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Determining The Coefficient Of Tr, Α And River Length (L) Of Flood Runoff Model Using Synthetic Unit Hydrograph Nakayasu

(Case Study Bedadung Watershed Jember)

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ABSTRACT: *Usage of synthetic unit hydrograph Nakayasu for calculating of flood discharge, often result in different values with a significant deviation of a field recording flood discharge. This will affect the design of water building, river cross-sectional studies and other hydraulics study purposes. Significant deviation values due to the characteristics of each watershed are not the same, especially land use in most of the watershed is currently changing dramatically, thus greatly affect the runoff coefficient. The results of modeling runoff patterns using synthetic unit hydrograph Nakayasu in the watershed Bedadung district of Jember in this study were obtained value of Tr = 0.3 and α = 0.651 gives the reliability of 71%. By obtaining value of Tr and α more detail, and utilizing the distribution of land use or runoff factors, then investigated coefficient of river length (L). As a result the value of the coefficient L is 0.052 which have a level of reliability model of 87.44%.*
Key Words: *Nakayasu, river, flood, plan*

I. Background

For planning of hydraulic river and water building, required assessment of the flood discharge plan. Flood discharge plan can be calculated in various ways such as rational method and synthetic unit hydrograph method. Various synthetic unit hydrograph methods such as synthetic unit hydrograph Nakayasu, Snyder, and GAMA has been widely used in calculating flood discharge plan. Results of previous studies showed that the synthetic unit hydrograph Nakayasu more applicable to small watersheds that have charateristics of rapid drainage.

Usage of synthetic unit hydrograph Nakayasu for calculating of flood discharge, sometimes have result in different values with a significant deviation of a recorded flood discharge. This will affect the design of water building, river cross-sectional studies and other hydraulics study purposes. Significant deviation values is caused by the different of characteristics of each watershed, especially land use in most of the watershed is currently changing dramatically, thus greatly affect the runoff coefficient. Results of previous studies for the watershed in Jember region showed that the usage of synthetic unit hydrograph Nakayasu for determining of flood discharge plans, obtained the value of Tr ranged from 0.2 to 0.3, while the value of α ranges from 0.5 to 0.7 with a reliability level of 60-70%.

In order to obtain the value of Tr and α with a higher accuracy closer to the actual conditions, it's need to study more detail by utilizing the land use maps and measurement of rainfall and longer observation discharge. The study followed by calculating the runoff coefficient and land use to increase the reliability models.

The purpose of this study conducted in Watershed Bedadung Jember using Synthetic Unit Hydrograph Nakayasu, are: 1) Determine the model trends or patterns of the flood runoff 2) Knowing the factors that most influence the pattern occurrence of runoff floods in the region, 3) Obtain the coefficient of river length with a higher degree of reliability, that can be used as a reference in the calculation of flood discharge plan in the watershed around them.

II. Hydrology Concept

As we know that the characteristics of rain in several area will be very different from other regions, thus to be able to estimate the amount of rainfall in an area can only be done based on measurements of the amount of rainfall at certain times in the past (historical data) using a graduated rainfall at station / specific post.

These data were collected from rainfall observation station that affect on the study area. The average rainfall regions is calculated from the observational data at each station. It is used to calculate the maximum rainfall design. To calculate the maximum rainfall design used frequency analysis in accordance with the data obtained. To determine the validity of the analysis of the frequencies, it is necessary to test the suitability of the frequency distribution. To complete the missing rainfall data, estimation can be calculated using rainfall data from three sampling sites adjacent and or surround the observation that data are not complete. If the differences between the normal annual rains from the observation that incomplete data is less than 10% then estimation of missing data should be taken from the average count (Arithmatic Mean) of data points surrounding the observation, by the following equation:

$$r = \frac{r_A + r_B + r_C}{3} \qquad \text{...(1)}$$

If the dispute data between the normal annual rains and the observation, that the data are not complete, more than 10%, estimation is calculated by using the normal ratio method as follows:

$$r = \frac{1}{3}\left(\frac{R}{R_A} r_A + \frac{R}{R_B} r_B + \frac{R}{R_C} r_C \right) \qquad \text{..............................(2)}$$

where :

R = Average rainfall of the year in place of observations R with missing data

r_A, r_B, r_C = Rainfall observations at RA, RB, RC at the same time with rain observation r.

R_A, R_B, R_C = Average rainfall of the year on the site of observation A, B and C.

