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Time Lag Modeling in Modification of Nakayasu Synthetic Unit Hydrograph

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Abstract: In the development of the synthetic unit hydrograph method, the empirical formula expresses the relation between the watershed morphometry characteristic and the constituent elements of hydrographs that are peak discharge (Q_p), time to peak (t_p), time lag (T_L), and time base (T_b). This research intends to build a model of time lag in order to modify the Nakayasu SUH modeling. The Nakayasu synthetic unit hydrograph (SUH) model, seen as very popular and widely used by practitioners, needs to be adjusted for the main parameters that form the hydrograph to be able to be directly used based on the watershed morphometry characteristic. Based on the specific characteristic of the Nakayasu SUH formulation, this research will focus on developing the Nakayasu SUH model by the modification with adding the watershed characteristic parameter to the time lag parameter (t_L). This research was conducted in 23 watersheds in Indonesia. The previous research in the same watersheds indicates five morphometry parameters with a positive effect on the time lag with the ranking due to the strongest effect as follows: watershed area (A), the river length from outlet to the weight point of the watershed (Lc), H = L.Lc, and the main river length (L). However, the two other parameters negatively affect the time lag with the ranking due to the strongest effect as follows: river network density (D) and river slope (K). Then, the modeling of time lag is carried out based on the research result, and the result of the time lag model is as follows: $t_L = L_c^{\,0.1809} H^{-0.00159} A^{0.003459}$.

Keywords: time lag, Nakayasu synthetic unit hydrograph, modification, modeling.

中安合成单元水位线修改中的时滞建模

摘要：在合成单位过程线法的发展过程中，经验公式表达了流域形态特征与峰值流量（Qp）、达峰时间（tp）、时滞（TL）和时间等过程线构成要素之间的关系。碱基（结核病）。本研究旨在建立一个时间滞后模型，以修改中安 H 模型。便宜的合成单元水位线（苏）模型被视为非常流行并被从业者广泛使用，它需要根据流域形态特征对形成水位线的主要参数进行调整，以便能够直接使用。基于中安 H 公式的具体特点，本研究将重点通过在时滞参数（tL）中添加分水岭特征参数的修改来开发中安 H 模型。这项研究在印度尼西亚的 23 个流域进行。以往对同一流域的研究表明，五个形态测量参数对时滞有正向影响，其影响最强的排名如下：流域面积（一个）、流域出水口到流域权重点的河流长度（Lc），H = L．Lc，以及主要河流长度（大号）。然而，其他两个参数对排名的时间滞后产生负面影响，因为最强的影响如下：河网密度（D）和河坡（K）。然后，根据研究结果对时滞进行建模，时滞模型的结果如下：$t_L = L_c^{\,0.1809} H^{-0.00159} A^{0.003459}$.

关键词：时滞，便宜的合成单元水道线，修改，建模。

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1. Introduction

The hydrological analysis has a very important role in estimating and determining the design flood in the stage of planning, development, design, and management of water resources, mainly in designing water structures like dykes, weirs, reservoirs, drainage channels, and other water buildings [1], [2]. This matter is related to determining dimension, plan lifetime, and the water structure's capacity. The hydrological analysis is a transformation process from rainfall into discharge in a watershed, a complicated phenomenon. The complicated phenomenon is related to many factors that affect determining the flow characteristics, which are the rainfall transformation result, like the rainfall factor as an input and the watershed as a transformation media. This problem can be solved if the long discharge's recorded data are available and the data quality is good in a watershed, so determining the design flood does not need to transform the rainfall into discharge, using a model [3], [4]. However, in the location of water structure design, the discharge data is often only available for a short period, the data quality is bad, or even there is no discharge data.

Synthetic unit hydrograph (SUH) is a method for estimating the discharge using the unit hydrograph concept in a design without directly measuring the flood hydrograph [5, 13]. The setting and selection of the SUH model are based on the limitation of hydrology and hydrometry data, so the discharge hydrograph is presented by the watershed characteristic [6], [7]. SUHs are often used in Indonesia, such as Nakayasu SUH (1945), Snyder SUH (1938), and Gamma I (1985). The practicality of the SUH model in application makes the three models very popular and used by researchers and practitioners in analyzing the design flood in the ungauged watershed [8], [9].

