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Suitable Synthetic Unit Hydrograph at Rungun Hulu Sub-Watershed, Centre Kalimantan of Indonesia

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ABSTRACT

Synthetic Unit Hydrograph (SUH) could become the source of some important information that was necessary for reliable hydraulic structures and planning. Among stakeholders, the application of the models was meant for analyzing design floods through the uses of rainfall data input. Ideally, every watershed had its own specific unit hydrograph. The aim of this study was to compare two kinds SUH application of Nakayasu and Limantara. This study conducted at Rungun Hulu Sub-Watershed in Centre Kalimantan of Indonesia. In order to produce the suitable models, method was based on calibration parameter of each model due to observed unit hydrograph. The results suggested the suitable physical parameter of each model for applying in location study. In further development, the results intended to find out the nature of watershed responses against precipitation data input, where by it could become the supportive warning system to area that were vulnerable to flooding and resumed up hydrograph data availability that were previously vacant due to operational problem of the Automatic Water Level Recorder (AWLR)

Keywords: Synthetic Unit Hydrograph (SUH), Nakayasu, Limantara, parameter

INTRODUCTION

Approximately more than 50% of water disasters worldwide were floods, and most of people annually were exposed to catastrophic flooding. Floods were natural disasters causing functional damages to critical infrastructures, transportation, and communications. Otherwise they were causing damages to property and facilities [1]. There were several factors contributing to the flooding problem. It was ranging from topography, drainage, engineering structure, and climate. Most floods were caused by storms in which a lot of precipitation fell in a short period of time [2]. Duration and intensity of the rain were the most influencing factors for flood hazards. Human activities such as major land use changes, uncontrolled construction of buildings, and development of unplanned rapid settlement could influence the temporal and spatial pattern of hazards. Design purposes on watersheds with limited data needed the estimation of peak discharge that was as a continuous problem in hydrology. Estimation of direct runoff in a watershed was necessary for water resources system planning [3]. The characteristic of hydrological processes governing direct surface runoff vary both in time scales and space. Model of rainfall was differentiated between high flow and low flow due to the intensity events [4]. Rainfall-runoff models were used in hydrology for a wide range of application on estimation of flow, the extension of stream flow records, observation and evaluation of climate change impact, and prediction of land use change effect [5]. Structural and non structural approached were implemented to mitigate the impacts of floods. Hydraulic and hydrologic models were used to plan and develop structural and non structural flood mitigation. Models of flood had been developed from the estimation of peak discharge and time to peak approached to multi-dimensional, multi-scale distributed models capable of representing the flood flows over a watershed surface [1]. One of the major problems in applied hydrology related to floods was the prediction of flood resulting from heavy rain over a catchment or watershed. Design of hydraulic structure demanded reliable information concerning the design flood or peak flow which was expected after a given probability of occurrence and return period. In this sense, the hydrologist often faced with predicting extreme flood events on basis of historical flood records [6]. Regardless of history in flood model, an important characteristic in watershed had been known as unit hydrograph. The hydrological approaches in the watershed systems had granted great many contributions to the hydraulic structures planning [7], though it was still difficult to understand thoroughly the process of rainfall-runoff. Rainfall-runoff forecasting widely used the instantaneous unit hydrograph (IUH) concept. Consequently, the IUH method should still be used either on its own or as a component in more complex conceptual models [8]. Several observations and investigations developed models for IUH from multi periods events [9]. These investigations were ever since the inception of unit hydrograph (UH) by Sherman (1932) [10]. Researchers had come up successfully with models which in nowadays hydrology were known well as the Synthetic Unit Hydrographs (SUH) [11].

Synthetic Unit Hydrograph (SUH) could become the source of some important information that was necessary for the reliable of hydraulic structures. However there were some kinds of SUH founded by

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researchers in the world, such as SUH Nakayasu (researched in Japan), SUH Snyder (researched in USA), SUH Gama I (researched in Indonesia), SUH Limantara (researched in Indonesia), etc. Though in fact, the application of these model on the Java Island still firstly required calibration of several parameters. Realizing that SUH Models had been researched in areas which watersheds were far different than the ones applied. They therefore quite often came up with inaccurate result, which affected the design of hydro structure. Ideally, every watershed had to have its own particular unit hydrograph.

This study had been carried out at Rungun Hulu sub-watershed, Centre Kalimantan of Indonesia. It was intended to calibrate the parameters of SUH Nakayasu and Limantara.

