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Modification of Snyder Synthetic Unit Hydrograph Model

Riman[1]*, M. Bisri[2]*, Pitojo Tri Juwono[2], Aniek Masrevaniah[2]

([1] Doctoral Student, Department of Water Resources Engineering, Faculty of Engineering, University of Brawijaya, Jl. MT Haryono No. 167, Malang, Indonesia

[2] Department of Water Resources Engineering, Faculty of Engineering, University of Brawijaya, Jl. MT Haryono No. 167, Malang, Indonesia)

* Corresponding authors: riman.sipil@gmail.com, mbisri@ub.ac.id

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Abstract: This study intends to modify the Snyder Synthetic Unit Hydrograph (SUH) model. There are two physical parameters, C_t and C_p in Snyder SUH, which are coefficients that depend on watershed characteristics. In the original model, the values of C_t and C_p must be empirically determined according to the watershed condition. However, this research was conducted in 10 watersheds in Indonesia, which must have an Automatic Rainfall Recorder (ARR) and an Automatic Water Level Recorder (AWLR). The methodology consists of 1) finding the relation between input variables for determining the multi-co-linearity between the variables; 2) to find the relation between input and output variables; 3) to analyze by using multiple linear regression by using Partial Least Square-Structural Equation Model (PLS-SEM) and Artificial Neural Network (ANN); 4) to evaluate the regression value for determining whether the regression equation has good performance in presenting the input variables; 5) to obtain the model with a new constant in accordance with the watershed condition in the research location; and 6) to carry out model validation and verification. The modification result of the Snyder SUH model is as follows: Tp = Ct. $Lc^{0.325}$ (R^2 = 89.3%); Ct = 0.680 ($Wr^{0.153}$ / $S^{0.143}$); Qp= Cp. (1 / $Tp^{2.969}$) (R^2 = 91.6%); Cp = 0.537 $K^{1.624}$; Tb = 3.919

$A^{0.569}$ / $Qp^{0.562}$ (R^2 = 72.7%)

Keywords: Snyder synthetic unit hydrograph; regression; partial least square-structural equation model; artificial neural network

斯奈德合成单位线模型的修正

摘要：本研究旨在修改Snyder合成单位过程线(SUH)模型。Snyder SUH中有两个物理参数Ct和Cp，它们是取决于流域特征的系数。在原始模型中，Ct和Cp的值必须根据分水岭条件凭经验确定。然而，这项研究是在印度尼西亚的10个流域进行的，这些流域必须有自动降雨记录仪（ARR）和自动水位记录仪（AWLR）。该方法包括：1）寻找输入变量之间的关系，以确定变量之间的多重共线性；2）找出输入变量和输出变量之间的关系；3）利用偏最小二乘结构方程模型（PLS-SEM）和人工神经网络（ANN）进行多元线性回归分析；4）评估回归值，以确定回归方程是否具有良好的表现输入变量的性能；5）根据研究地点的流域条件，得到具有新常数的模型；6)进行模型验证和验证。Snyder SUH模型的修正结果如下：Tp=Ct。Lc0.325（R2=89.3%）；Ct=0.680（Wr0.153/S0.143）；Q p = Cp。(1 / Tp2.969) (R2 = 91.6%); Cp=0.537K1.624；Tb = 3.919 A0.569 / Qp0.562 (R2 = 72.7%)

关键词：斯奈德合成单位线；回归；偏最小二乘结构方程模型；人工神经网络

1. Introduction

Hydrological analysis is a transformation process of rainfall to discharge [1] in a watershed until the outlet of the structure plan. However, the design flood information is very important in relation to the design of the structure dimension [2], which influences the structure performance, development cost, and loss level caused by structures that experience failure due to design limits. Basically, this problem can be solved if there is available discharge data with good quality in a watershed [2-3], in determining the design flood, it is not necessary to use a model [4] to carry out the transformation analysis of rainfall to discharge. However, it is often found in the location of water structure design where discharge data are only available in a short time/period, the data quality is not too good, and there is no available data [4].

In the development of the synthetic unit hydrograph method [5-6], some empirical equations have been used to express the relationship between the characteristics of watershed morphometric [7-8] and the uncertainty of the hydrograph former, that is, peak discharge (Q_p), time to peak (T_p), and time base (T_b). The characteristic of watershed morphometry that is almost different in every region [9] causes a very accurate Synthetic Unit Hydrograph (SUH) model to be used if the SUH model is applied in the watershed where it is developed. However, if the SUH model is applied to other watersheds, there will be more deviation. This deviation produces inaccurate information about the design flood, which can be over-or underestimated. If a structure is designed by over-estimation, it will cause the dimension and development cost to be inefficient, and if a structure is designed by under-estimation, it will cause the failure risk of high structure.