Synthetic Unit Hydrograph Nakayasu

Nakayasu from Japan, has been investigating the unit hydrograph in some rivers in Japan by creating a synthetic unit hydrograph formula from the results of his investigations. The formula is as follows:

$$Qp = \frac{CxAxRo}{3.6(0.3Tp + T_{0.3})} \qquad \text{...….(3)}$$

with :

Qp = flood peak flow rate (m^3/s)

C = runoff coefficient

R_0 = unit rain (mm)

Tp = time interval from the beginning of the rain until the flood's peak unit (hour)

T0.3 = the time required by a decrease of peak discharge up to 30% of peak discharge.

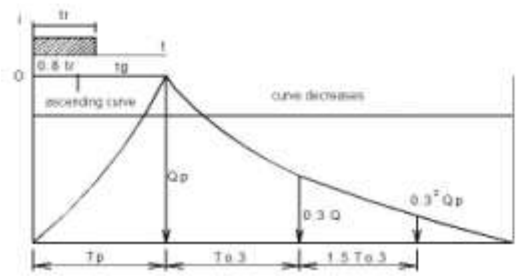

Figure 1: Increase and Decrease Curve at synthetic unit hydrograph Nakayasu Method

Arch rising hydrograph equation is as follows:

$$Qa = Qp\left(\frac{t}{T_p}\right)^{2.4} \qquad \text{……………………………………………(4)}$$

with :

Qa = runoff before reaching the peak flow rate (m^3/s)

t = time (hour)

While the arch down hydrograph equation is as follows:

$$Qd > 0.3\ Qp : Qd = Qp\ .\ 0{,}3^{\frac{i - T_p}{T_{0.3}}} \qquad \text{……………….(5)}$$

$$0{,}3\ Qp > Qd > 0.3\ Qp : Qd = Qp\ .\ 0{,}3^{\frac{t - T + 0.5T_{0.3}}{1.5T\,0.3}} \qquad \text{………...(6)}$$

$$0{,}32\ Qp > Qd : Qd = Qp\ .\ 0{,}3^{\frac{t\,T_p + 1.5T\,0.3}{2\,T\,0.3}} \qquad \text{……………….. (7)}$$

Time interval Tp= tg + 0,8 tr…………(8)

For

- L < 15 Km tg = 0,21 L0.7……..........(10)
- L > 15 Km tg = 0,4 + 0,058 L............(11)

L = The length of river flow (km)
tg = time of concentration (hour)
tr = 0.5 tg until tg
T 0.3 = α . tg……..………. (12)

The value of α is :

- Regional ordinary drainage α = 2
- The slow rise hydrograph and fast down section α = 1,5
- The rapid rise hydrograph and slow down section α = 3

III. Reliability Modeling

To determine how well a model can describe the actual events, it requires criteria of reliability models. The criteria used is the Nash criterion, that is (Subarkah Imam, 1980))

$$EF = \left[1 - \frac{\sum_{i=1}^{n} (Q_{hit,i} - Q_{obs,i})^2}{\sum_{i=1}^{n} (Q_{obs,i} - \overline{Q_i})^2} \right] \times 100\,\% \qquad \text{……………....………….(13)}$$

with :
EF = criteria of effectiveness or reliability of the model (%)
Q_{hit} = flow rate of the model (m^3/s)
Q_{obs} = flow rate based on observations (m^3/s)
$\overline{Q}$ = average flow observation (m^3/s)
i = period of observation (hour)

IV. Research Methods

At this stage, the following activities:

1. Collecting the secondary data and the results of previous studies, such as: daily rainfall, discharge data from the observation station AWLR taken from Mayang Bondoyudo Hall NRM, land use maps of bakosurtanal.
2. Rainfall data processing, including:
   a. Test data consistency
   b. Analysis of rainfall plans
3. Calculate the flood discharge plan with several return periode using synthetic unit hydrograph Nakayasu.
4. Perform calibration results of the calculation of flood discharge plan with synthetic unit hydrograph Nakayasu method of recording data from the field station to try AWLR variation coefficient of the river length, the output in the form of relative error value and the level of reliability of the model.
5. Then performed a ranking score based on the level of reliability of the results and the value of the relative error..

V. Analysis and Discussion

From measurement approach through a topographic map, scale 1: 25,000 gained widespread Bedadung Watershed is 499.5 km^2 with a length of 24.38 Km main river. Bedadung Watershed map presented in Figure 2.