MATERIALS AND METHODS

This study conducted at watershed of Kahayan River. The watershed was included 1 sub-watershed named as Rungun Hulu sub-watershed, which was located at Gunung Mas Regency, Centre Kalimantan of Indonesia. Map of location was as in Figure 1 below.

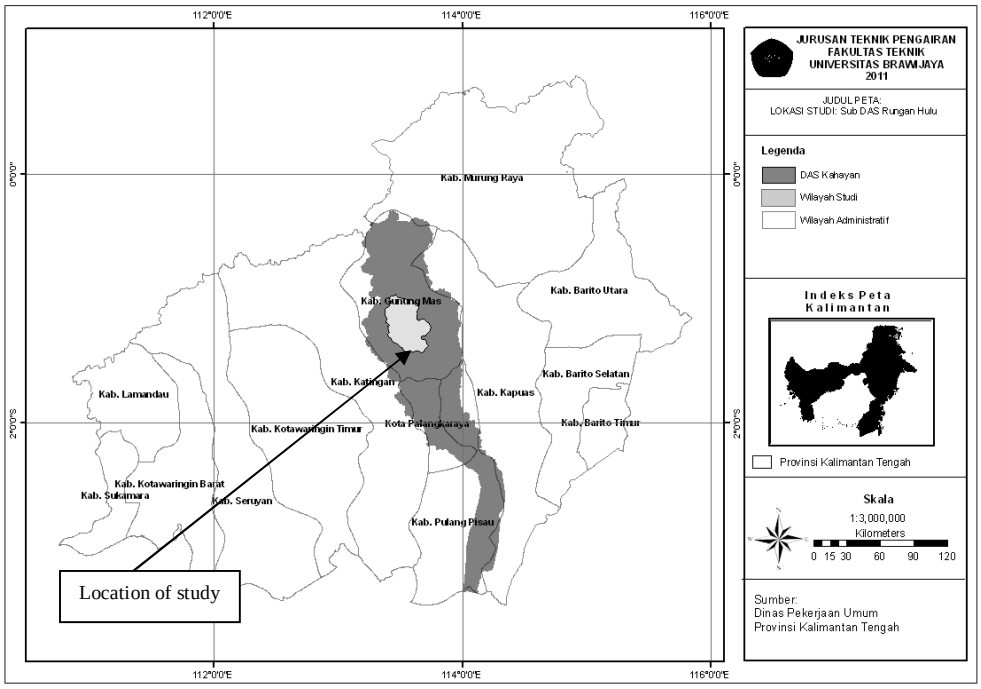

Figure 1 Map of Location

Data used in this study was included map of watershed, discharge data from Automatic Water Level Recorder (AWLR), hourly rainfall data from Automatic Rainfall Recorder (ARR), and river bed slope. There was Automatic Water Level Recorder (AWLR) and Automatic Rainfall Recorder (ARR) at location of study. Observed discharge hydrograph was selected which had single peak and caused by hourly rainfall. Time of rainfall had to be fitted to time of observed discharge hydrograph. In general, data needed for this study were included map of watershed, discharge data of AWLR, daily rainfall of ARR, and slope of Main River. The methodology was consisted of the steps as follow: (1) analysis of observed unit hydrograph; (2) analysis and calibration on parameter of Nakayasu SUH; and (3) analysis and calibration on parameter of Limantara SUH.

Analysis of observed unit hydrograph:

Observed unit hydrograph was sequent analysed with Collins method as follow: [10]

1. Stage hydrograph was transformed into discharge hydrograph with calibration curve of $Q = 26{,}35\ (H)^2 - 29.53H + 33.99$
2. Base flow was separated from discharge hydrograph using empirical method of straight line and it produced direct run off of hydrograph
3. Effective rainfall was analysed using infiltration index of phi index.

4. Trial hydrograph was determined as first trial of unit hydrograph. It was included ordinates of hydrograph and then ordinates of trial hydrograph were multiplied by effective rainfall except the maximum one.
5. Direct run off hydrograph caused by maximum effective rainfall = direct run off of hydrograph as above minus observed direct run off of hydrograph, it was as second trial of unit hydrograph.
6. The second trial of unit hydrograph was compared with first trial of unit hydrograph. If there was much difference (due to reliable standard error), it was needed to return step 4 and 5 as above and so on until it was produced small difference.

Observed unit hydrograph was found from each flood cases. Therefore, observed unit hydrograph was produced by averaging ordinates of these observed unit hydrographs at the same time. The averaged analysis included peak discharge and time to peak due to the procedures as follow: [10]

1. To analyse mean of time to peak and peak discharge.
2. To analyse dimensionless observed unit hydrograph (T/Tp and Q/Qp) for each flood cases.
3. To analyse dimensionless of averaged observed unit hydrograph.
4. To analyse mean of observed unit hydrograph.