In Snyder SUH, there are two non-physical parameters, C_t and C_p, which are dependent on the unit and characteristics of the watershed [10-11]. The C_t and C_p values were obtained from several watersheds in the Appalachian Highland (USA). However, the coefficients of C_t and C_p must be empirically determined because the values change between regions. Therefore, it is difficult to use this method for Indonesian rivers [12-13]. Therefore, it can be accepted in research locations in Indonesia, and the Snyder SUH model must be customized with local characteristics and conditions.

According to [14], in watersheds in East Java, Indonesia, the Snyder SUH produced an accuracy of T_p of 96.90%, Q_p of 82.72%, and T_b of 85.44%. Until now, the other islands in Indonesia have not had an SUH model that is used for the design and management of water resources, which is developed based on the characteristics of hydrology and watershed. Therefore, it is necessary to adjust the parameters to increase the performance of the Snyder SUH model for use in Indonesia. Based on the reasons above, it is necessary to carry out research related to the coefficients of C_t and C_p in watersheds in Indonesia, as well as T_p, T_b, and Q_p; therefore, it can be applied to other watersheds outside of the research location.

2. Materials and Methods

2.1. Research Location

The research locations are some watersheds in

Indonesia that are completed with an Automatic Water Level Recorder (AWLR) and Automatic Rainfall Recorder (ARR) with complete and long enough data recording, as presented in Figure 1 and Table 1.

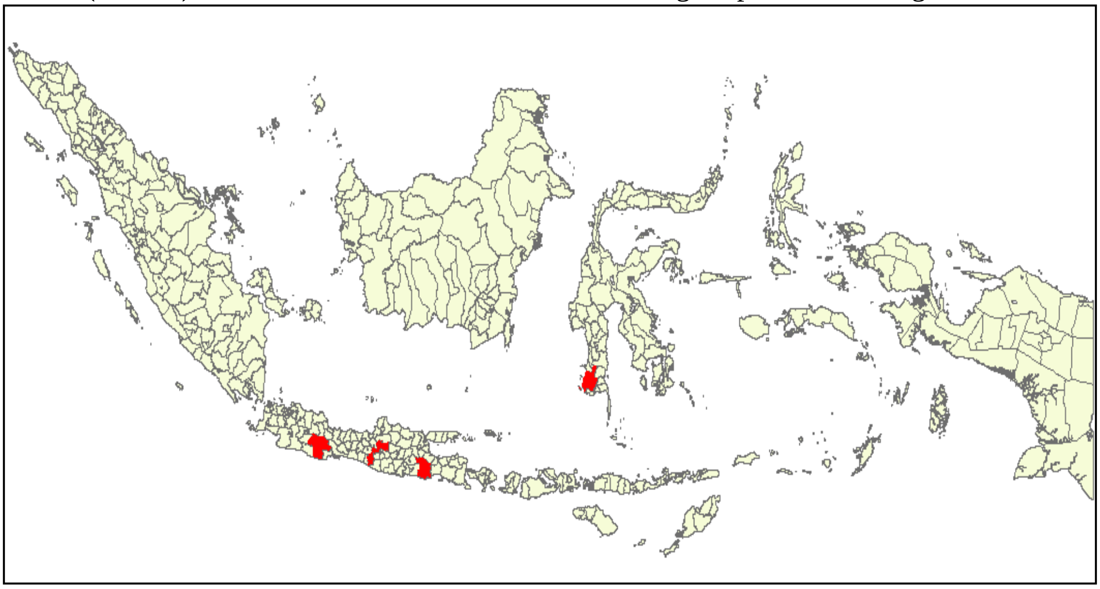


Figure 1. Watershed Map of Research Location
Source: Riman et.al [15]

2.2. Snyder SUH (Synthetic Unit Hydrograph) [15]

Snyder has developed a formulation using empirical coefficients that relate the uncertainty of the unit hydrograph with the specific characteristics of the watershed and to analyze the amount of watershed hydrographs in the Appalachian Mountain Region (USA) by the watershed area between 25 km^2 and 25,000 km^2.

The unit hydrograph is sufficient to determine the rainfall depth (d) = 1 cm, and the three other uncertain values are Qp (m^3/s), Tb (hours), and Tr (hours). The uncertainty of the hydrograph is related to A (watershed area, km^2), L (length of the main river, km), and Lc (the length of the river until the point nearest to the weight point of the catchment area, km).

