaining an area's hydrological features. The results of the spatial analysis of the hydrological parameters of the Akelaka watershed are explained as follows:

a. The length of the main river (L) of the Akelaka river is 19,951 km;
b. The area of the Akelaka sub-watershed is 45.72 km^2;
c. The river flows in a dendritic pattern, which shows that the rocks in the Akelaka sub-watershed don't let water through. The fact that the tributaries can be seen shows that the rock is not easily broken down;
d. The letter U-shaped sub-watershed shows that the flood flow will be smaller and last longer;
e. Figure 3 shows that the order of the Akelaka river is 4, and the river branching index is 4.68. This number is between 3 and 5. It means that the flood water level rises and falls at a rate that is neither too fast nor too slow;
f. The river network density index (Dd) is 1.25 km/km^2, with values ranging from 0.25 to 10 km/km2. It indicates that the Akelaka sub-watershed has a medium density, implying that runoff will be greater.

The Akelaka watershed slopes (Figure 4) are often placed at intervals of 10% - 30%, classified as hilly areas, with an area of 25.34 km2 or up to 55%. Table 1 depicts an overall description of the slope of the Akelaka watershed.

Table 1. Slope class of Akelaka sub-watershed

No	*Slope Class*	*Area (km2)*	*Percentage*
1	*Flat Slops (0 %- 5%)*	*11.775*	*26%*
2	*Wavy (5% - 10%)*	*3.691*	*8%*
3	*Hilly (10% -30%)*	*25.342*	*55%*
4	*Steep (> 30%)*	*4.971*	*11%*

g. According to BP DAS North Maluku mapping (Figure 5), the Akelaka sub-watershed is 82% dominated by secondary dryland forest, covering an area of 37,386 km2. As illustrated in Table 2, the remainder consists of scrub forests, mixed agricultural land, rice fields, and transmigration residential areas.

Table 2. Types of Akelaka Watershed Land Cover

No	*Types of Land Cover*	*Area (km2)*	*Percentage*
1	*Thicket*	*0.723*	*2%*
2	*Secondary Dryland Forest*	*37.386*	*82%*
3	*Mixed Dryland Agriculture*	*6.375*	*14%*
4	*Ricefield*	*0.686*	*1%*
5	*Transmigration Settlements*	*0.609*	*1%*

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h. Using the Cook equation, researchers can determine the runoff coefficient (C) of the Akelaka sub-watershed by considering the land cover and slope. The C value for the whole Akelaka sub-watershed was found to be 0.31.