Formula of index infiltration (phi index): [10]

$$\phi = \frac{(\sum R - DRO)}{Td} \quad \text{.....} \quad (1)$$

Note:
R = depth of rainfall (mm)
DRO = direct runoff (mm)
Td = duration of unit rainfall (hour)

Collins Method [10]

Linear relation between direct run off (Q) and effective rainfall (R) could be expressed as follow:

$Q_0 = 0$
$Q_1 = R_1 . U_1$
$Q_2 = R_1 . U_2 + R_2 . U_1$
$Q_3 = R_1 . U_3 + R_2 . U_2 + R_3 . U_1$
..
$Q_j = R_1 . U_J + R_2 . U_{J-1} + R_3 . U_{J-2} + \ldots + R_J . U_1$
.
$Q_{n-1} = R_{J-1} . U_K + R_J . U_{K-1}$
$Q_n = R_J . U_K$
$Q_{n+1} = 0$

Note:
n = number of hydrograph ordinates
j = number of effective rainfall (hour)
k =number of unit hydrograph ordinates

If observed hydrograph was false, it would cause rainfall recorder false too. It meant that theory of unit hydrograph did not really illustrate characteristic of the watershed and unit hydrograph could not assumed to represent the watershed. Collins methods could produce observed unit hydrograph with complex period of rainfall.

End estimation formula of unit hydrograph ordinates was as follow:

$$Ue = (V * U^{**}) / (3600 * \sum U^{**}) \quad \text{.....} \quad (2)$$

Note

$$U^{**} = (U_i + F^* U^*) / (1 + F) \quad \text{.....} \quad (3)$$

$$U^* = dQ/Re_{max} \quad \text{.....} \quad (4)$$

Ue = initial hydrograph ordinate (m^3/s/mm)
V = volume of run off (m^3)
Ui = hydrograph ordinate at-i (m^3/s/mm)
F = factor of calibration
U* = hydrograph ordinate after correction (m^3/s/mm)
DQ = observed hydrograph ordinate (m^3/s/mm)
Re_{max} = maximum effective rainfall (mm)

Synthetic Unit Hydrograph of Nakayasu

Nakayasu had observed unit hydrograph at some rivers in Japan. Formula of synthetic unit hydrograph based on his research was as follow: [10]

$$Qp = \frac{C.A.Ro}{3{,}6(0{,}3Tp + T_{0,3})} \qquad (5)$$

Note:

Qp = peak discharge (m^3/s)
C = coefficient of run off (=1)
A = number area (km^2)
Ro = unit rainfall (1 mm)
Tp = time from the beginning of rainfall until peak discharge (hour)
$T_{0,3}$ = time needed for decreasing peak discharge until 30% of peak discharge (hour)

Formula of Tp and $T_{0.3}$ were as follow: [10]

Tp = Tg +0.8 Tr …….. (6)
$T_{0,3}$ = α.Tg …….... (7)
Tr = 0.75.Tg ……. (8)

Limitation:

If length of river > 15 km then Tg = 0.4 +0.058 L
If length of river < 15 km then Tg = $0.21.L^{0.7}$

Note:

Tg = time of concentration (hour)
Tr = time of unit rainfall (hour)
α = parameter of hydrograph
L = length of main river (km)

- For normal area: α = 2
- For hydrograph with slow time to peak and fast time recession: α = 1,5
- For hydrograph with fast time to peak and slow time recession: α = 3

Based on the previous research in Indonesia, there was needed calibration of α parameter for producing accurate results [10]. Illustration of synthetic unit hydrograph of Nakayasu was presented as in Figure 1 below.

