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A Study on Design-Flood Discharge of Tello River in Makassar-Indonesia

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Abstract-This paper attempts to evaluate the design-flood discharge of Tello River, a vital river in Makassar City, South Sulawesi, Indonesia, because in recent years the river has flooded Tamalanrea Sub-District of the city. The condition of the Tello River could no longer accommodate the volume of water discharge and sediment transport due to the influence of the upstream river flow. Therefore, this study attempts to conduct an analysis of the design- flood discharge on Tello River in the city; to find out the expected ratio between the design-flood discharge prior to the flood discharge analysis and after the design flood discharge analysis. For this purpose, the study uses the Nakayasu method, which is a synthetic unit hydrograph method. The study also re-analyzes the design-flood discharge plan for the river using the Gamma I method. The analysis results showed that the magnitude of the flood discharge obtained by using the Nakayasu method was smaller than the existing calculations using Gamma I method. The 2-year return period calculated by using the Nakayasu method was 301.658 mm^3, while the results of the Gamma I method was 790.078 mm^3. This great difference strongly influences the planning, both in terms of costal and technical terms. The study results are expected to be utilized in the calculation of the further plan to improve the water management system around the river, particularly in controlling the flood discharge on Tello River.

Keywords- *design flood discharge, Nakayasu method, Gamma I method, Tello River*

I. INTRODUCTION

Recently, in Makassar City, South Sulawesi, Indonesia, more specifically in the Sub-District of Tamalanrea, floods have occurred almost every year. In that district, there flows the main river of the city, called Tello River. Tello River has a total area of 627.8 km2 and a total length of 76.73 km. The river has some facilities such Tello River Drainage Area (RDA) and irrigated rice fields covering 12,700 ha of which the main water source is Tello River. The condition of Tello River could no longer accommodate the volume of water discharge and sediment transport due to the influence of river flow from upstream.

Therefore, there should be various ways to control floods, such as the flood discharge arrangements, normalization of the river, embankment constructions, and so forth. The flood discharge rate should be used in planning the building of water which is an important figure, called the design-flood discharge.

In the field of the design-flood discharge analysis, the hydrograph analysis is a method used to estimate the river flow in gauge and un-gauge watershed. This method simulates the rainfall to become a runoff in a rainfall runoff model. However, there are many various methods of this approach.

The first old generation of the rainfall-runoff model used the empirical equations developed from a region to some other regions, before it was developed using a rational method which was used to predict the peak discharge [1]. In 1932, Sherman as in Chow [2] found the unit hydrograph method as the first method in determining the peak discharge [3]. Then, Snyder (1938) and Gray (1961) gave some hydrograph characteristics such peak discharge, peak time and time base as extension of the synthetic unit hydrograph research, as well as the additional characteristic of the watershed reservoirs which was proposed by Clark (1943) [2]. In addition, Nakayasu (1940) promoted a synthetic unit hydrograph based on rivers in Japan. This method has widely been used recently and known as a Nakayasu synthetic unit hydrograph or Nakayasu method [4]. The Soil Conservation Service (SCS) also produced a dimensionless synthetic unit hydrograph in 1972 [5]. However, Woodward et al (1980) as in Solanki [5] corrected the SCS synthetic unit hydrograph with the proposed value of C = 284 for a named Delmarva peninsula. In a side, the University of Florida (1986) proposed the C's value from 75 to 100 for a flat watershed. For Indonesia condition, Harto [6] presented four basic properties of synthetic unit hydrograph, i.e. time of rise (TR), peak discharge (QP), time base (TB) and storage coefficient (K). He called the synthetic unit hydrograph as Gama-1 synthetic unit hydrograph method, and met that the rivers in Java Island followed the straight line rising curve and exponential recession curve. Usul and Kupçu obtained the unit hydrograph of Kumdere watershed, Turkey, with SCS unit hydrograph. The watershed parameters such as area, the length of the main rivers, the length of the central watershed to the outlet, and the slope of the watershed were obtained using the geographic information systems (GIS) [7].

Furthermore, Clark developed an instantaneous unit hydrograph (IUH) with the route technique [8]. The technique consists of two stages, firstly, to determine the IUH of the observed rainfall and runoff data, and secondly, to convert the IUH to the unit hydrograph. Next, Gupta [9] developed the IUH into the more detailed data collection for watershed geomorphology which is called as Geomorphology Instantaneous Unit Hydrograph (GIUH). The GIUH parameters, such as the channel parameters, area, shape of the watershed, etc. are currently developed with GIS as Noorbakhsh et al [10].