Nakayasu SUH is a SUH model that is very popular used in Indonesia. However, the Nakayasu SUH is developed in Japanese watersheds with various characteristics. The Nakayasu SUH practice is used because the input data includes only the morphometry parameter of rivers such as watershed area (A) and main river length (L) along with the non-physical parameter α similar to the watershed characteristic coefficient dependent on the watershed unit and characteristic. Due to the practicality of SUH, there are some practitioners using it for analyzing the design flood hydrograph; however, the usage still gives the error or deviation if applied in Indonesia because of the difference of characteristics in the watershed in Japan where the SUH is found. Research by Limantara [5] in the watersheds in East Java Province-Indonesia produced the deviation of peak discharge (Qp), which was about 20.7%, In addition, Rosmala [10] has studied the Nakayasu SUH to analyze the design flood in the Kodina watershed which produced a big enough deviation of 26% for time to peak (Tp) and 22.4% for peak discharge (Qp). Meanwhile, the research by Tunas [11] that was conducted in the two watersheds in Center Sulawesi-Indonesia produced a very big deviation of 45.44%.

The Nakayasu SUH model is very popular and is used for analyzing design flood despite there still being some big enough deviation. Until now, the watersheds in Indonesia have not had the model modification of Nakayasu SUH that is used for planning and management of water resources and is built based on the hydrological characteristic and watershed that has the specific characteristic of the topography side. Therefore, the adjustment of the parameter for increasing the model performance of SUH is needed if it is applied in Indonesia [10], [11].

There are four main parameters in the Nakayasu which comprise the composer of unit hydrograph—peak discharge (Qp), time to peak (Tp), recession time from Qp to 30% of Qp ($T_{0.3}$), and time lag (tg). The time lag (tg) parameter is the main parameter that determines the three other parameters: Qp, Tp, and $T_{0.3}$. They are the function of time lag (tg). The formulation of the time lag (tg) parameter itself contains the physical characteristic of main river length (L) that is limited regarding the category of main river length as follows: L > 15 km and L < 15 km. Therefore, based on the specific characteristic of the Nakayasu SUH formulation, this research will focus on the development of the Nakayasu synthetic unit hydrograph (SUH) by the modification with adding the watershed characteristic parameter to the time lag parameter (tg). Then, we assessed the volume of the watershed due to its characteristic in Indonesia, as the object of developing the hydrograph parameter. It is hoped that the Nakayasu SUH model modification can produce the best performance and become the procedure reference [12] for analyzing the design flood in ungauged watersheds.

2. Materials and Method

2.1. Research Location

The selected research locations are medium watersheds with the area (A): $A \leq 5.000$ km^2 that have been completed with the Automatic Water Level Recorder (AWLR) and Automatic Rainfall Recorder (ARR) with the complete data recording and overlapping between rainfall and discharge data. The 23 watersheds selected in this research are distributed in Java and Sulawesi (Table 1).

Table 1 Research location

No	Name of watershed	Area (km^2)	Length of main river (km)	Province (Indonesia)
1	Kampili	630.1	60.53	South Sulawesi
2	Bontojai	276.62	36.14	South Sulawesi
3	Daraha	25.99	11.81	South Sulawesi
4	Jonggoa	128.53	21.26	South Sulawesi
5	Maccini Sombala	661.49	79.21	South Sulawesi
6	Jenelata	222.95	34.70	South Sulawesi
7	Pataruman	1398.14	101.97	Center and West Java
8	Guwo	250.29	47.93	Center Java
9	Lesti	378.88	44.20	East Java
10	Gadang	719.31	40.40	East Java
11	Brantas Konto 1	104.29	33.50	East Java
12	Brantas-Gadang	703.77	35.23	East Java
13	Bsolo-Tapan	8.6	6.17	Center Java
14	Ciessel Binangun	324.99	47.02	West Java
15	Ciliwung-Sugutamu	253.541	78.00	West Java
16	Cipedes-Cikumulutuk	69.64	11.71	West Java
17	Dengkeng-Jarum	567.11	62.07	Center Java
18	Garang-Patemon	75.00	34.26	Center Java
19	Kaduang-Ngadipiro	375.57	44.52	Center Java
20	Widas Lengkong	1257.00	64.74	East Java
21	Lesti-Tawangrenjeni	382.51	40.07	East Java
22	Madiun-Sekayu	1002.60	45.62	Center Java
23	Sadar-Hilir	515.56	63.07	East Java