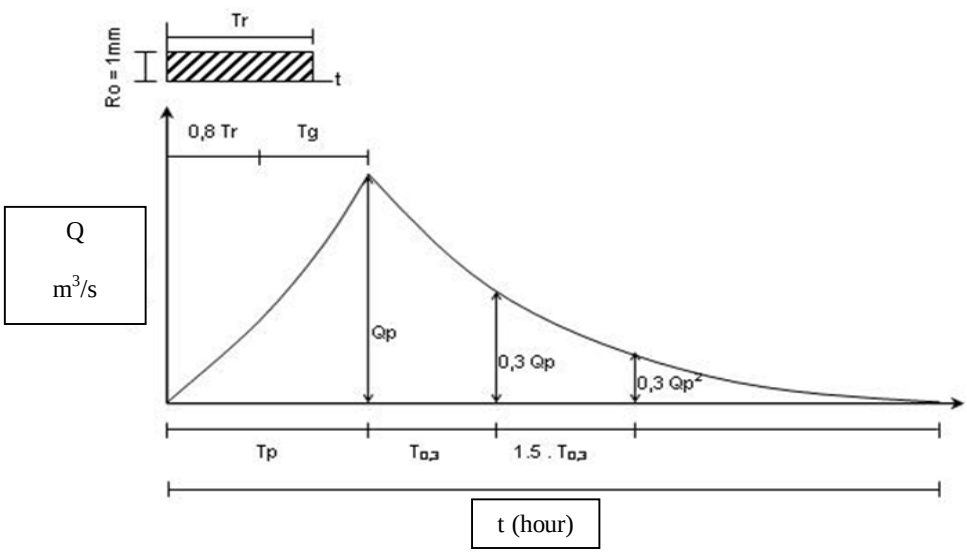

Figure 1 Synthetic Unit Hydrograph of Nakayasu

Equation formula of synthetic unit hydrograph of Nakayasu:

1. Equation for rising curve

$$Qn = Qp.\left(\frac{t}{T_p}\right)^{2,4} \quad (9)$$

2. Equation of recession curve

$Tp \leq t < (T_p+T_{0,3})$:

$$Qt = Qp.\,0,3^{\left[\frac{t-Tp}{T_{0,3}}\right]} \quad (10)$$

$(T_p+T_{0,3}) \leq t < (T_p+T_{0,3}+1,5T_{0,3})$:

$$Qt = Qp.\,0,3^{\left[\frac{t-Tp+0,5T_{0,3}}{1,5-T_{0,3}}\right]} \quad (11)$$

$t > (T_p+T_{0,3}+1,5T_{0,3}$
:

$$Qt = Qp.\,0,3^{\left[\frac{t-Tp+1,5T_{0,3}}{2T_{0,3}}\right]} \quad (12)$$

Synthetic Unit Hydrograph of Limantara

Limantara had researched synthetic unit hydrograph on the year of 2006. Locations of study were some areas of Indonesia included Java Island (6 watersheds and 67 sub-watersheds), Bali Island (2 watersheds and 13 sub-watersheds), Lombok Island (1 watershed and 5 sub-watersheds), and East Kalimantan (1 watershed and 9 sub-watersheds). Parameters used in this method were number area of watershed (A), the length of main river (L), the length of river measured until the nearest point with weight point of watershed (Lc), slope of river (S), and roughness coefficient (n). Formula of synthetic unit hydrograph of Limantara was as follow:

Formula of hydrograph peak discharge: [10]

$$Qp = 0.042.A^{0.451}.L^{0.497}.Lc^{0.356}.S^{-0.131}.n^{0.168} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

Note:

Qp	=	peak discharge of unit hydrograph (m^3/s/mm)
A	=	number area of watershed (km^2)
L	=	length of main river (km)
Lc	=	length of river from outlet until the nearest point to weight point of watershed (km)
S	=	slope of main river
n	=	roughness coefficient of watershed
0.042	=	coefficient for unit conversion ($m^{0.25}$/s)

Formula of rising curve [10]

$$Qn = Qp.\left(\frac{t}{T_p}\right)^{1,107} \quad (14)$$

Note:

Qn	=	discharge of rising curve (m^3/s/mm)
Qp	=	peak discharge of unit hydrograph (m^3/s/mm)
t	=	time of hydrograph (hour)
Tp	=	time rise or time to peak (hour)

Formula of recession curve [10]

$$Qt = Qp.\,e^{0,175(tp-t)} \quad (15)$$

Note:

Qt	=	discharge of recession curve (m^3/s/mm)
Qp	=	peak discharge of unit hydrograph (m^3/s/mm)
t	=	time of hydrograph (hour)
Tp	=	time rise or time to peak (hour)
0.175	=	coefficient for unit conversion (s^{-1})

Limitation of synthetic unit hydrograph of Limantara

Time to peak on synthetic unit hydrograph of Limantara used the formula of Nakayasu. The other limitations were presented as in Table 1 below.