The latest method in analyzing synthetic unit hydrograph that was developed by some researchers such as Francisco Olivera and David Maidment R [11], M Hubail Ajward and I Muzik [12] was the spatially distributed unit hydrograph (SDUH). In this method, rhe digital elevation model (DEM) was used in the contours map of watershed and made the cells for the flow lines, the flow direction, the flow length and the slope. The SDUH method with the distributed rainfall-runoff model requires the computer equipment with a high specification [13]. The application of the method also required a topographic map which has been integrated with GIS. Due to the constraints, this method and its variant are difficult to be applied in developing countries, such as Indonesia.

However, simpler existing synthetic unit hydrograph methods, such as Snyder, SCS, Nakayasu, and Gama I methods in their application for a un-gauge watershed often lead to the variation of the peak discharge, peak time, time base and the shape of hydrograph unit. This difference provides a considerable impact in the determination of peak discharge to be used.

As for the contribution to solution of the issue of the design- flood discharge of Tello River in Makassar City, and also for the consideration of the restriction and easiness of some synthetic unit hydrograph methods, therefore, this study attempts to analyze the design-flood discharge on Tello river in the city, and to find out the ratio between the expected design-flood discharge prior to the flood discharge analysis and the obtained design-flood discharge after the flood discharge analysis.

In this regards, the study uses the Nakayasu method, a synthetic unit hydrograph method. The study is also a re-analysis of the design-flood discharge planning for the river using the Gamma I method.

The remainder of this paper is composed as follows: the next chapter presents the Synthetic Unit Hydrograph methods which were used in this study. Then, Chapter 3 demonstrates the results of the analysis using the methods. The final chapter provides the conclusion and the discussion related to the key findings.

II. THE SYNTHETIC UNIT HYDROGRAPH METHODS

A. Nakayasu Synthetic Unit Hydrograph

Nakayasu has provided a synthetic unit hydrograph based on his research on rivers in Japan [4] as shown in Fig. 1. There are four variables have to be obtained, i.e. time lag (T_p), peak discharge (Q_p), rising limb curve (Q_a), and decreasing limb curve (Q_d). Each variable will be explained as follows.

Discharge (Q_p), rising limb curve (Q_a), and decreasing limb discharge (Q_p), rising limb curve (Q_a), decreasing limb curve (Q_d). Each variable will be explained as follows: time lag (T_p) is the function of the time of concentration (t_g) and the duration of the effective rainfall (t_r). Nakayasu provided the equation of T_p as follows [4]:

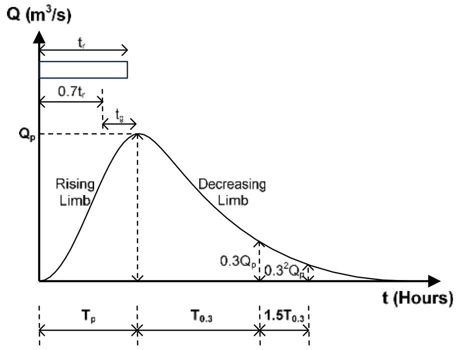

Figure 1. Nakayasu Synthetic Unit Hydrograph

$$T_p = t_g + 0.8t \quad (1)$$

Peak discharge (Q_p) is determined by some factors such as watershed area (A), watershed characteristic coefficient (C), unit rainfall (R_o), tame lag (T_p) and time required to discharge reduction up to 30% peak discharge ($T_{0.3}$). The relationship among the variables is shown as follows [4]:

$$Q_P = \frac{CAR_0}{3.6(0.3T_P + T_{0.3})} \quad (2)$$

The rising limb curve (Q_a) is the function of time lag (T_p), peak discharge (Q_p), and time (t). The function of Q_a is expressed as follows [4]:

$$Q_a = Q_P\left(\frac{t}{T_P}\right)^{2.4} \quad (3)$$

The decreasing limb curve (Q_d) is influenced by time lag (T_p) peak discharge (Q_p), time (t), and time required to discharge reduction up to 30% of the peak discharge ($T_{0.3}$). Its function is follows [4]:

$$Q_d > 0.3Q \qquad Q_d = Q_p 0.3^{\frac{t-T_p}{0.3}} \quad (4)$$

$$0.3Q_p > Q_d > 0.3^2\ Q_p \qquad Q_d = Q_p 0.3^{\frac{t-T_p+0.5T_{0.3}}{1.5T_{0.3}}} \quad (5)$$

$$0.3^2 Q_p > Q_d \qquad Q_d = Q_p 0.3^{\frac{t-T_p+1.5T_{0.3}}{2T_{0.3}}} \tag{6}$$