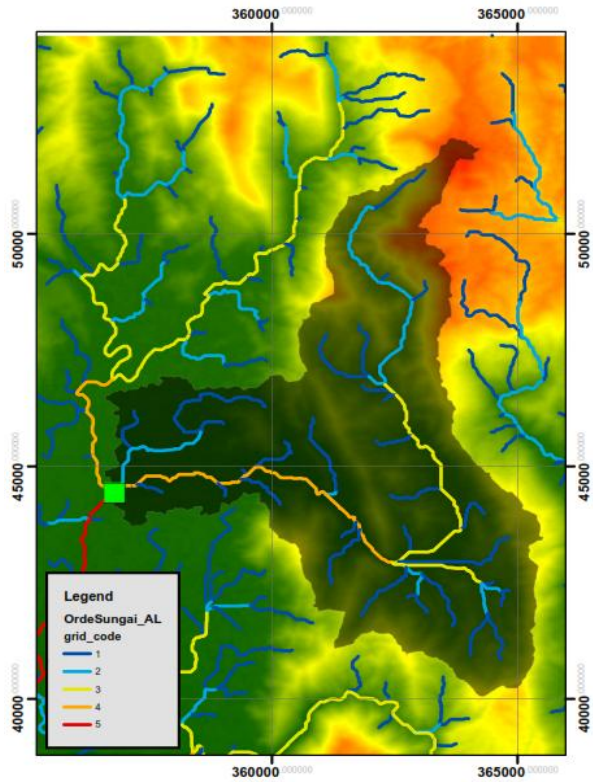

Figure 3. The Akelaka River Order System

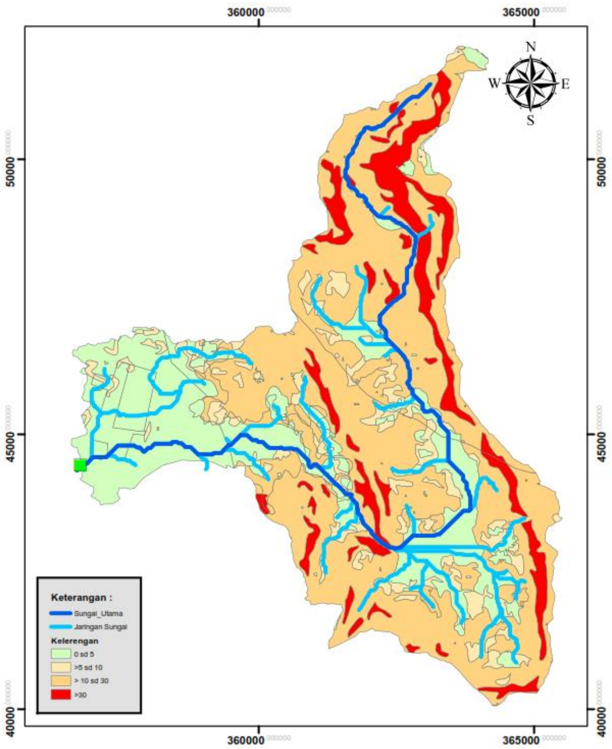

Figure 4. Akelaka watershed sub-basin slope class

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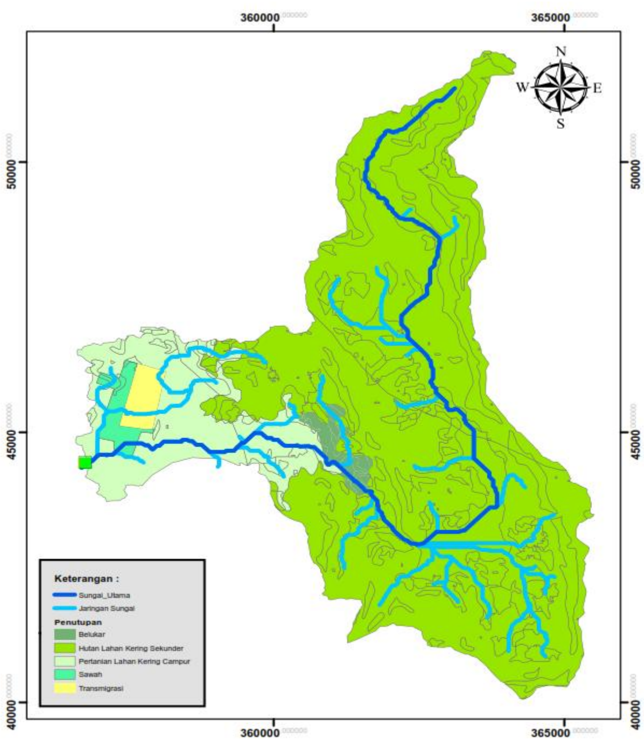

Figure 5. Akelaka Watershed Land Cover Map

B. Distribution of Rainfall in the Akelaka sub-watershed

The annual maximum daily rainfall series data from 2009 to 2021 will be used to analyze the Rain. Figure 6 shows how Thiessen's polygon analysis results can be used to determine which PCH stations are the source of rainfall data. This figure shows how the PCH Tayawi and PCH Kobe stations can be used to get an idea of how much Rain falls in the Akelaka sub-watershed.