Based on this uncertainty, Snyder built the following formulations [1-20]:

$$t_p = C_t\ (L_c \times L)^{0.3} \quad (1)$$

$$t_r = \frac{t_p}{5.5} \quad (2)$$

$$Q_p = 2.78\frac{C_{p\times A}}{t_p} \quad (3)$$

$$T_b = \frac{72+3T_p}{24} \quad (4)$$

Table 1 Location of Research Watershed, AWLR, and ARR (Source: Riman et.al [15])

No.	Research Location	Watershed	AWLR	ARR
1	Jawa Barat	Pataruman,WS Citanduy	AWLR Pataruman	St. Cibereum, St. Pataruman, St. Cihonje, St. Kawali, St. Cineam, and St. Pagerageung
2	Jawa Timur	Lesti, WS Brantas	AWLR Tawang Rejeni	St. Poncokusumo, St. Dampit
3	Jawa Timur	Gadang WS Brantas	AWLR Gadang	St. Jabung, and St. Malang
4	Jawa Timur	Dungus, WS B.Solo	AWLR Dungus	St. Ahmad Yani, St. Jatirogo
5	Jawa Tengah	Girimargo, WS Pemali Juana	AWLR Kunthi	St. Kunthi
6	Jawa Tengah	Jurug WS B.Solo	AWLR Jurug	St. Klaten, St. Jatipuro, and St. Gunungan
7	Daerah Istimewa Yogyakarta	Code, WS Serayu Opak	AWLR Kaloran	St. Prumpung, St. Kemput, and St. Angin-angin
8	Sulawesi Selatan	Sombala, WS Pompengan Jeneberang	AWLR Sombala	St. Janelata,

No.	Research Location	Watershed	AWLR	ARR
				St. Bonto Jai, and St. Jonggoa
9	Sulawesi Selatan	Kampili WS Pompengan Jeneberang	AWLR Kampili	St. Janelata, St. Bonto Jai, and St. Jonggoa
10	Sulawesi Selatan	Jonggoa WS Pompengan Jeneberang	AWLR Jonggoa	St. Jonggoa, and St. Daraha

However, the coefficients C_t and C_p must be empirically determined because the dimensions are changed between one area and another. C_t is a coefficient that is dependent on the slope-basin (0.75 – 3.00), and can be used in the approach of Taylor and Schawarz as follows:

$$C_t = \frac{0.6}{\sqrt{s}} \quad (5)$$

C_p is a coefficient that is dependent on watershed characteristic (0.40 – 0.80).

The Snyder formulation, which has been changed, is used more frequently. The change is in the exponential of 0.30 is changed with n as follows:

$$t_p = C_t\ (L_c \times L)^n \quad (6)$$

t_r in formulation-2 is changed to t_e, which is the duration of the effective rainfall; however, t_r = 1 h. The duration of effective rainfall (t_e) is influenced by the time lag; this relationship can be seen in the formulation below:

$$t_e = \frac{t_p}{5.5} \quad (7)$$

The relation between t_e, t_p, t_r, and T_p is as follows:

If $t_e > t_r$

$$t'_p = t_p + 0.25\ (t_r - t_e \quad (8)$$

Therefore, there is obtained time to peak as follows:

$$T_p = t'_p + 0.50 t_r \quad (9)$$

If $T_p = t_p + 0.50 t_r$ (10)

$$Thus, q_p = 0.278\ \frac{C_p}{t_p} \quad (11)$$

where:

t_e : duration of effective rainfall (hour)
t_r: duration of 1-hour effective rainfall (hour)
t_p: time lag (hour)
T_p: time to peak (hour)
n : coefficient of proportional (0.10 – 0 .38)
Q_p: peak discharge (m^3/s/mm)
Q: unit hydrograph peak (m^3/s/mm/km^2)
S : average slope of watershed
H: rainfall depth= 1 mm

The other functions that are used is as follows:

$$T_p = C_t \left\{\frac{L \times L_c}{S}\right\}^n \quad (13)$$

$$T_b = 5 + (T_p + t_r/2) \quad (14)$$

Snyder built an empirical formula for the peak discharge (Q_p) and time to peak (T_p) of a hydrograph. To obtain a hydrograph curve, time was required to calibrate the parameters. To accelerate the process, the Alexeyev formulation is used, which provides the unit hydrograph form. The form of the unit hydrograph determined using the Alexeyev formulation is as follows:

$$Q = f(t) \quad (15)$$

$$Y = \frac{Q}{Q_p} \quad (16)$$

$$x = \frac{t}{t_p} \quad (17)$$

$$Y = 10^{-a\frac{(1-x)^2}{x}} \quad (18)$$

$$a = 1.32\ \lambda^2 + 0.15\ \lambda + 0.045 \quad (19)$$

$$\lambda = \frac{Q_p T_p}{h.A} \quad (20)$$

Figure 2 shows the Synthetic Unit Hydrograph of Snyder with Alexeyev formulation.