B. Gama-1 Synthetic Unit Hydrograph

Gama-1 method presented the synthetic unit hydrograph from the results of 30 researches on watersheds in Java Island [14] as shown in Fig.2. The figure shows several important factors which greatly affect the unit hydrograph of a watershed. These factors involve the source factor, the source frequency, the width factor, the upstream catchment area, the symmetric factor, and the number of junctions.

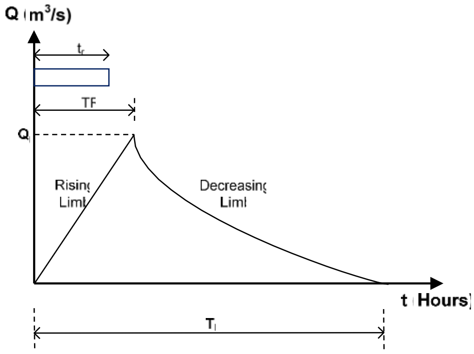

Figure 2. Gama-1 Synthetic Unit Hydrograph

The definitions of those factors are provided as follows. The source factor (SF) is the sum of the lengths of all river order compared with the sum of the lengths of the river all order. The source frequency (SN) is the number of the first order of the river compared to all order of the river. The width factor (WF) is the ratio of the watershed width at the 0.75 river length to the watershed width at the point 0.25 length. The upstream catchment area, (Rua), which is the relative width of the watershed in upstream line drawn through a point on the river closest to the centroid of the watershed, perpendicular to the line connecting these points with the outlet. The symmetric factor (SIM) is the product of the width factor (WF) and watershed area upstream (Rua). The number of junctions (JN) is the total number of river crossing point in the watershed.

As Nakayasu method, the Gamma-1 method also describes the synthetic unit hydrograph using the time lag (TR), the peak discharge (Qp), the decreasing curve (Qt). However, this method added two different parameters, i.e. the time base (TB) and the storage capacity (K). These variables will be explained in the following paragraphs.

Time lag (TR) is the function of SF and SIM as the following equation [14]:

$$TR = 0.43\left(\frac{L}{100SF}\right)^3 + 1.0665\,SIM + 1.2775 \tag{7}$$

Peak discharge (Qp) is the function of watershed area (A), JN and TR, as the following equation [14]:

$$Q = 0.1836\, A^{0.5886}\, JN^{0.2381}\, TR^{-0.4008} \tag{8}$$

Decreasing curve (Q_t) is the function of peak discharge (Q_p), time (t) and storage capacity (K) as the following equation [14]:

$$Q_t = Q_p e^{-t/K} \tag{9}$$

Time base (TB) is the function of TR, slope (S), SN and RUA as the following equation [14]:

$$TB = 27.4132\, TR^{0.1457}\, S^{-0.0986}\, SN^{0.7344}\, RUA^{0.2574} \tag{10}$$

Storage capacity (*K*) is the function of the watershed area (*A*), the slope (*S*), *SF* and the drainage density (*D*) as the following equation [14]:

$$K = 0.5617\, A^{0.1798}\, S^{-0.1446}\, SF^{-1.0897}\, D^{0.0452} \tag{11}$$

III. THE ANALYSIS RESULTS

A. The Rain-Gauge Data

In this study, the rainfall data were collected from three rainfall monitoring stations located in Tello watershed, i.e. Panaikang Station, Antang Station, and Batu Bassi Station. The rainfall data were used in analyzing the design rainfall, and the reference parameter was used in determining the flood discharge. The rainfall analysis is conducted to evaluate the distribution pattern of events during the observation years, so that the amount of rainfall distribution for each return period can be determined. In this case, the Log Pearson Type III method with the return periods of 2, 5, 10, 20, 50, and 100 years was used. The rainfall data are presented in maximum daily rainfall as shown in Fig.3.