2.2. Research Methodology

2.2.1. Analysis of Watershed Morphometry

Analysis of watershed morphometry is started with analyzing the topography data like National DEM (DEMNAS). The data analysis uses the geographic information system (GIS) to determine the watershed and sub-watershed boundary, river ordo, river length of each segment, and main river slope. The river ordering and determination of watershed and sub-watershed boundaries are carried out using the spatial analyst tool Hydrology. If the National DEM (DEMNAS) data that is obtained from the Geo-spatial Information Institution (BIG) does not have the good object appearance due to cloud cover or other factors, data improvement is performed using the SRTM data. The SRTM raster, DEM, and contour can be adjusted.

2.2.2. Analysis of Time Lag for Flood Events

The time lag in the basin can be determined in two ways: with a hydraulic and an empirical approach. In addition, it can be estimated from the time concentration (TC) and from the water characteristics. Although the direct run-off is started from the initial effective rainfall, most of the run-off is generally left behind after the rainfall, because it needs time to flow from its location in the watershed to the outlet. Time lag has been widely used as a measure in many studies and hydrological applications, but some definitions have been used to develop different hydrology procedures. The watershed time lag is usually defined as the time difference from the center of the effective rainfall mass to the center of the direct run-off mass that is produced by rainfall. It is also sometimes defined as the time from the center of the mass of surplus rainfall to the level of peak discharge in a hydrograph (Fig. 1), or as the period from the level of maximum rainfall until the level of peak run-off.

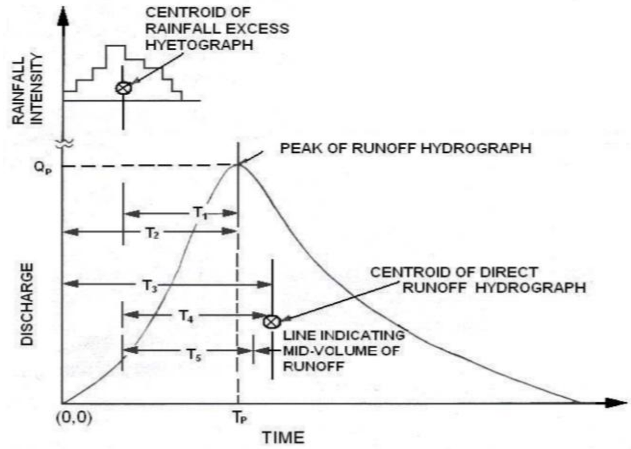

Fig. 1 Curve for defining the time lag

Following some definitions that have been set out by some experts in the related literatures, time lag is defined in this study as the time lag difference from the center of the effective rainfall mass to the flood peak of a hydrograph.

2.2.3. Modeling of Time Lag as the Modification of Nakayasu SUH Model

The modification of the Nakayasu SUH model is based on the independent (input) variable determined based on the watershed morphometry characteristic and the dependent variable determined based on the mean unit hydrograph. The steps of building the model are as follows:

a. *Finding the relation between the input variables for determining the multi-collinearity between the variables and the correlation analysis:* If the correlation between the variables is high, the two variables influence each other, so one of them is enough to determine the regression variable;

b. *Finding the relation between each input variable and each output variable:* The input variable with high correlation can be used as the input variable;

c. *The multiple linear regression* is carried out to compile Nakayasu SUH's modification. The regression analysis shows the relation between two or more variables and has an independent variable (VB) and a dependent variable (VTB). The independent variable in this research is the variable whose value is known (watershed parameter). However, the dependent variable value will be found;