Figure 2. Map of Bedadung watershed area (499.5 km^2) and Location of stations Rain

To calculate the mean of the maximum daily rainfall used Thiessen Polygon Method, because there are several stations spread evenly Bedadung Watershed. This method is giving specific weights for each rainfall station which is considered to represent rain in a region with a particular area which is a correction factor for rain at the station (Sri Harto, 1993: 55). The calculation equation of Nakayasu synthetic unit hydrograph:

- Curved Up (*rising limb*)

  For $0 < t < T_p$
  So the interval : $0 < t < 2.540$
  $Q_a = Q_p \left(\frac{t}{Tp}\right)^{2,4}$
  $= 24.346 \left(\frac{t}{2.540}\right)^{2,4}$

- Curved Down (*decreasing limb*)
  a. For $Tp < t < (T_p + T_{0,3})$

  So the interval : $2.540 < t < 7.477$
  $Q_{d1} = Q_p.0.3 \left(\frac{t-Tp}{T0.3}\right)$
  $= 24.346 \text{ x } 0,3 \left(\frac{t-2.540}{4.937}\right)$
  b. For $(T_p + T_{0.3}) < t < (T_p + T_{0.3} + (1.5 \text{ x } T_{0.3}))$
  So the interval: $7.477 < t < 14.8825$
  $Q_{d2} = Q_p . 0.3 \left(\frac{t-Tp+1,5\,T0,3}{1.5.T0.3}\right)$
  $= 24.346 \text{ x } 0.3 \left(\frac{t-0.07}{7.470}\right)$
  for $t > (T_p + T_{0.3} + (1.5 \text{ x } T_{0.3}))$
  so : $t > 14.8825$
  $Q_{d3} = Q_p. 0.3 \left(\frac{t-Tp+1.5\,T0.3}{2.T0.3}\right)$
  $= 24.346 \text{ x } 0.3 \left(\frac{t-4.868}{9.876}\right)$
  The calculation of the base flow (Harto,Sri, 1985 : 165) :
  $Q_b = 0.4751 . A^{0.6444}.D^{0.9340}$
  With : $D = L_N / A$
  $= 198.2 /\text{x } 499.5 = 0.397$
  Thus :
  $Q_B = 0.4751 \text{ x } 499.5^{0.6444} \text{x} 0.397^{0.9340} = 10.899 \text{ m}^3\text{s}^{-1}$

To determine how well a model can describe the actual events, it requires criteria of reliability models.

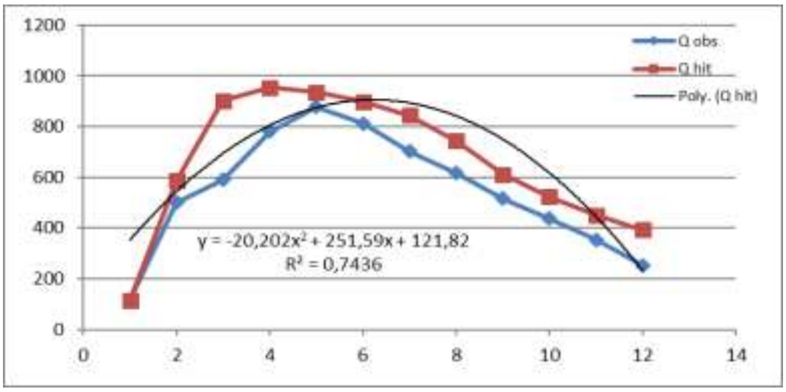

Figure 3. Ratio of Q observation dan Q count

Tabel 1. Debit Count and Debit Observation and Calculation Results Relative Error

T	Q Obs	Q Count	Relative Error
1	114.838	114.864	-0.023
2	500.552	586.851	-17.241
3	590.935	901.195	-52.503
4	780.817	954.183	-22.203
5	877.640	935.649	-6.610
6	812.282	897.614	-10.505
7	702.266	843.395	-17.095
8	617.273	742.534	-20.293
9	516.275	611.164	-18.380
10	437.149	522.553	-19.537
11	353.597	451.424	-27.666
12	252.246	393.196	-55.878
		Total	- 267.933
		Average	-22.328

Source : Calculation Result Based on the optimization results of Table 1 with an average error of 22.33% and correlation coefficient of 0.743 was obtained α coefficient is 0.651 and the coefficient of Tr is 0.3. However, the value obtained by the model only has a level of 71.491% reliability.
So taking consideration of the factor of river length (L) will be optimized to obtain the higher reliability level of the model.