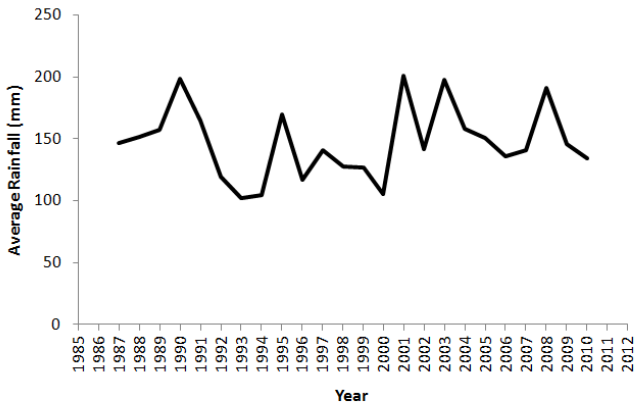

Figure 3. The Average of Maximum Daily Rain Precipitation of the Tello Rivers

B. The Rainfall Region Analysis

The annual average rainfall data were calculated using the Thiyssen Polygonal method. Table 1 shows the calculation results i.e., the ratio of influence area of the Tello rainfall station.

The coefficient ratios in Table 1 are used to calculate the maximum average rainfall in each station region. Then, the highest annually rainfall was selected in obtaining the maximum rainfall in the Tello watershed.

TABLE I. RATIO OF INFLUENCE AREA OF TELLO RAINFALL STATION

The Rainfall Station	Region Area (km^2)	Coefficient
Panaikang	86.52	0.312
Antang	128.50	0.464
Batu Bassi	61.94	0.224
Total	276.96	1.000

C. *The Rainfall Frequency Analysis*

In this step, the first analysis is the selection of the rainfall distribution. This study considers four type distributions in order to fit the rainfall frequency data for 24 years, as shown in Table 2.

TABLE II. SELECTION OF THE RAINFALL DISTRIBUTION

Distribution Type	Requirement	Parameters	Test Result
Normal Log	Cs >= 0.0 Ck >= 3.0	0.417 2.880	Reject
Normal	Cs (Ln X) >= 0.0 Ck(Ln X) >= 3.0	0.012 2.786	Reject
Gumbel	Cs >= 1.14 Ck >= 5.4	0.417 2.880	Reject
Log Pearson Type III	If the others are rejected		Accepted

Table 2 also provides the analysis results of the statistical parameters such as the average, the standard deviation, the asymmetry coefficient (Cs), and the coefficient of kurtosis (Ck), for the four distribution types. The table shows that only the distribution of Log Pearson Type III method that meets Tello River design flood discharge. In the next analysis, this study uses the distribution type.

D. *The Design Flood Discharge Analysis*

In the design flood discharge analysis, firstly the study calculated the hourly average rain until the *t* time (R_t) as shown in Fig.4. Then, the obtained data on Automatic Water Level Recorder (AWLR), i.e. the water level (H) which was recorded daily, in relation to the discharge data; the technique used to collect the data was a random collection. The relationship that was represented in each year was sorted from the smaller up to the greater. Fig.5 provides the AWLR debit of Tello River in relation to its water level. The water level data were then converted to the discharge using discharge curve (rating curve) and the basic data were used for planning all the water building. In this regard, a good quality of discharge data was required.

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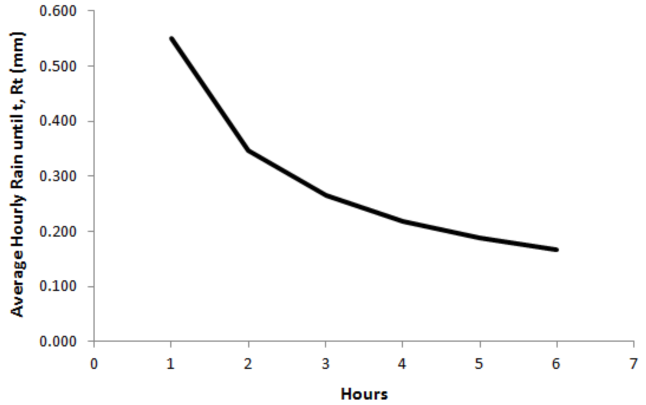

Figure 4. The Hourly Average Rain of Tello River

Based on the discharge curve on Fig. 5, the polynomial regression equation as a relationship between flood discharge (*Q*) and the water level (*H*) was obtained by using the statistical method. The result of the regression analysis is expressed in the following equation.

