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Alpha Modeling of Nakayasu Synthetic Unit Hydrograph for Part of Watersheds in Indonesia

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Abstract*: The lacks of hydrograph data in the field has become the drawback of the hydraulic structure planning. However, such a conditional deficiency in particular, has urgently placed the Synthetic Unit Hydrograph (SUH) models to be very great utility. The Synthetic Unit Hydrograph (SUH) is a popular model that is used in many water resources designs especially in design flood analysis in ungagged watershed. One of the SUH that is usually used in Indonesia is Nakayasu SUH. This model is depended on the α parameter that is influencing the unit hydrograph ordinate and time base. This research intends to build a model of α parameter that is as the characteristic factor of part of watersheds in Indonesia. The methodology consists of observed unit hydrograph analysis for obtaining the α parameter in each watershed, to collect the characteristic data in each watershed, and then to formulate the α parameter model that is as the function of watershed characteristic. The result is formulation model of α that can be used to analyze the design flood in the watershed in Indonesia

***Keywords* : Nakayasu SUH, alpha (α), design flood, watershed characteristic factor**

I. INTRODUCTION

Synthetic Unit Hydrograph (SUH) will become as the source of urgent information that is needed for the hydraulic structures reliable [1]. To well understand the process of run off is very difficult [2]. Ideally, every watershed has its own particular unit hydrograph. If the physical and hydrological conditions in general are quite homogeneous, it would be quite possible to create a new SUH model that resembles the ones made up by previous researchers [3]. Realizing that SUH Models have been researched and developed in areas which watersheds are far different than the ones applied, they therefore quite often come up with inaccurate results which affects the design of the hydro structure.

So that was needed to calibrate some parameters for the ideal cases [4]. There are many patterns to develop SUH. One of them is based on regression analysis. The limiting physical parameters of Synthetic Unit Hydrogragh has been studied before [5][6]

Nakayasu Synthetic Unit Hydrograph (SUH) is found by Nakayasu on 1948 based on the researches in Japan. The Nakayasu SUH is depended on the corrected factor of α that is affected the unit hydrograph ordinate (Up) and time base (Tb). The formula of time to peak of Nakayasu SUH does not accommodate the river slope factor in Indonesia. Hoesein and Limantara [8] have carried out to calibrate the Nakayasu SUH in the Lesti watershed. The calibration result is $0.67 < \alpha < 1.20$, and it is out of the boundary that is suggested in Nakayasu SUH model [7],

This study intends to build the correction factor that is α parameter of Nakjayasu Synthetic Unit Hydrograph (SUH). This α parameter is predicted as the function of the morphometric factor of a watershed.

II. MATERIAL AND METHOD

A. Research Location

The research is conducted in some plain areas that have the river slope less than 10%, have the Automatic Water Level Recorder (AWLR) and Automatic Rainfall Recorder (ARR) completely. The research locations that are connected with the conditional above are some watersheds in South Sulawesi Province and Java Island. In South Sulawesi Province, there is Jeneberang river area that consists of Bruto Jai, Jenelata, Jonggoa, Kampili, Maccini Sombala, Kelara, and Maros watersheds. Map of Jeneberang river area is presented as in the Fig. .1