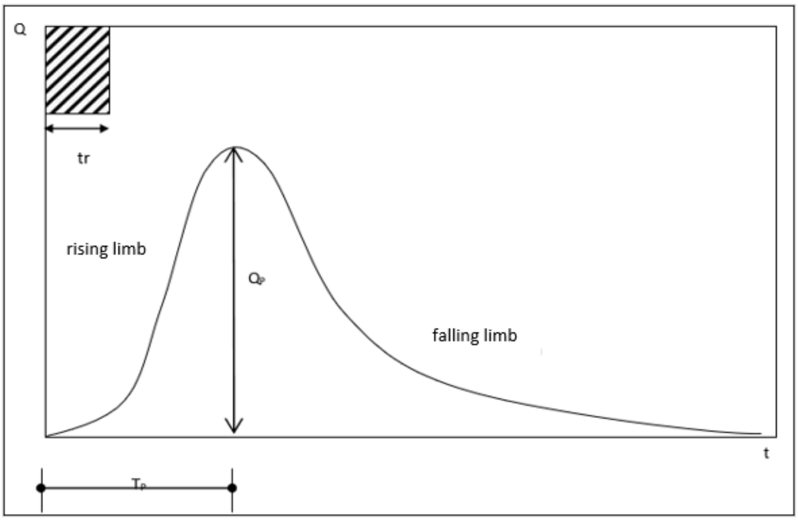


Figure 2. Synthetic Unit Hydrograph of Snyder with Alexeyev Formulation [8]
Source: own study

2.2. Methodology

The modification of the Snyder SUH model is based on the independent variable input, which is determined based on the characteristics of the watershed morphometric and dependent variable output, which is determined based on the average unit hydrograph. The steps for building the model are as follows.

(1) Correlation analysis was used to find the relationship between input variables for determining the multicollinearity between variables. If the correlation between variables is high, it means that both variables influence each other; therefore, in determining the regression variable, one of both variables is sufficient.

(2) To determine the relationship between each input variable and each output variable, an input variable with a high correlation can be used as the input variable of the model.

(3) Analysis of multiple linear regressions using the partial least squares structural equation modeling (PLS-SEM) method was carried out to modify the SUH model. This analysis is carried out to show the relationship between two or more variables; in this analysis, there are two variables: independent variables (VB) and dependent variables (VTB). However, the independent variable is variable that has been known as the value (watershed parameter), and the dependent variable is that will be found the value.

(4) The regression test was used to determine whether the regression equation performed well in presenting input variables. This test is carried out to evaluate the best form of the model; it indicates whether the model has shown good performance, and it is seen from the values of the correlation coefficient, determination coefficient, and variance analysis. The model performance can also be analyzed based on the residual test, which is a normally distributed residual, non-auto-correlation residual to each other, and homogeneous residual variance. The arrangement and evaluation of the model was carried out using the graded residual gradient (GRG) method with an Artificial Neural Network (ANN).

(5) Based on the regression analysis using PLS-SEM, the model was obtained with a new constant (parameter) in accordance with the watershed condition in the research location, and it is expressed by the formula.

(6) Validation and verification of the model to determine the model performance are then carried out to validate and verify the modification of the Snyder SUH model that has been built using ANN-based GRG. Validation is intended to evaluate the enforceability of the model using other data. Validation was carried out by measuring the model performance using rainfall and discharge data in other periods (years) that were not used in the model building. Verification was then carried out using data from other watersheds on the islands of Indonesia that were not used for building the model. The evaluation results of the validation and verification of the model can be observed from the error indicator of the parameter.

3. Results and Discussion

3.1. Time to peak (T_p)

The time to peak is explained by Lc, Wr, and S by the nonlinear equation as follows:

$$Tp = b_0 .\ Lc^{b1} .\ Wr^{b2} .\ S^{b3}$$

Table 2 presents the test results of the regression coefficient for the time to peak, and Table 3 presents the coefficient of ANN for the time to peak.

Table 2. Test Result of regression coefficient for time to peak (Source: own study)

Variable	Parameter	Estimate	Std. Error	t	p
Contant	b_0	0.680	0.162	4.198	0.001
Lc	b_1	0.325	0.068	4.779	0.000
Wr	b_2	0.153	0.049	3.122	0.008
S	b_3	-0.143	0.051	-2.804	0.014

The regression equation for time to peak is as follows:

$Tp = 0.680\ Lc^{0.325}\ Wr^{0.153}\ S^{-0.143}$; $R^2 = 0.893$

or

$Tp = 0.680\ (Wr^{0.153} / S^{0.143}).\ Lc^{0.325}$

$= Ct.\ Lc^{0.325}$

$Ct = 0.680\ (Wr^{0.153} / S^{0.143})$

Table 3. ANN coefficient for time to peak (Source: own study)

Predictor		Predicted							
		Hidden Layer [a]							Output Layer
		H(1)	H(2)	H(3)	H(4)	H(5)	H(6)	H(7)	T_p
Input Layer	Lc	20.146	10.268	33.412	21.552	33.459	28.935	10.909	
	Wr	18.466	22.999	24.622	32.031	5.177	43.090	6.595	
	S	0.023	0.048	0.016	0.020	0.019	0.009	0.045	
Hidden Unit Width		3.550	2.736	2.736	2.736	2.736	4.411	4.151	

Continuation of Table 3

Hidden Layer	H(1)	5.102
	H(2)	3.861
	H(3)	5.976
	H(4)	5.402
	H(5)	5.190
	H(6)	7.402
	H(7)	2.998

a. Displays the center vector for each hidden unit.