d. *The evaluation of regression value for knowing whether the regression equation produced has a good performance in presenting the input variable:* This test is carried out to evaluate the best form of the model. It indicates whether the model has shown good performance; besides, it is seen from the correlation coefficient, determination coefficient, and variance analysis. The model performance can also be analyzed based on the residual test: normal distributed residual, not each auto-correlation residual+, and homogenous residual variance. The compilation and evaluation of the model can be carried out by using the software of SPSS 25. The regression model will also be verified with the step-wise regression;

e. Based on the regression analysis, the new constant (parameter) regarding the watershed condition in the research location will be obtained and expressed with the formulation.

In this research, validation and verification are carried out to assess the performance of the time lag model. The aim of this validation is to evaluate the model enforceability for other data. The validation is carried out by measuring the model performance using rainfall and discharge data for other years that were not used in the model compilation. Then, verification is carried out by using the data in the other watersheds that were not used in the model compilation. The test results of validation and verification can be seen from the error indicator of each parameter. Fig. 2 presents the flow chart of the time lag modeling.

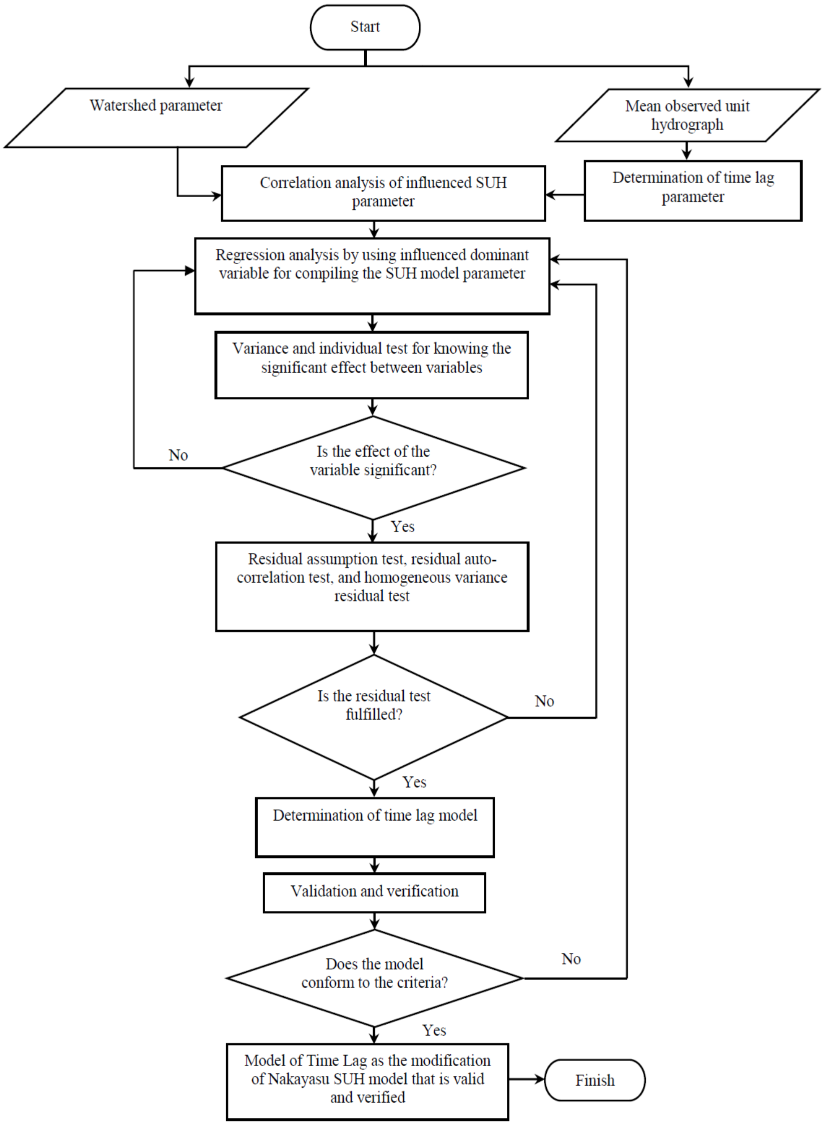

Fig. 2 Flow chart of time lag modeling

3. Results and Discussion

3.1. Results of Time Lag with Various Numbers of Independent Variables

There were 63 function equations for determining the time lag using between one and six independent variables, as presented in Table 2. Statistical analysis was carried out for each function equation to obtain each value of the coefficient in the function equation. The analysis was carried out using multiple linear regression, and the results are presented in Table 2.