Table 1 Technical specification of synthetic unit hydrograph of Limantara

Item	Notation	Unit	Range
Area number	A	km^2	0.325 – 1667.500
Length of main river	L	km	1.16 – 62.48
Distance of weight point of watershed to outlet	Lc	km	0.5 – 29.386
Slope of main river	S	-	0.0004 – 0.147
Roughness coefficient of watershed	N	-	0.035 – 0.07
Percentage of number area of forest	Af	%	0.00 - 100

RESULTS AND DISCUSSION

Observed unit hydrograph

Unit hydrograph which was analyzed for every flood case had not been as representative unit hydrograph of the watershed. Therefore, it was needed unit hydrograph that was differentiated from many flood cases and then they were averaged to produce representative unit hydrograph of the watershed or sub-watershed. Result of observed unit hydrograph at Rungun Hulu sub-watershed was presented as in Figure 2 below.

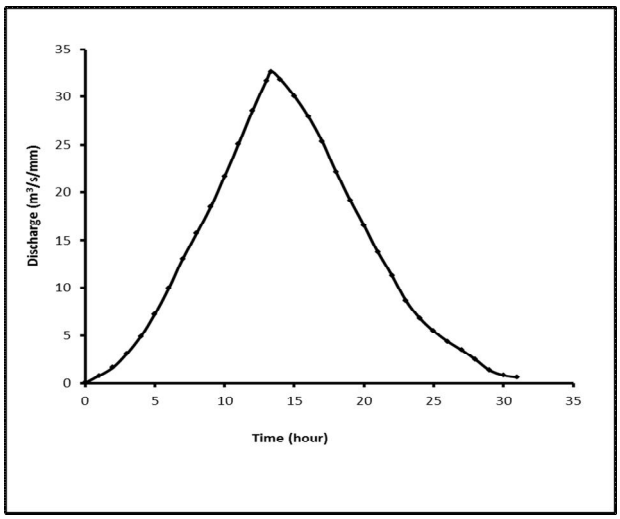

Figure 2 Average of observed unit hydrograph

Figure 2 showed that time to peak was 13.33 hours with peak discharge was 32.676 $m^3/s/mm$ and time of recession was 17.667 hours. Therefore, time base of hydrograph was 31 hours. It was concluded that hydrograph of Rungun Hulu sub-watershed had characteristic of rising was faster than recession (time of rising < time of recession). Based on the characteristic of watershed, Rungun Hulu sub-watershed was not influenced by tidal because the observed unit hydrograph did not had the characteristic of both of rising and recession was fast.

Analysis of synthetic unit hydrograph of Nakayasu

Calibration on synthetic unit hydrograph of Nakayasu was carried out for parameter of α and time of concentration (tg) [4][10], so that was produced time to peak and peak discharge with least deviation (≤ 10 %) compared to observed unit hydrograph (HSO). This condition was presented as in Table 2 and Figure 3 below.

Table 2 Parameter of Nakaysu before and after calibration

Parameter before calibration	Parameter after calibration
$\alpha = 3$ $tg = 0.4 + 0.058*L$	$\alpha = 0.946$ $tg = 0.4 + 0.058L^{1.401}$

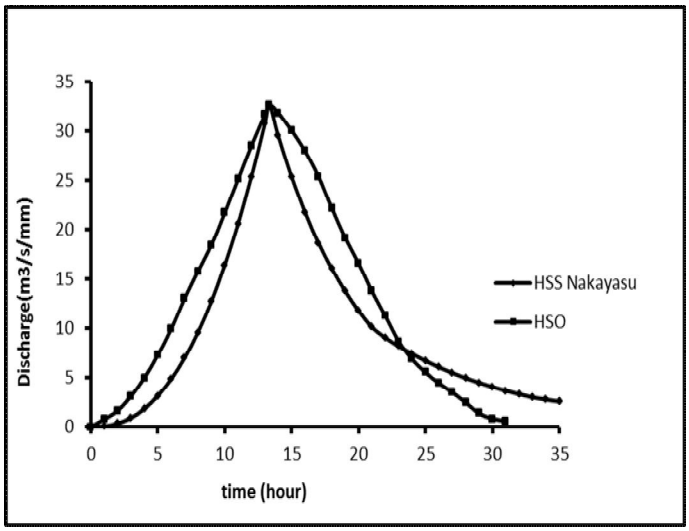

Figure 3 Comparison between observed unit hydrograph and calibrated synthetic unit hydrograph of Nakayasu

The standard equation of Nakayasu for tg parameter was tg = 0.4 + 0.058L for L > 15 km and tg = $0.21L^{0.7}$ for L < 15 km. This parameter was modified as tg = 0.4 + $0.058L^{\lambda}$ due to the need of calibration with trial and error so it produced synthetic unit hydrograph which was closely to observed one. It was relatively the same treatment as the research before that had an effort to calibrate some parameters [3][4][10]. Result of calibration presented that α parameter = 0.946 and equation of tg = 0.4 + 0.058 $L^{0.401}$, and peak discharge was 32.6763 m3/s/mm with deviation of 0.0002%. Synthetic unit hydrograph of Nakayasu was researched and developed at Japan which watershed was far different than the ones of Indonesia. So that was needed to calibrate some parameters for ideal cases [4][5].