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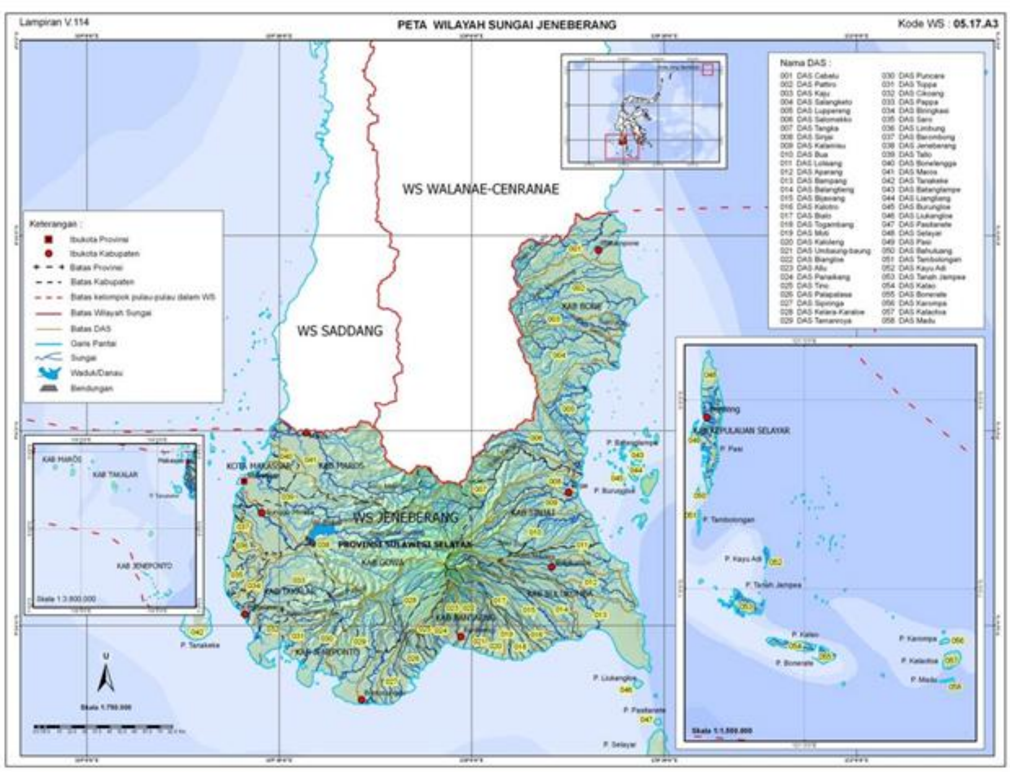

Fig. 1 Map of Jeneberang River Area

The other research location is in the Lesti watershed that is located in Malang Regency, East Java Province and it is as the catchment area of Sengguruh reservoir. The upstream Lesti watershed has the outlet in Twangrejeni village, Turen district, Malang regency, East java Province. The area of Lesti is about 383.58 km^2 with the river length is 48 km and the river slope is 0.042. Map of Lesti sub-watershed is presented as in the Fig. 2.

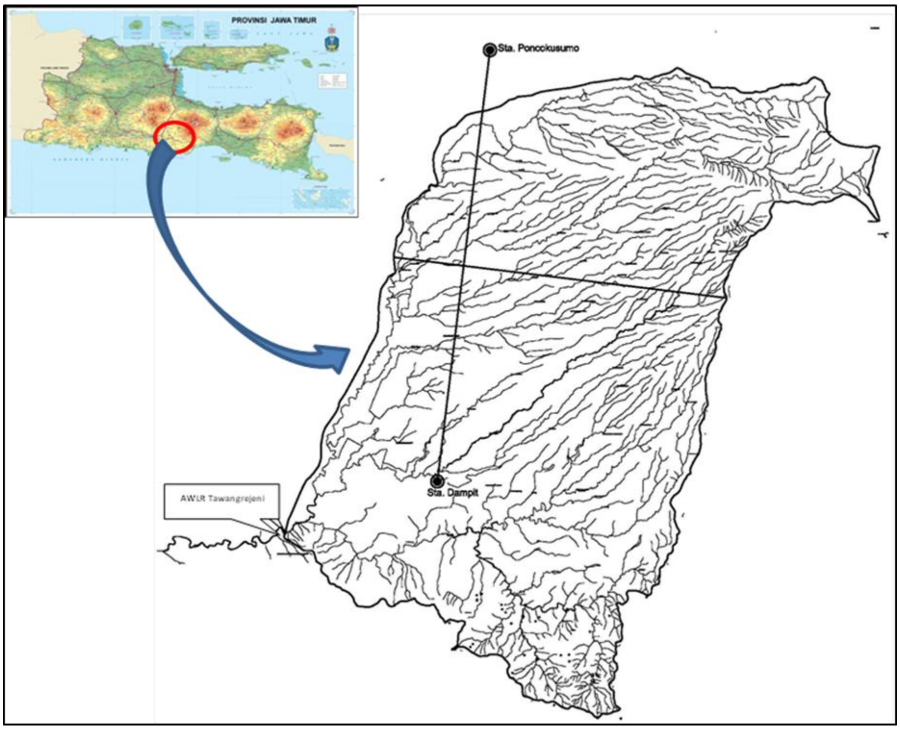

Fig. 2 Map of Lesti sub-watershed

However, the other research location is the upstream Ciliwung watershed that is located in Bogor regency, West Java Province. The area of upstream Ciliwung watershed is about 149.79 km^2, the river length is 23.00 km, and the river slope is 0.0151. Map of upstream Ciliwung watershed is presented as in the Fig. 3.