The validation of the regression equation result for the time to peak (T_p) had NSE = 89.2% and MAPE = 9.7%. This means that the predicted value is a very good category. The comparison with the ANN result has the best model with a hidden layer of 7, and the prediction of time to peak has higher validation than the nonlinear model. The validation of the ANN result had an NSE of 92.0% and MAPE of 6.4%.

The verification of the prediction result for Tp for the four datasets of the watershed produces a regression equation for time to peak (T_p) with NSE = 69.5% and MAPE = 5.2%, which explains why the prediction value of the verification data is a very good category. The verification using the ANN result had an NSE of 72.0% and MAPE of 5.0%, indicating that the prediction value of the verification data is a very good category.

3.2. Peak Discharge (Q_p)

The peak discharge is explained by Lc, Wr, and S using the following nonlinear equation:

$$Q_p = b_0.\ Tp^{b1}.\ K^{b2}$$

Table 4 presents the test results of the regression coefficients for the peak discharge.

Table 4. Test result of regression coefficient for peak discharge (Source: own study)

Variable	Parameter	Estimate	Std. Error	t	p
Constant	b_0	0.537	0.281	1.911	0.069
T_p	b_1	-2.969	0.988	-3.005	0.009
K	b_2	1.624	0.325	4.997	0.000

The regression equation for peak discharge is as follows:

$Q_p = 0.537\ T_p^{-2.969}\ K^{1.624}$; $R^2 = 0.916$

or

$Q_p = 0.537\ K^{1.624}\ (1 / T_p^{2.969})$

$= C_p\ (1 / T_p^{2.969})$

$C_p = 0.537\ K^{1.624}$

The result validation of the regression equation for the peak discharge (Q_p) has an NSE of 91.6% and MAPE of 39.6%, which indicates that the prediction value is a good category. The comparison with the ANN result has the best model with a hidden layer of six, and the prediction of peak discharge has the validation is almost the same as that of the non-linear model. The result validation of the ANN had an NSE of 81.4% and MAPE of 6.8%.

The result of T_p verification for the four watershed datasets produces the regression equation of peak discharge (Q_p) with NSE = 94.0% and MAPE = 30.5%, which explains that the prediction value of the verification data is a good category. The verification using ANN had an NSE of 79.9% and MAPE of 13.2%, which indicates that the prediction value of the verification data is a good category. Table 5 presents the coefficients of ANN for peak discharge.

Table 5. ANN Coefficient for peak discharge (Source: own study)

Predictor		Predicted						
		Hidden Layer [a]						Output Layer
		H(1)	H(2)	H(3)	H(4)	H(5)	H(6)	Q_p
Input Layer	T_p	4.493	5.082	5.700	8.200	6.600	3.167	
	K	92.546	235.874	426.154	1195.397	714.085	17.163	
Hidden Unit Width		27.476	41.229	2.361	2.361	2.361	2.361	
Hidden Layer	H(1)							14.493
	H(2)							28.228
	H(3)							55.591
	H(4)							97.750
	H(5)							98.780
	H(6)							2.641

The regression equation for time base is as follows:

$T_b = 3.919\ Q_p^{-0.562}.\ A^{0.569}$; $R^2 = 0.727$

or $T_b = 3.919.\ A^{0.569} / Q_p^{0.562}$

Table 6. Test Result of regression coefficient for time to base (Source: own study)

Variable	Parameter	Estimate	Std. Error	t	p
Constant	b_0	3.919	1.332	2.942	0.011
Q_p	b_1	-0.562	0.129	-4.357	0.001
A	b_2	0.569	0.106	5.368	0.000

The regression equation for time base is as follows:

$T_b = 3.919\ Q_p^{-0.562}.\ A^{0.569}$; $R^2 = 0.727$

or $T_b = 3.919.\ A^{0.569} / Q_p^{0.562}$

The result validation of the regression equation for the time base (Tb) has an NSE of 72.7% and MAPE of 16.6%, which indicates that the prediction value is a good category. The comparison with the ANN results showed that the best model with a hidden layer of 9. However, the prediction of peak discharge has a higher validation than that of the nonlinear model. The result validation of the ANN had an NSE of 80.7% and MAPE of 11.2%. Table 7 presents the coefficients of the ANN for the time base.

Table 7. ANN coefficient for time base (Source: own study)

Predictor		Predicted									
		Hidden Layer [a]									Output Layer
		H(1)	H(2)	H(3)	H(4)	H(5)	H(6)	H(7)	H(8)	H(9)	T_b
Input Layer	Q_p	98.78	97.75	21.43	32.92	18.22	55.59	3.11	13.76	8.13	
	A	3284.91	3725.05	1257.98	777.36	379.04	1376.75	52.24	157.31	238.24	
Hidden Unit Width		3.96	3.96	3.96	131.08	3.96	3.96	26.01	31.56	16.76	
Hidden Layer	H(1)										19.800
	H(2)										31.430
	H(3)										39.716
	H(4)										26.690
	H(5)										25.635
	H(6)										32.780
	H(7)										16.720
	H(8)										12.944
	H(9)										28.496

a. Displays the center vector for each hidden unit.