Table 2 Output resume result of multiple linear regression analysis

No	Equation	Summary Output				
	1 Variable	**Multiple R**	**R^2**	**Adj. R^2**	**Std. Error**	**Sig. F**
1	A	0.8727	0.7615	0.7161	2.3084	0.000000039
2	L	0.8944	0.7999	0.7544	2.1147	0.000000006
3	I	0.6551	0.4291	0.3836	3.5719	0.000554365
4	D	0.5385	0.2900	0.2446	3.9833	0.006856411
5	Lc	0.8994	0.8089	0.7635	2.0664	0.000000004
6	H	0.7976	0.6362	0.5907	2.8513	0.000003745
No	**Equation**	**Summary Output**				
	2 Variables	**Multiple R**	**R^2**	**Adj. R^2**	**Std. Error**	**Sig. F**
1	A.L	0.9096	0.8273	0.7715	2.0106	0.000000016
2	A.I	0.9109	0.8298	0.7741	1.9960	0.000000014
3	A.D	0.9153	0.8378	0.7824	1.9488	0.000000008
4	A.Lc	0.9176	0.8419	0.7868	1.9238	0.000000006
5	A.H	0.8789	0.7725	0.7140	2.3079	0.000000254
6	L.I	0.9077	0.8240	0.7680	2.0301	0.000000019
7	L.D	0.8972	0.8050	0.7481	2.1367	0.000000054
8	L.Lc	0.8995	0.8092	0.7525	2.1137	0.000000043
9	L.H	0.9098	0.8277	0.7718	2.0087	0.000000015
10	I.D	0.6556	0.4298	0.3551	3.6536	0.002935947
11	I.Lc	0.9126	0.8329	0.7773	1.9780	0.000000011
12	I.H	0.8714	0.7593	0.7002	2.3741	0.000000450
13	D.Lc	0.9014	0.8124	0.7559	2.0955	0.000000036
14	D.H	0.8296	0.6882	0.6257	2.7020	0.000006200
15	Lc.H	0.9191	0.8448	0.7898	1.9063	0.000000005
No	**Equation**	**Summary Output**				
	3 Variables	**Multiple R**	**R^2**	**Adj. R^2**	**Std. Error**	**Sig. F**
1	A.L.I	0.9261	0.8576	0.7934	1.8710	0.000000020
2	A.L.D	0.9227	0.8514	0.7865	1.9115	0.000000030
3	A.L.Lc	0.9206	0.8475	0.7823	1.9360	0.000000039
4	A.LH	0.9255	0.8566	0.7922	1.8778	0.000000022
5	L.I.D	0.9110	0.8299	0.7629	2.0449	0.000000109
6	L.I.Lc	0.9126	0.8329	0.7662	2.0268	0.000000092
7	L.I.H	0.9128	0.8333	0.7666	2.0245	0.000000090
8	I.D.Lc	0.9175	0.8419	0.7761	1.9714	0.000000055
9	I.D.H	0.8767	0.7686	0.6955	2.3850	0.000002027
10	I.D.A	0.9171	0.8410	0.7751	1.9771	0.000000058
11	D.Lc.H	0.9193	0.8451	0.7796	1.9516	0.000000045
12	D.Lc,A	0.9280	0.8611	0.7972	1.8479	0.000000016
13	D.Lc.L	0.9015	0.8128	0.7440	2.1454	0.000000272
14	Lc.H.A	0.9432	0.8896	0.8286	1.6474	0.000000002
15	Lc.H.L	0.9202	0.8468	0.7815	1.9406	0.000000040
16	Lc.H.I	0.9210	0.8483	0.7832	1.9309	0.000000037
17	A.I.D	0.9171	0.8410	0.7751	1.9771	0.000000058
18	A.I.Lc	0.9324	0.8695	0.8064	1.7914	0.000000009
19	A.I.H	0.9166	0.8401	0.7741	1.9828	0.000000061
20	A.D.H	0.9157	0.8384	0.7723	1.9930	0.000000067
No	**Equation**	**Summary Output**				
	4 Variables	**Multiple R**	**R^2**	**Adj. R^2**	**Std. Error**	**Sig. F**
1	A.L.I.D	0.9264	0.8582	0.7832	1.9155	0.000000134
2	A.L.I.Lc	0.9373	0.8786	0.8068	1.7726	0.000000033
3	A.L.I.H	0.9303	0.8655	0.7916	1.8656	0.000000083
4	L.I.D.Lc	0.9176	0.8421	0.7645	2.0216	0.000000350
5	L.I.D.H	0.9150	0.8372	0.7589	2.0523	0.000000458
6	I.D.Lc.H	0.9252	0.8559	0.7805	1.9309	0.000000154
7	I.D.Lc.A	0.9325	0.8695	0.7963	1.8376	0.000000064
8	I.D.Lc.L	0.9176	0.8421	0.7645	2.0216	0.000000350