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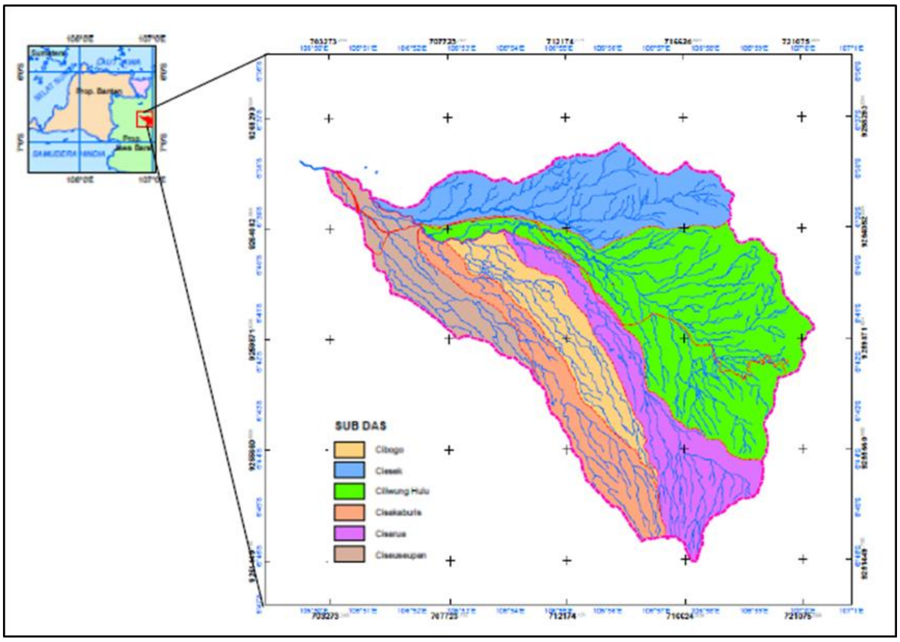

Fig.3 Map of Ciliwung watershed

B. HSS Nakayasu

To use this method, it needs some characteristic of watershed parameters as follow [10]: a) time lag from rainfall run-off until peak of hydrograph; b) time lag from weighted point of rainfall until the weighted point of hydrograph; c) hydrograph time base: d) watershed area: e) the main river length

Nakayasu is developed in Japan [7]. The equation of Nakayasu Synthetic Unit Hydrograph (SUH) is as follow::

$$QP = \frac{CA\ R_0}{3{,}6\ (0{,}3\ TP + T_{0,3})} \qquad (1)$$

Where:

QP = peak discharge (m^3/s/mm)

R_0 = unit of rainfall (mm)

TP = time lag from the beginning of rainfall to flood peak (hour)

$T_{0,3}$ = duration time which is needed for decreasing discharge until 30% of flood peak (hour)

CA = watershed area (km^2)

Tp and $T_{0,3}$ is determined by the formula as follow::

Tp = tg + 0,8 tr

$T_{0,3}$ = α tg

Tr = 0,5 tg until tg

tg is analyzed due to the condition as follow:

- For the river length: L > 15 km, so tg = 0,4 + 0,058 L
- For the river length: L < 15 km, so tg = 0,21 $L^{0,7}$

However, $T_{0,3}$ is calculated due to the condition as follow:

α = 2 → general area

α = 1,5 → rising limb is slow and recession limb is fast

α = 3 → rising limb is fast and recession limb is slow

The equation of hydrograph for: 0 < t < Tp

$$Qa = \left(\frac{t}{Tp}\right)^{2,4} \qquad (2)$$

Where Qa is run-off before reaching the peak discharge (m^3/s/mm)