Analysis of synthetic unit hydrograph of Limantara

Based on the suggestion of the researcher of Limantara synthetic unit hydrograph, there was needed to advanced study on the parameter of river slope and roughness coefficient [4][10][11]. Therefore this study made an effort to calibrate the parameters by changing the formula into $Qp = 0.042.A^{0.451}.L^{0.497}.Lc^{0.356}.S^{\Phi}.n^{\beta}$ with calibrating Φ and β due to trial and error so that the synthetc unit hydrograph was relatively close to observed one. The base formula of Limantara synthetic unit hydrograph was $Qp = 0.042.A^{0.451}.L^{0.497}.Lc^{0.356}.S^{-0.131}.n^{0.168}$.

Beside the suggestion as above, the researcher also suggested to consider the use of time concentration formula, which used the formula of Nakayasu [10]. Therefore this study had carried out calibration parameter of this formula. The same as being carried out on Nakayasu synthetic unit hydrograph as above, this part calibrated too the time concentration formula into tg = 0.4 + $0.058L^{\lambda}$ with trial and error of λ so that the synthetic unit hydrograph was relatively close to observed one [4].

Result of calibration showed that suitable λ was in the range of 0.700 to 1.450 with time concentration of tg was 8.333 hours and the formula of tg was tg = 0.4 + 0.058 $L^{1.401}$ with deviation of time to peak was 0.004% due to time to peak of observed unit hydrograph. Based on trial and error, it produced Φ = -0.195 and β = 0,113, and peak discharge was 32.6763 m^3/s/mm with the deviation of 0.00003% due to observed unit hydrograph. This condition was presented as in Table 3 and Figure 4 below.

Table 3 parameter of Limantara before and after calibration

Parameter before calibration	Parameter after calibration
tg = 0.4 + 0.058*L $Qp = 0.042.A^{0.451}.L^{0.497}.Lc^{0.356}.S^{-0.131}.n^{0.168}$	tg = 0.4 + $0.058L^{1.401}$ $Qp = 0.042.A^{0.451}.L^{0.497}.Lc^{0.356}.S^{-0.193}.n^{0.113}$

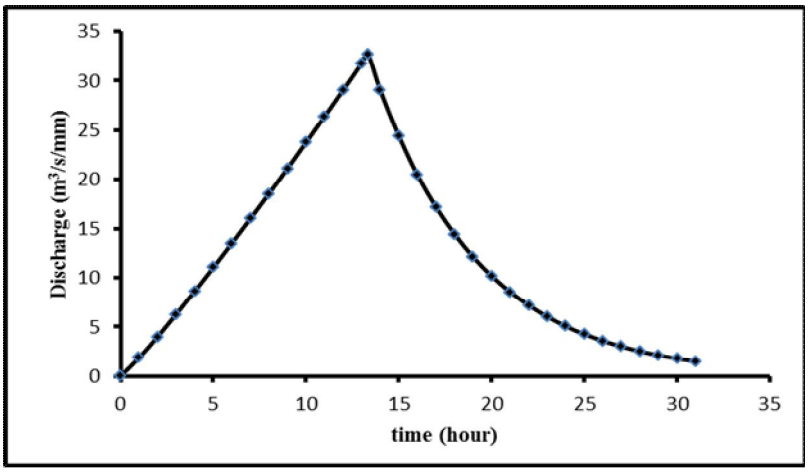

Figure 4 Comparison between observed unit hydrograph and calibrated synthetic unit hydrograph of Limantara

This result was very suitable to the research of Limantara [4][10][11] which said that shallow slope of watershed would produce higher peak discharge. It was caused by if the slop was shallow, it meant that time base hydrograph was long and would produce shallow recession curve of hydrograph so that would rise peak discharge. Result of this study showed roughness coefficient of sub-watershed firm influenced peak discharge though only little [4][10][11].