From the analysis of the frequency, the value of the coefficient of skewness and the coefficient kurtosis are not eligible to Normal distribution, Log Normal and Gumbel, then the calculation of rainfall plans using methods Logs Pearson Type III. The results of the calculation of the design rainfall are presented in Table 2.

Table 2. Rainfall Calculation Plan

No.	Return Period (Years)	Cs	P	G	Si	Log Xt	Design Rainfall
1	10	-0.041	10%	1.287	0.080	2.010	102.329
2	20	-0.041	5%	2.080	0.080	2.073	118.304
3	50	-0.041	2%	2.106	0.080	2.075	118.850
4	100	-0.041	1%	2.356	0.080	2.095	124.451
5	200	-0.041	0.5%	2.614	0.080	2.116	130.617

Source : Calculation Result Pattern of centralized rainfall distribution in the study area showed an average of 6 hours per day (in Indonesia usually between 4-7 hours). To determine the distribution of an hourly rainfall for watershed Bedadung use Mononobe method.

Table 3. Distribution Calculation

Duration (Hour)	Ratio (%)	Hourly Rainfall				
		10	20	50	100	200
		71.6303	82.8182	83.195	87.1157	91.4319
1	55.0	39.397	45.547	45.757	47.914	50.287
2	14.4	10.315	11.925	11.980	12.545	13.166
3	10.1	7.235	8.364	8.403	8.799	9.235
4	7.7	5.515	6.376	6.406	6.708	7.040
5	6.8	4.871	5.631	5.657	5.924	6.217
6	6.2	4.441	5.134	5.158	5.401	5.669

Source : Calculation Result

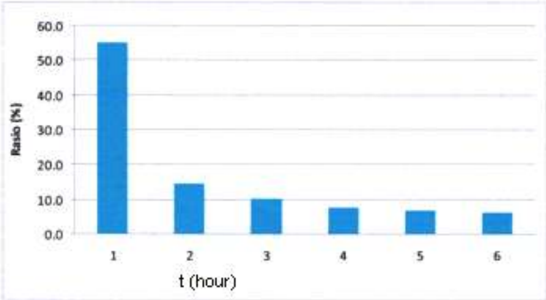

Figure 4. Hourly Rainfall Distribution with Mononobe Method

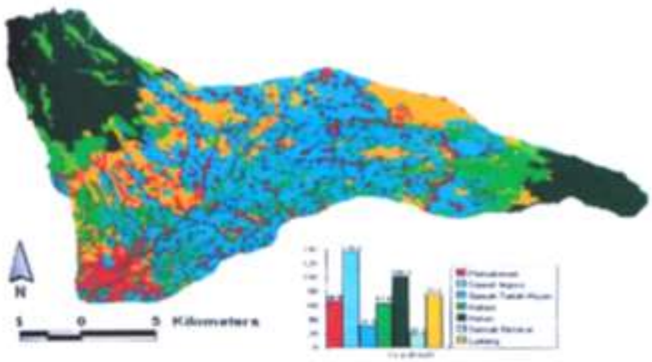

Figure 5. Map of Land Use at Bedadung Watershed

Nakayasu Method

Given technical data as follows:

- The area of watershed Bedadung = 499.5 Km^2
- The length of river channel = 24.38 Km
- Ro (unit rain $_{(mm)}$) $\longrightarrow$ generally 1 hour

Tried factor coefficient river 0.045

So : $T_g = 0.4 + 0.045\ L$ (L > 15 km)

$= 0.4 + 0.045\ L$

$= 1.497$ hour

$$\alpha = \frac{0.47(A.L)^{0.25}}{Tg}$$

$$= \frac{0.47(499.5x24.38)^{0.25}}{1.497}$$

$= 3.298$

The value of α based on the condition of the area is divided into 3 (Soemarto, 1987:169)

- α = 1.5 : for the slow part of the hydrograph rise and decline rapidly
- α = 2 : for regular drainage area
- α = 3 : for part of a quick rise and slow decline hydrograph

because the calculation of the value of α more than 3 means the flow pattern categorized by the part of the hydrograph rising fast and slow decline. Further used for the calculation of the parameter α on the calculation (α = 3.298)

$T_{0,3} = \alpha\ .\ T_g$

$= 3.298 \times 1.497$

$= 4.937$ hour

$T_r = 0.5\ T_g$

$= 0.5\ x1.497$

$= 0.749$ hour

$T_p = T_g + 0.8\ t_r$

$= 1.497 + (0.8 \times 0.749)$

$= 2.096$ hour

Value of C is obtained by searching for the mean value of the land use in accordance with the extent of land use as shown in Table 4.