Equation for the recession limb:

a. $0 \le t \le (Tp + T_{0,3})$

$$Qd_1 = Qp\ .0{,}3^{\frac{(t-Tp)}{T_{0,3}}} \qquad (3)$$

b. $(Tp + T_{0,3}) \le t \le (Tp + T_{0,3} + 1{,}5\ T_{0,3})$

$$Qd_2 = Qp\ .0{,}3^{\frac{(t-Tp+0{,}5\ T_{0,3})}{1{,}5\ .\ T_{0,3}}} \qquad (4)$$

c. $t > (Tp + T_{0,3} + 1{,}5\ T_{0,3})$

$$Qd_3 = Qp\ .0{,}3^{\frac{(t-Tp+1{,}5\ T_{0,3})}{2\ .\ T_{0,3}}} \qquad (5)$$

The volume:

$$V = (Q_t + Q_{t+1}).(T_{t+1} - T_t).0{,}5\ .3600 \qquad 6)$$

C. Morphometric of Watershed

Morphometric is as the size and mathematical analysis of shape, configuration, and dimension of earth [10]. The watershed morphometric is watershed characteristic size that is related to the geomorphology of an area. The watershed characteristic consists of watershed shape, watershed area, drainage pattern, density, river network, and river steepness gradient. The characteristic is related to the rainfall drainage process which the rain is drop in the watershed affecting the outflow in outlet (hydrograph). The watershed morphometric analyses have the important role in understanding the relation among the watershed parameters [7].

C.1. **Watershed area**

Watershed size is one of the urgent factors in making the discharge hydrograph. If the watershed area is bigger, the rainfall that is accepted is getting more and more [10]. So, the big watershed will produce higher time base (Tb) and peak discharge (Qp) than the small one and it is needed a longer time for reaching the time to peak of hydrograph (Tp).

C.2. River length

The river length is as the main river length from upstream to outlet. The typology of river from upstream to downstream generally has the meander pattern and it is depended on the typology of slope and shape.

C.3. Watershed and river slope

The watershed and river slope is directly related to the topography shape, river length, and gradient length. However, the watershed slope (as well as the river slope) gives the direct impact to the velocity of river flow.

D. Formulation of model

The criteria of data selection for each watershed is as follow: 1) The watershed has the Automatic Water Level Recorder (AWLR) and the Automatic Rainfall Recorder (ARR) inside or outside, watershed area is not more than 5,000 km^2; 2) The watershed physical factor has relatively homogeneous the yearly rainfall, therefore there are the almost similar hydrograph shape; 3) To select the hydrograph with a single peak that is due to the hourly rainfall. Time hydrograph and rainfall has to be fitted.

III. RESULT AND DISCUSSION

A. Observed Unit Hydrograph

Based on the observed discharge hydrograph for each watershed, there is calculated the observed unit hydrograph by using Collins method. The discharge hydrograph of Automatic Water Level Recorder (AWLR) is used for differentiating the observed unit hydrograph from the selected observed discharge hydrograph that are the highest one and has the single peak. For each watershed, the time period of observed discharge hydrograph has to be the same with the time period of hourly rainfall from Automatic Rainfall Recorder (ARR). However, it is not needed the homogeneous time inter watershed because the objective of hydrograph analysis is for the high flow. Therefore, data for the analyses has to have the extreme value as optimal as possible that is by taking the flood hydrograph with the highest peak in every hydrograph. Fig. 4 presents the single peak of direct run-off hydrograph in Jonggoa watershed on 2008.

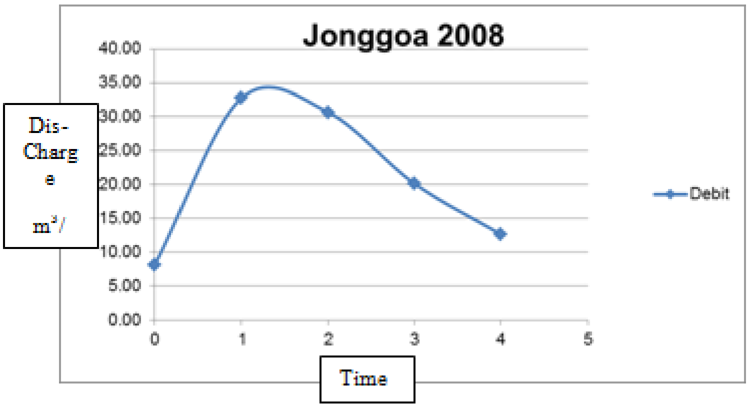

Fig. 4 Single peak of direct run-off hydrograph in Jonggoa watershed on 2008

The next step of Collin method is to analyze the volume of direct run-off, then to carry out the trial and error of unit hydrograph ordinate/ the initial unit hydrograph regarding to the direct run-off. After that, to calculate the estimation of unit hydrograph and it is continued with analyzing the deviation of initial ordinate to the end of trial. If it has not been accurate, so the initial ordinate is trialed with the ordinate in the previous step and then the process is return until it is obtained the minimum deviation (the tolerance is 4%). Table 1 presents the unit hydrograph in Jonggoa watershed on 2008 by using Collins method.