The verification of the prediction result for the Tb to 4 watershed data is as follows. The result of the regression equation for peak discharge (Q_p) has NSE = 71.1% and MAPE = 4.5%, which indicates that the prediction value of the verification data is a good category. However, the verification using the ANN result had an NSE of 60.1% and MAPE of 4.6%, which indicates that the prediction value of the verification data is a good category.

3.3. Calibration of Model

After obtaining the selected regression model for time to peak (T_p), peak discharge (Q_p), and time base (T_b), the next stage was to calibrate the model. The aim of model calibration is to evaluate the accuracy of the modeled unit hydrograph parameters. From the calibration process that is carried out based on the criteria of Nash (KN), the accuracy value for the nonlinear regression result is obtained as follows:

Model time to peak (T_p), KN = 89.2%

– Model of peak discharge (Q_p), KN = 91.6%

– Model time base (T_b), KN = 72.7%

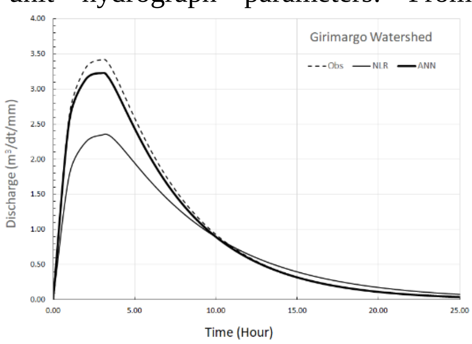
The calibration process that is performed based on the criteria of Nash (KN) produces the accuracy value for the ANN result as follows:

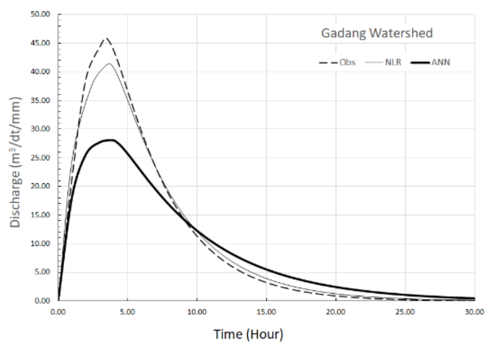
– Model of time to peak (T_p), KN = 92.0%

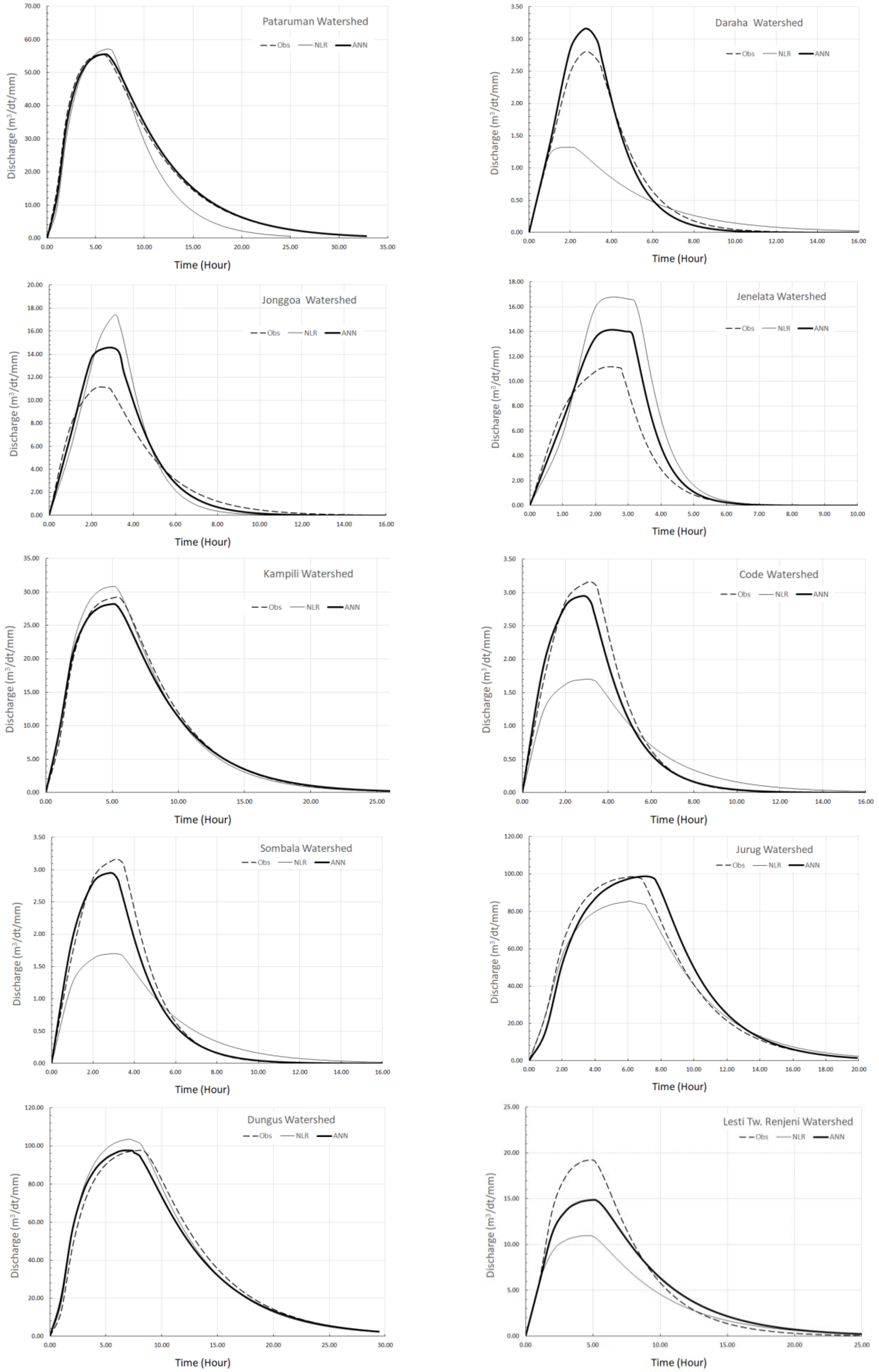
– Model of peak discharge (Q_p), KN = 94.0%