Verification of calibration results

Result of calibration showed that synthetic unit hydrograph of Nakayasu had peak discharge (Qp) of 32.676 m^3/s/mm with time to peak was 13.333 hours and the deviation due to observed unit hydrograph was 0.0002%. But synthetic unit hydrograph of Limantara had peak discharge of 32.676 m^3/s/mm with time to peak was 13.333 hours and the deviation due to observed unit hydrograph was 0.00003%. This condition was presented as in Figure 5 below.

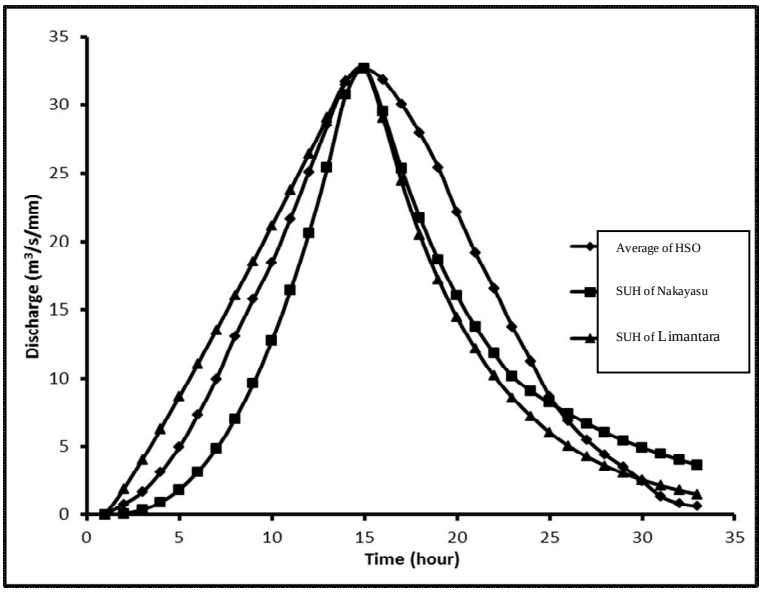

Figure 5 Comparison between observed unit hydrograph and synthetic unit hydrograph of Nakayasu and Limantara (after calibration)

After calibration, there was carried out verification on synthetic unit hydrograph of Nakayasu and Limantara. Verification was intended to eliminate unused data for matching α value of synthetic unit hydrograph and β, Φ of synthetic unit hydrograph of Limantara on peak discharge equation . Otherwise it was

also to macth λ value of time concentration (tg) equation. Comparison between verification of observed unit hydrograph due to synthetic unit hydrograph of Nakayasu and Limantara was presented as in Figure 6 below.

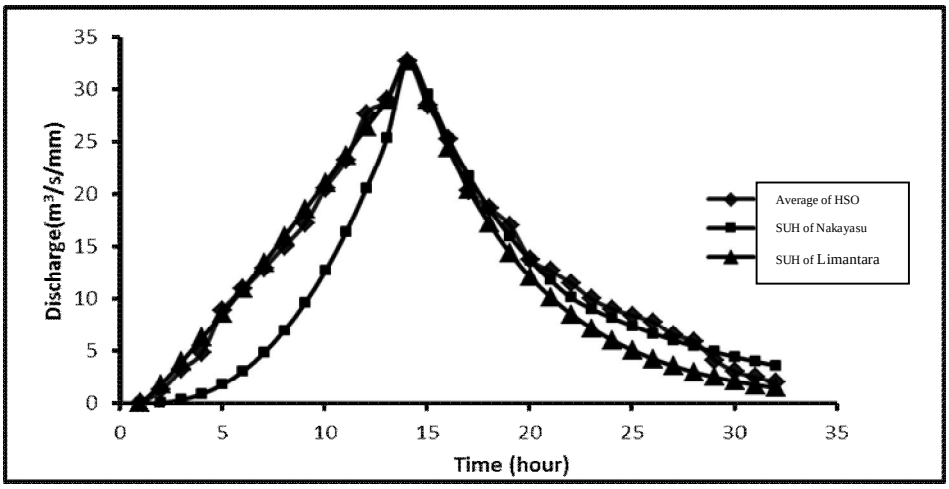

Figure 6 Comparison between verification of observed unit hydrograph and synthetic unit hydrograph of Nakayasu and Limantara (after calibration)

Result of verification showed that time to peak (Tp) was 13 hours and peak discharge (Qp) was 32.67 $m^3/s/mm$. Result on synthetic unit hydrograph of Nakayasu after calibration was 13.333 hours for time to peak (Tp) and 32.676 $m^3/s/mm$ for peak discharge (Qp). Therefore the equation of peak discharge after calibration was recommended to be used in this location of study. Otherwise, result on synthetic unit hydrograph of Limantara after calibration was 13.333 hours for time to peak (Tp) and 32.676 $m^3/s/mm$ for peak discharge (Qp).So the equation of peak discharge after calibration was also recommended to be used at this location of study.