Table- I. Unit Hydrograph in Joggoa watershed on 2008 by using Collins method (trial-2)

time	Ut initial	Effective rainfall		Q run-off	Q run-off	Observed -	Observed-Model /	Ut jus	F * UT jus	Ut-1*	Ut - 2
	m^3/s	5.26	4.26	(model)	(observed)	model	Reff max				
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	9.345	49.109	39.764	88.873	25.827	-63.046	-11.997	8.715	-6.629	11.345	11.345
2	9.200	48.348	39.148	87.496	24.886	-62.610	-11.914	8.655	-6.583	10.932	10.932
3	7.752	40.740	32.988	73.728	15.471	-58.257	-11.085	8.053	-6.125	6.796	6.796
4	6.772	35.588	28.817	64.405	9.096	-55.309	-10.524	7.646	-5.816	3.996	3.996
	33.069			314.502		-239.222	-45.520	33.069	-25.153	33.069	33.069

Based on the analysis of observed unit hydrograph, it is carried out to measure the peak discharge (Qp), time to peak (Tp), and time base (Tb), and then to analyze the mean, so the result of Collins method is presented as in the Table- II and the hydrograph is presented as in the Fig. 4.

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Table- II. Recapitulation of t/Tp, Q/Qp, T, and Q in Jonggoa watershed

No	T/Tp	Q/Qp	T	Q
1	0	0	0	0
2	0	0.04	0	0.41
3	0.19	0.23	0.43	2.614
4	0.48	0.49	1.09	5.661
5	1	1	2.3	11.467
6	1.53	0.62	3.51	7.081
7	2.05	0.44	4.72	5.014
8	2.31	0.36	5.3	4.082
9	2.44	0.31	5.62	3.556
10	2.67	0.27	6.13	3.147
11	3	0.25	6.9	2.91
12	3.33	0.17	7.67	1.955

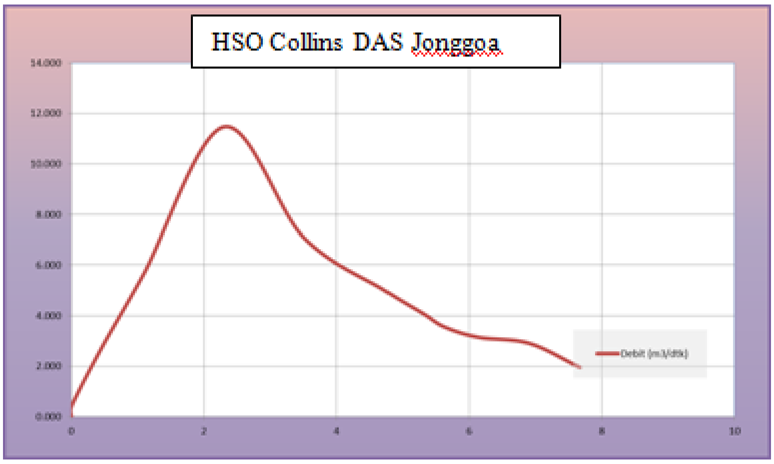

Fig. 4 Observed unit hydrograpgh in Jonggoa watershed by using Collins method

B. The value of alpha (α) parameter and morphometric data of each watershed

The value of alpha (α) is obtained fron the calibration result in each watershed due to the observed unt hydrograph. For examples in the Jongga watershed is presented as in the Fig. 5. However, the morphometric data for each watershed is presented as in the Table- III