– Model of time base (T_b), KN = 80.7%

The comparison of hydrographs between the observation data, Snyder SUH modification with NLR, and Snyder SUH modification with ANN is as follows:






Pataruman Watershed
Obs
NLR
ANN
Discharge (m3/dt/mm)
Time (Hour)
Daraha Watershed
Obs
NLR
ANN
Discharge (m3/dt/mm)
Time (Hour)
Jonggoa Watershed
Obs
NLR
ANN
Discharge (m3/dt/mm)
Time (Hour)
Jenelata Watershed
Obs
NLR
ANN
Discharge (m3/dt/mm)
Time (Hour)
Kampili Watershed
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ANN
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Code Watershed
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Dungus Watershed
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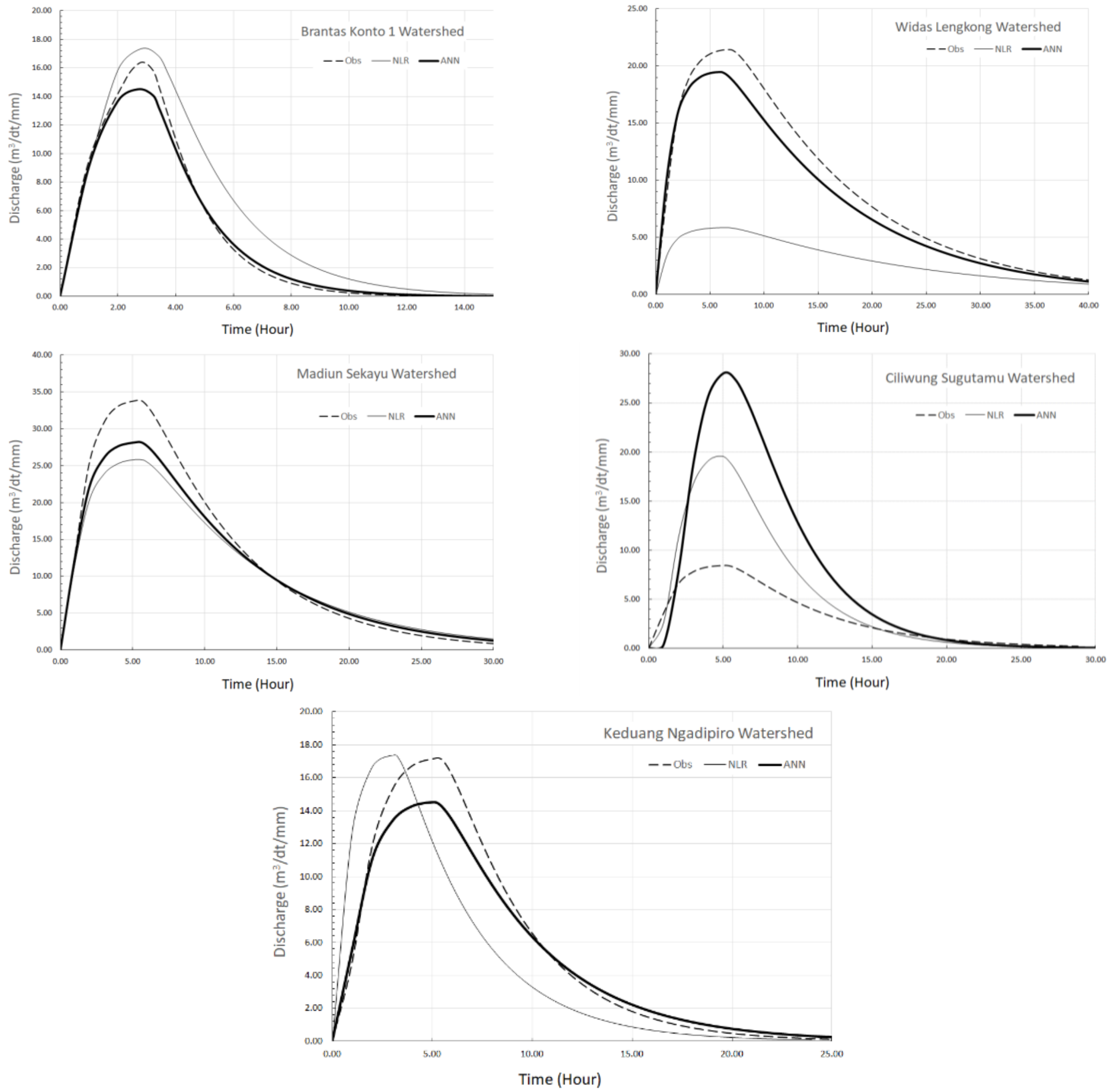