Continuation of Table 2						
9	D.Lc.H.A	0.9452	0.8934	0.8240	1.6606	0.000000010
10	D.Lc.H.L	0.9204	0.8471	0.7704	1.9890	0.000000262
11	D.Lc.H.I	0.9252	0.8559	0.7805	1.9309	0.000000154
12	Lc.H.A.L	0.9447	0.8925	0.8229	1.6678	0.000000011
13	Lc.H.A.I	0.9447	0.8925	0.8229	1.6677	0.000000011
14	H.A.L.D	0.9307	0.8662	0.7924	1.8610	0.000000080
15	H.A.D.I	0.9187	0.8440	0.7668	2.0090	0.000000313
No	**Equation**	**Summary Output**				
	5 Variables	**Multiple R**	**R^2**	**Adj. R^2**	**Std. Error**	**Sig. F**
1	A.L.I.D.Lc	0.9375	0.8788	0.7963	1.8192	0.000000205
2	L.I.D.Lc.H	0.9253	0.8562	0.7687	1.9817	0.000000858
3	I.D.Lc.H.A	0.9453	0.8935	0.8143	1.7055	0.000000069
4	D.Lc.H.A.L	0.9477	0.8981	0.8199	1.6685	0.000000048
5	Lc.H.A.L.I	0.9471	0.8970	0.8185	1.6776	0.000000053
6	H.A.L.I.D	0.9311	0.8670	0.7819	1.9059	0.000000447
No	**Equation**	**Summary Output**				
	6 Variables	**Multiple R**	**R^2**	**Adj. R^2**	**Std. Error**	**Sig. F**
1	A.L.I.D.Lc.H	0.9511	0.9046	0.8064	1.7118	0.000000903

3.2. Selection of the Time Lag Function Equation Model

A model of the function equation that could be selected to estimate the time lag was applied using specific tests. In statistical analysis, there are some basic steps for determining whether a regression function has a good value. They involve determining the value of R^2 from the regression result for the independent variable that is used, which should be no greater than 1. If the independent variable that is used has a value greater than 1, it is often evaluated using multiple regression, so the parameter that is used for determining whether the regression result is good is the adjusted R^2. Usually, the value of R^2 will be close to 1 if there are many independent variables, but its greater value does not show that the value of the adjusted R^2 is greater. Therefore, the initial model selection that is suitable is based on the biggest value of the adjusted R^2.

The coefficient of determination is a scale that describes a portion of the dependent variable. The value of the determination coefficient is between 0 and 1. This research used the adjusted R^2, where the range is also between 0 and 1. The closer the adjusted R^2 value is to 1, the better the model's ability to describe the dependent variable becomes. In the opposite direction, if the value of the adjusted R^2 is far from 1, it indicates that the model's ability to describe the dependent variable is poor. Based on the statistical analysis, the value of the adjusted R^2 for 63 models was in the range between 0.2446 and 0.8236. The range of adjusted R^2 has high variation, so the assessment was carried out by selecting an adjusted R^2 that was greater than 0.75.