CONCLUSION

Based on analysis of observed unit hydrograph, verification, and calibration on synthetic unit hydrograph of Nakayasu and Limantara, suitable synthetic unit hydrograph of Rungun Hulu sub-watershed could follow the conclusion below:

1. Time rise of average observed unit hydrograph was 13.333 hours and time of recession was 17.667 hours, so time base was 31 hours. Therefore the average observed unit hydrograph had characteristic of the rising was faster than recession. According to the limitation of Nakayasu, for watershed with the characteristic like that, he suggested α value was 3, but result of calibration in this study the value of α was 0.946 and $tg = 0.4 + 0.058L^{1.401}$ (the standard of formula was tg = 0.4 + 0.058 L).
2. Result of standard formula of Nakayasu was 3 for α and 2.343 hours for tg (time of concentration). The deviation of using standard formula was 45.69%. Result of calibration on synthetic unit hydrograph of Nakayasu was 0.946 for α and 8.333 hours for tg with deviation of peak discharge was 0.0002%.
3. Result of calibration on standard formula of Limantara was 2.343 hours for tg (time of concentration) with deviation of peak discharge was 32.902%. Result of calibration on synthetic unit hydrograph of Limantara was 8.33 hours for tg with deviation of peak discharge was 0.00003%.
4. Suitable synthetic unit hydrograph at Rungun Hulu sub-watershed was recommended used Limantara with formula of calibration result was: $Qp = 0.042.A^{0.451}.L^{0.497}.Lc^{0.356}.S^{-0.193}.n^{0.113}$ and $tg = 0.4 + 0.058L^{1.401}$.

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REFERENCES

1. Kalyanapu, Alfred J.; Burian, Steven J.; and Mc. Pherson, Timothy N. 2009. Effect of Land Use-Based Surface Roughness on Hydrologic Model Output. *Journal of Spatial Hydrology*, Vol 9(2); 51-71
2. Pradhan, Biswajeet. 2009. Flood Susceptible Mapping and Risk Area Delineation Using Logistic Regression, GIS, and Remote Sensing. *Journal of Spatial Hydrology*, Vol 9(2): 1-18
3. Dutta, Subashisa; Mishra, Ashok; Kar, S; and Panigrahy, Sushma. 2006. Estimating Spatial Curve Number for Hydrologic Response Analysis of a Small Watershed. *Journal of Spatial Hydrology*, Vol 6(2): 57-67
4. Limantara, Lily Montarcih. 2010. Calibration of Synthetic Unit Hydrograph: Case Study in Brantas Hulu Sub-Watershed, Province East Java-Indonesia. *International Journal of Academic Research*, Vol 2(5): 146-148
5. Nandakumar, N; and Mein, R.G., 1997. Uncertainty in Rainfall-Runoff Model Simulations and The Implications For Predicting The Hydrologic Effects Of Land Use Change. *Journal of Hydrology*,192: 211-232
6. Yurekli, Kadri; Kurunc, Ahmet; and Simsek, Huseyin. 2004. Prediction of Daily Maximum Streamflow Based on Stochastic Approaches. *Journal of Spatial Hydrology*, Vol 4(2): 1-11
7. Limantara, Lily Montarcih. 2009. The Limiting Physical Parameters of Synthetic Unit Hydrograph. *World Applied Sciences Journal*, 7 (6): 802-804
8. Hoybye, Jan; and Rosbjerg, Dan. Effect of Input and Parameter Uncertainties in Rainfall-Runoff Simulations. 1999. *Journal of Hydrologic Engineering*, July 1999 Vol. 4 No. 3, page 214-224
9. Rasad, T. Devi; Gupta, Rajiv; and Prakash, Satya. 1999. Determination of Optimal Loss Rate Parameters and Unit Hydrograph. *Journal of Hydrologic Engineering*, Vol. 4 No. 1, page 183-187
10. Limantara, Lily Montarcih. 2010. *Hidrologi Praktis*. Cetakan ke-1. CV Lubuk Agung. Bandung
11. Limantara, Lily Montarcih. 2009 Evaluation of Roughness Constant of River in Synthetic Unit Hydrograph. *World Applied Sciences Journal*, 7 (9): 1209-1211