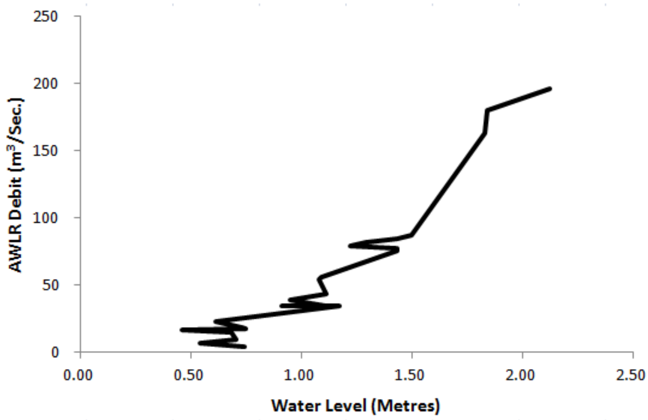

Figure 5. The AWLR Debit of Tello River

$$Q = 61.460\, H^2 - 34.965\, H + 11.107 \quad (12)$$

Then, the equation (12) is used in predicting Tello river flood discharge regarding the water level data from the rainfall stations for the return period 2, 5, l0, 20, 50 and 100 years. Regarding the parameter which was used in the rainfall discharge calculation, the design-flood discharge could be obtained by using the same data. In this regard, three design- flood discharges are produced, i.e. the design flood discharge based on AWLR data, the Nakayasu method, and the Gamma I method. The existing flood discharge planning for the river used the Gamma I method. The calculation results of the three design flood discharges are provided in Fig.6.

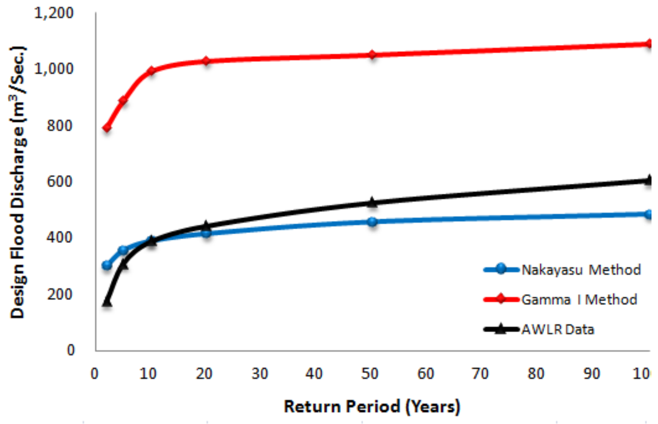

Figure 6. The Design-Flood Discharge of Tello River

Figure 6 shows that the calculation result of design-flood discharges produced by the Gamma I method revealed a big difference or dispute when compared with the design-flood discharge which was yielded by the Nakayasu method and the AWLR data. On the other hand, the design-flood discharges using the two latest methods were the most similar range. In this regard, the difference was caused by the difference between the rainfall station data and AWLR because the measurement was conducted manually when recording the rainfall data periodically. This method resulted in a so large discharge, that it influenced the coefficient of runoff and other influential parameters or factors when calculating the flood discharge.

The further reason is that the Nakayasu method assumed that the occurrence rainfall not only on the surface, but also on the infiltration occurrence. The Nakayasu method also calculated the amount of rain that infiltrated the ground, and the effective rainfall. Consequently, the great difference affected the states of the cost and resources.

IV. CONCLUSION AND DISCUSSION

The design flood discharge on Tello Basin in Makassar, South Sulawesi, Indonesia, has been analyzed in this study by using two methods of the synthetic unit hydrograph methods, i.e. the Nakayasu method, and the Gamma I method. The rainfall data of daily rain precipitation of the Tello Rivers were collected from the three rainfall stations at the Tello influenced area, i.e. Panaikang station; Antang station; and Batu Bassi station. Then, the design-flood discharge of Tello River was analyzed.

The design flood discharge resulted from the Nakayasu method was smaller than the result of the existing flood discharge planning using the Gamma I method. In addition, the Nakayasu's result is more fitted to the design flood discharge based AWLR data than the Gamma I's result.

Furthermore, the different results of the flood discharge using both methods were caused by the fact that the difference on the share of each sub-basin, and also the fact that the Nakayasu method used the approach from the upstream to downstream. The impact of the differences had led to a difference in the value affecting planning in terms of both the cost and the technical point. In this regard, the design-flood discharge should not use one or two methods alone, but should use several existing methods to produce more accurate results.

Briefly, in the design-flood discharge calculation, we should be aware to select the calculation methods which will produce the calculation results fitted to the observed results.

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