Based on the criteria delineated above, 11 models did not pass the evaluation or had an adjusted R^2 less than 0.75. After identifying these models, the selected model result was re-evaluated to determine whether the regression result had a significant effect. The results of the regression analysis needed to be tested to determine the significance of the independent variables for each other. The test was carried out via simultaneous testing (simultaneous and integrated) with the F test and a partial test for each independent variable using the *t*-test. To see the results of the *t*-test, an analysis of variance (ANOVA) analysis was carried out, as presented in Table 3 (one of the regression model samples with six independent variables).

Table 3 ANOVA result of the regression model with six independent variables

ANOVA						
	df	*SS*	*MS*	*F*	*Sig. F*	
Regression	6	441.6407	73.60679	25.02088	2.786E-07	
Residual	17	50.01085	2.941815			
Total	23	491.6516				
	Coef.	*St. Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Luas	0.004379	0.001652	2.651143	0.016801	0.0008941	0.00786373
Panjang Sungai utama	-0.05858	0.065629	-0.89256	0.384552	-0.1970438	0.07988746
Kemiringan	3.957532	21.51687	0.183927	0.856247	-41.439096	49.3541599
Kerapatan Sungai	1.525825	3.257642	0.468383	0.64546	-5.3471985	8.39884776
Panjang Sungai ke titik DAS (Lc)	0.230363	0.100776	2.2859	0.035368	0.017745	0.44298041
H= L.Lc	-0.00126	0.0007	-1.80286	0.089165	-0.0027376	0.00021476

From the result of t-test, about seven models were selected that allow the partial test toward the independent variables. From the seven models replicated, the models generally used a small number of independent variables (≤ 2 variables); only one model had three independent variables. Meanwhile, for more independent variables, partial testing was unavoidable. To select the final model to be used, the last step was to look back at the biggest value of adjusted R^2 among the seven models. The biggest value of adjusted R^2 of the seven models was 0.8286, with three independent variables. Therefore, the selected model for time lag from the 63 models was as follows:

$$t_L = aL_c{}^b H^d A^e$$

The results of the statistical analysis of the model are presented in Table 4.

Table 4 Result of statistical analysis

Summary Output						
Regression Statistics						
Multiple R	0.943185					
R Square	0.889599					
Adjusted R Square	0.828559					
Standard Error	1.647406					
Observations	23					
ANOVA						
	df	***SS***	***MS***	***F***	***Sig. F***	
Regression	3	437.3727	145.7909	53.71916	1.801E-09	
Residual	20	54.27892	2.713946			
Total	23	491.6516				
	Coef.	***St. Error***	***t Stat***	***P-value***	**Lower 95%**	**Upper 95%**
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
River length to the weight point of the watershed (Lc)	0.180905	0.039277	4.605916	0.000171	0.0989752	0.2628344
H = L.Lc	-0.00159	0.000542	-2.93913	0.008112	-0.0027259	-0.000463
Area	0.003459	0.001214	2.849352	0.009911	0.0009267	0.0059913
Residual Output					**Probability Output**	
Observation	**Predicted Time Lag (Jam)**	**Residuals**	**Standard Residuals**		**Percentile**	**Time Lag (Jam)**
1	5.254143	-2.25414	-1.46734		2.17	1.42
2	3.654297	-1.20985	-0.78755		6.52	1.57
3	1.375157	1.053414	0.685721		10.87	2.43
4	2.327768	0.272232	0.17721		15.22	2.44
5	5.278834	-0.56455	-0.36749		19.57	2.50
6	3.462375	-0.66237	-0.43117		23.91	2.60
7	5.789768	-0.28977	-0.18862		28.26	2.80
8	3.297168	-0.79717	-0.51892		32.61	3.00
9	3.656168	-0.65617	-0.42713		36.96	3.00
10	4.321695	0.789416	0.513871		41.30	3.00
11	3.080179	-1.50875	-0.98212		45.65	3.11
12	4.988931	-0.58893	-0.38336		50.00	4.25
13	0.732751	0.683916	0.445196		54.35	4.40
14	4.338298	1.161702	0.756211		58.70	4.71
15	3.735888	0.514112	0.334661		63.04	5.00
16	1.457611	5.342389	3.477634		67.39	5.11
17	5.270212	1.396455	0.909024		71.74	5.17
18	3.017283	-0.01728	-0.01125		76.09	5.40
19	4.560714	0.439286	0.285954		80.43	5.50
20	7.700776	2.299224	1.496682		84.78	5.50
21	4.09762	-0.99236	-0.64598		89.13	6.67
22	6.649746	-1.48308	-0.96541		93.48	6.80
23	5.000474	0.399526	0.260072		97.83	10.00