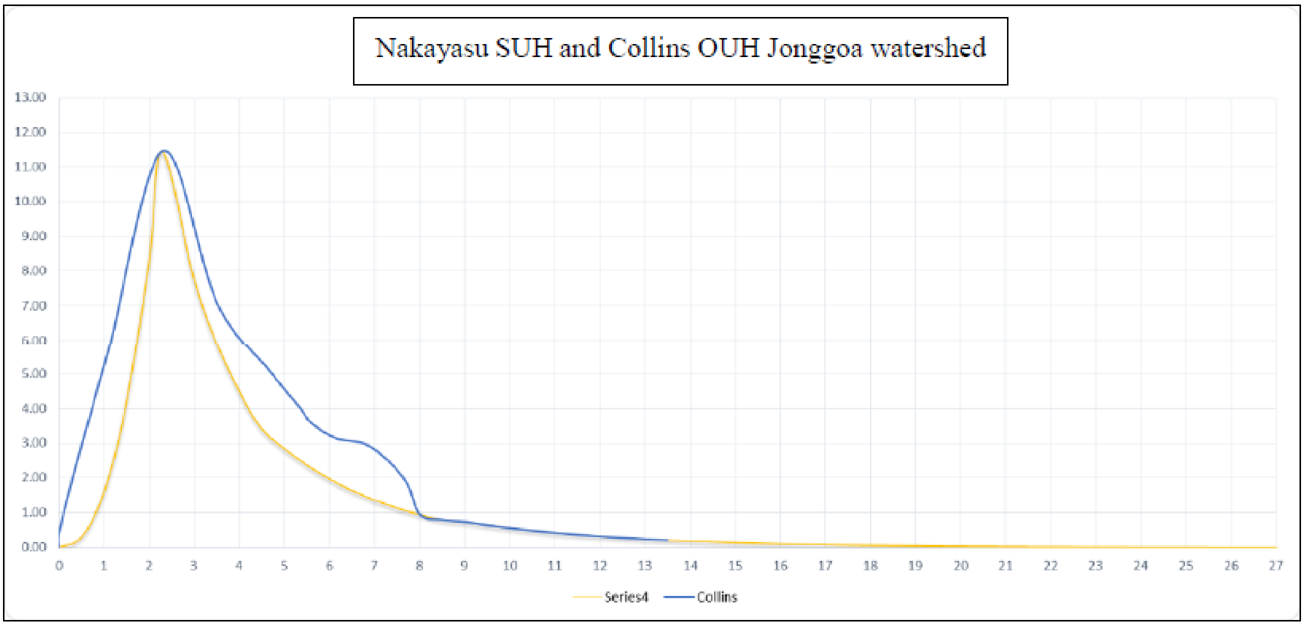

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Fig. 4 Nakayasu SUH and Observed Unit Hydrograph by Collins method in Jongga watershed

Table- III. Recapitulation of morphometric data in each watershed

No	Name of watershed	Area (A)	Length (L)	Slope	α
		km^2	km	S	
1	Bonto jai	312.008	33.000	0.018	1.000
2	Janelata	187.998	29.000	0.028	1.200
3	Jonggoa	119.047	20.000	0.082	1.406
4	Kampili	646.651	55.000	0.040	0.544
5	Maccini	737.080	73.000	0.007	1.042
6	Kelara	388.200	55.000	0.035	0.967
7	Maros	277.000	84.000	0.014	0.936
8	Ciliwung	149.790	23.000	0.015	2.611
9	Lesti	384.580	48.000	0.042	1.054

C. Modeling of alpha (α) parameter

The best modeling of synthetic unit hydrograph parameter that is selected is depended on the criteria of the highest determination coefficient that is calibrated to the observed hydrograph. The calibration test is intended to know the reliability level of the model for predicting the parameter value of the synthetic unit hydrograph.

The selection of model is carried out based on the: 1) statistical criteria: the highest determination coefficient and the smallest standard error; and 2) rationalization of model: for any value of A, L, and S does not produce the negative value of discharge. Based on the criteria above, the alpha model generally is as follow:

$\alpha = A^{-0,383} . L^{-0,354} . S^{-0,310} . e^{2,465}$ $(R^2 = 0,776)$

IV. CONCLUSION

Based on the analysis as above, it can be concluded as follow:

1. The alpha parameter on the Nakayasu Synthetic Hydrograph is as the function of area (A), river length (L), and river slope (s) regarding to the criteria modelling and the highest determination coefficient (0.776).
2. The general model of alpha is: $\alpha = A^{-0,383} . L^{-0,354} . S^{-0,310} . e^{2,465}$ $(R^2 = 0,776)$

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