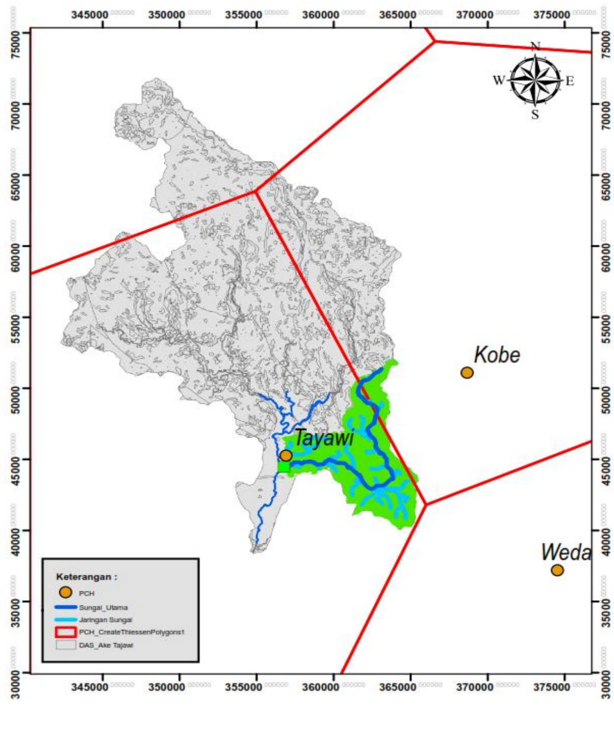

Figure 6. Thiessen polygon analysis results for rainfall stations.

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Table 3. Daily Maximum Rainfall Data

Year	Rain Station		Algebraic Average
	Kobe	Tayawi	
2009	80	-	80.00
2010	75	-	75.00
2011	119.5	-	119.50
2012	68	-	68.00
2013	68.5	-	68.50
2014	43.3	-	43.30
2015	87	-	87.00
2016	60	-	60.00
2017	60.7	149	104.85
2018	53.3	79	66.15
2019	60.7	141	100.85
2020	113	133	123.00
2021	139.5	140	139.75

Table 4 shows the results of the analysis of the distribution of rainfall using the Normal Distribution, Normal Log, Gumbel, and Pearson III Log models of rainfall distribution. The statistical parameter test results show that the Log Pearson III distribution model is good enough to be used.

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Table 4. Result of rainfall distribution

T	Flood Discharge (m3/second)			
	Normal	Log-Normal	Gumbel	Log Pearson III
2	101.59	100.33	91.73	97.34
5	116.46	114.92	107.89	113.05
10	124.25	123.38	118.59	124.58
25	131.83	132.21	132.11	140.31

The distribution fit test using the Chi-Square and Smirnov-Kolmogorov tests showed that the Pearson III Log Distribution Model met the statistical requirements. In contrast, for the Chi-Square Test, the calculated Chi value was 2.00. This value is smaller than the Chi Critical value for DK = 2 at a degree of confidence (α = 5%) of 5,991. Meanwhile, based on the Smirnov-Kolmogorov method, Δmax Smirnov – Kolmogorov for the amount of data (n) of 13 will obtain an α value of 0.368. The results of the calculation of Δcr obtained a value of 0.155. The results of the two tests show that the chi count and Δmax are still smaller than the specified conditions. Thus the results of the distribution analysis:

1. Effective Rainfall Akelaka sub-watershed

The examination of rainfall intensity yields effective rainfall in the Akelaka sub-watershed. The Mononobe equation was used to analyze rainfall intensity in this study, and the relationship between rainfall intensity, duration, and frequency is illustrated in Figure 7.

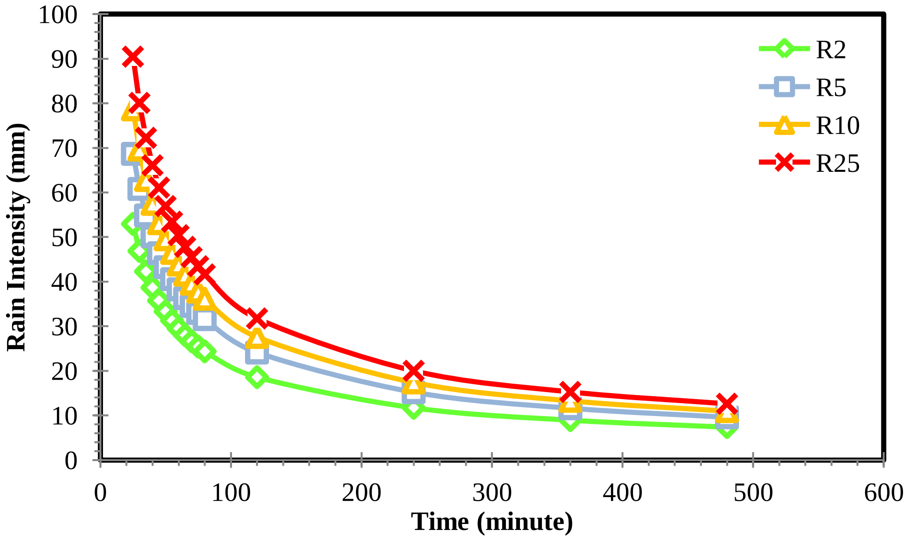

Figure 7. IDF curve of the Akelaka sub-watershed

Estimating the peak flood discharge requires knowing how long the Rain will last. In general, the duration of Rain must be at least equal to the concentration time when determining peak flood discharge (Mays, 2001). It is also reported that the rain duration is measured in multiples of three or six hours. The average length of rainfall in Indonesia is 6 hours. As indicated in Table 5.7, rainfall in the Akelaka sub-watershed is distributed for 6 hours using the Mononobe Formula.