Based on the analysis results above, the value of each variable for the above equation can be determined. This is expressed as follows:

$$t_L = L_c{}^{0.1809} H^{-0.00159} A^{0.003459}$$

3.3. Validation of the Model

Validation of the model was carried out for all watersheds. The validation process was used to illustrate the comparison between the values of the time lags from the observation and the selected model. The validation result was controlled by the values of rootmean-square error (RMSE), mean absolute error (MAE), and Nash–Sutcliffe efficiency (NSE), which fulfilled the requirements.

The validation was analyzed, for example, in the Singkoyo watershed and produced the following results for the SUH: RMSE = 0.4507 or 45.07%, MAE = 0.296 or 29.6%, and NSE = 0.92. However, the analysis of time lag by using the time lag modification of Nakayasu SUH in the Singkoyo watershed produces the following results: RMSE = 0.27, MAE = 0.20, and NSE = 82.22%. The error value is the same as the error of every ordinate that is produced. Looking at the error in the time to peak (Tp) analysis for Nakayasu SUH in the Singkono watershed, it was about 0.88 hours, whereas the Tp based on the Nakayasu SUH was about 3.88 hours. In contrast, based on actual field data, it was about 3 hours. Therefore, the error for the Tp was about 30%. For the time lag, based on the analysis result and compared with the result of the observed (actual) unit hydrograph, it can be seen that the error level produced emerged because of the values of RMSE, MAE, and NSE. The RMSE is about 0.273 or 27.3%; however, the MAE is about 0.196 or 19.6; the NSE is about 91.78%. The result shows a decreasing error level starting from RMSE and MAE values and increasing NSE value. However, after the modification of the Nakayasu SUH model, the time to peak (Tp) gives an error of about 2.6%.

4. Conclusion

The watershed morphometry characteristic is different in almost every region. As such, an SUH model is very accurate if it is applied in the watershed where the SUH model is developed; however, if it is applied in another watershed, it will produce errors or deviations.

There are four main parameters in the Nakayasu SUH that make up the unit hydrograph: peak discharge (Qp), time to peak (Tp), recession time from Qp to 30% of Qp ($T_{0.3}$), and time lag (tg). The time lag (tg) parameter is the main parameter that determines the three (3) other parameters: Qp, Tp, and $T_{0.3}$. The three (3) other parameters are functions of time lag (tg).

Until now, the watersheds in Indonesia have not had the model modification of Nakayasu SUH, which is used for planning and managing water resources. It is built based on the hydrological characteristic and watershed that has the specific characteristic of the topography side. Therefore, an adjustment of the parameter is needed to increase the model performance of SUH when applying it in Indonesia. The result of model modification for time lag is $t_L = {L_c}^{0.1809} H^{-0.00159} A^{0.003459}$. The validation has been analyzed, for example, in the Singkono watershed and produces the result for the SUH as follows: RMSE = 0.45; MAE = 0.30; and NSE = 0.92. However, the analysis of time lag using the time lag modification of Nakayasu SUH in the Singkoyo watershed produces the result as follows: RMSE = 0.27, MAE = 0.20, and NSE = 0.92.

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