Table 4. Hourly Rainfall Distribution Calculation

No	Types of Land Use	A (km^2)	C	C.A
1	Settlement	66.20	0.9	59.58
2	Non-irrigated rice field	32.10	0.4	12.84
3	Irrigated rice field	20.90	0.3	6.27
4	Farm	60.70	0.4	24.28
5	Forest	101.50	0.7	71.05
6	Bush	138.30	0.5	69.15
7	Field	79.80	0.5	39.90
	Total	499.50		287.07

The value of C is = C.A / Watershed Area
= 283.07 / 499.50
= 0.567

Q_p can be obtained by using the equation (3):

$$Q_p = \frac{C.AxRo}{3.6(0.3Tp + T0.3)}$$

$$= \frac{0.567 \ x\ 499.5\ x\ 1}{3.6(0.3x2.096+4.937)}$$

$= 14.134\ m^3 s^{-1} mm^{-1}$

Calculation of synthetic unit hydrograph Nakayasu equations

- Curved up (*rising limb*)

For $0 < t < T_p$

So the interval : $0 < t < 2.540$

$$Q_a = Q_p \left(\frac{t}{Tp}\right)^{2.4}$$

$$= 14.134 \left(\frac{t}{2.096}\right)^{2.4}$$

- Curved Down (*decreasing limb*)

c. Untuk $Tp < t < (T_p + T_{0.3})$

So the interval : $2.540 < t < 7.477$

$$Q_{d1} = Q_p.0.3 \left(\frac{t-Tp}{T0.3}\right)$$

$$= 14.134 \text{ x } 0.3 \left(\frac{t-2.096}{4.937}\right)$$

d. For $(T_p + T_{0.3}) < t < (T_p + T_{0.3} + (1.5 \text{ x } T_{0.3}))$

So the interval : $7.033 < t < 14.439$

$$Q_{d2} = Q_p \cdot 0.3 \left(\frac{t-Tp+1.5\ T0.3}{1.5xT0.3}\right)$$

$$= 14.134 \text{ x } 0.3 \left(\frac{t-5.309}{7.406}\right)$$

For $t > (T_p + T_{0.3} + (1.5 \text{ x } T_{0.3}))$

So : $t > 14.439$

$$Q_{d3} = Q_p.\ 0.3 \left(\frac{t-Tp+1.5\ T0.3}{2T0.3}\right)$$

$$= 14.439\text{x } 0.3 \left(\frac{t-5.309}{9.874}\right)$$

The calculation of the base flow (Harto,Sri,1985 : 165) :

$Q_b = 0.4751 \text{ x } A^{0.6444} \text{ x} D^{0.9340}$

with : $D = L_N / A$
= 198.2 /x 499.5 = 0.397

So :

$Q_B = 0.4751 \text{ x } 499.5^{0.6444} \text{ x } 0.397^{0.9340}$
$= 10.899\ m^3 s^{-1}$

To determine how well a model can describe the actual case, it is treated by reliability criteria of model which is developed. After optimization based on the equation 13, obtained 87.055% reliability of the model, and the relative error is 193.165%. To obtain the highest level of reliability that is done by performing optimization with some variation of the river length from 0.045 to 0.07, and the results as presented in Table 5.

Table 5. Variation of factors L and relative error (R) and Reliability Models (K Model)

Factor L	**KR (%)**	**K model (%)**
0.045	193.165	87.055
0.049	218.073	87.385
0.050	223.066	87.416
0.051	227.627	87.433
0.052	231.782	87.439
0.053	235.555	87.435
0.054	238.968	87.425
0.055	242.043	87.409
0.058	249.416	87.341
0.060	252.951	87.288
0.065	257.731	87.159
0.070	257.728	87.057

Source : Calculation Result

Based on Table 5, acquired coefficient of river length (L) of 0.052 which provide the highest level of reliability of the model that is equal to 87.439%.

VI. Conclusion

After a comparison of the various alternatives presented above it is concluded that the calculation of flood runoff patterns, especially in the area of Jember can use synthetic unit hydrograph Nakayasu, but there needs to be an adjustment in the use of increases and decreases of hydrograph coefficient (α coefficient) and coefficient of concentration time (Tr).

Based on the results of the optimization obtained α coefficient is 0.651 and Tr coefficient is 0.3. This value is obtained at the level of 71.491% reliability of the model.

Based on the results of the optimization are also obtained the value of the coefficient of river length is 0.052. This value is obtained at the level of 87.439% reliability of the models.

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