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Table 5. Planned rainfall with a duration of 6 hours.

Effective Rain (jam)		*1*	*2*	*3*	*4*	*5*	*6*
R2 (mm)	*80.91*	*44.53*	*11.57*	*8.12*	*6.46*	*5.46*	*4.77*
R5 (mm)	*110.25*	*60.67*	*15.77*	*11.06*	*8.81*	*7.44*	*6.50*
R10 (mm)	*126.25*	*69.48*	*18.06*	*12.67*	*10.08*	*8.52*	*7.44*
R25 (mm)	*145.26*	*79.94*	*20.78*	*14.58*	*11.60*	*9.80*	*8.56*

2. Repeated flood discharges in the Akelaka sub-watershed

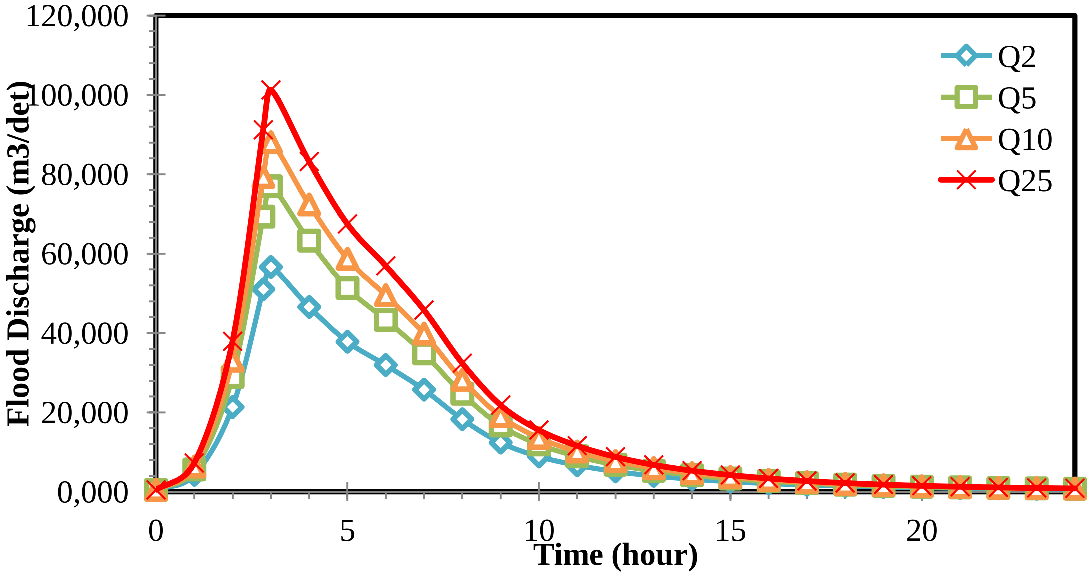

Figure 8. Hydrograph of the Akelaka river flow

The Nakayasu synthetic hydrograph shows that the peak flood discharge (Qp) with a rainfall duration of 6 hours for return periods of 2, 5, 10, and 25 years is 56.636 m3 /sec; 76, 987 m3/s; 88,091 m3/s; and 101,279 m3/s, respectively. These values were derived from the Akelaka Watershed morphometric calculations and hydrological analysis. Meanwhile, there were only 2.8 hours before the flood's peak.

IV. CONCLUSION

The Nakayasu HSS data showed that the highest flood discharge (Qp) for return periods of 2 years, five years, ten years, and 25 years was 56.636 m^3/s, followed by 76.987 m^3/s, 88.091 m^3/s, and 101,279 m^3/s. The peak flood time (Tp) for the Akelaka sub-watershed was 2.8 hours.

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