Figure 3. Comparison of hydrograph observation data, modification of Snyder SUH with NLR, modification of Snyder SUH with ANN (Validation) (Source: own study)

3.4. Verification of Model

Verification of the model is carried out to determine whether the Snyder SUH model that is developed based on watershed characteristics in the research location is feasible for use. This model verification is carried out in Lesti Watershed, Bonto Jai Watershed, Brantas Gadang Watershed and Probo Kranggan Watershed. The four watersheds were not used to build the regression model or ANN. Using the equation of the selected regression model, the component of the unit hydrograph for the four watersheds can be determined with the following result.

The analysis results and reliability level of the model in the four watersheds based on the NLR results are as follows:

– Lesti Watershed: T_p model = 3.89 hours; T_p measured = 4.11 hour; with the accuracy = 94.6%, Q_p model = 15.98 m^3/s; Q_p measured = 16.22 m^3/s; with the accuracy = 98.5%; T_b model = 24.03 hours; T_b measured = 25.33 hours; with the accuracy = 94.9%.

– Bonto Jai Watershed: T_p model = 3.98 hours; T_p measured = 4.24 hours; accuracy = 93.9%; Q_p model = 18.17 m^3/s; Q_p measured = 19.25 m^3/s; accuracy = 94.4%; T_b model = 18.24 hours; T_b measured = 21.95 hours; and accuracy = 83.1%.

– Brantas Gadang Watershed: T_p model = 5.00 hours; T_p measured = 5.17 hours; with the accuracy = 96.7% Q_p model = 24.84 m^3/s; Q_p measured = 29.79 m^3/s; with the accuracy = 83.4% T_b model = 24.74 hours; T_b measured = 25.30 hours; with the accuracy = 97.8%.

– Progo Kranggan Watershed: T_p model = 5.08 hours; T_p measured = 4.80 hours; accuracy = 94.2%; Q_p model = 15.12 m^3/s; Q_p measured = 14.63 m^3/s; accuracy = 96.7% T_b model = 27.35 hours; T_b measured = 28.10 hours; and accuracy = 97.3%.

The analysis results and reliability level of the model in the four watersheds based on the ANN results are as follows.

– Lesti Watershed: T_p model = 4.35 hours; T_p measured = 4.11 hours; with the accuracy = 94.2%; Q_p model = 14.61 m^3/s; Q_p measured = 16.22 m^3/s; with the accuracy = 90.1%; Tb model = 25.65 hours; T_b measured = 25.33 hours; with the accuracy = 98.7%.

– Bonto Jai Watershed: T_p model = 4.50 hours; T_p measured = 4.24 hours; with the accuracy = 93.9%; Q_p model = 15.04 m^3/s; Q_p measured = 19.25 m^3/s; with the accuracy = 78.1%; Tb model = 28.26 hours; T_b measured = 21.95 hours; dengan with the accuracy= 71.3%.

– Brantas Gadang Watershed: T_p model = 5.38 hours; T_p measured = 5.17 hours; with the accuracy = 95.9%; Q_p model = 28.23 m^3/s; Q_p measured = 29.79 m^3/s; with the accuracy = 94.8%; T_b model = 26.69 hours; Tb measured = 25.30 hours; with the accuracy = 94.5%.

– Progo Kranggan Watershed: T_p model = 4.99 hours; T_p measured = 4.80 hours; with the accuracy = 96.0%; Q_p model = 16.92 m^3/s; Q_p measured = 14.63 m^3/s; with the accuracy = 84.3%; T_b model = 26.69 hours; T_b measured = 28.10 hours; with the accuracy = 95.0%.

The comparison of hydrographs between the observation data, Snyder SUH modification with NLR, and Snyder SUH modification with ANN is as follows:

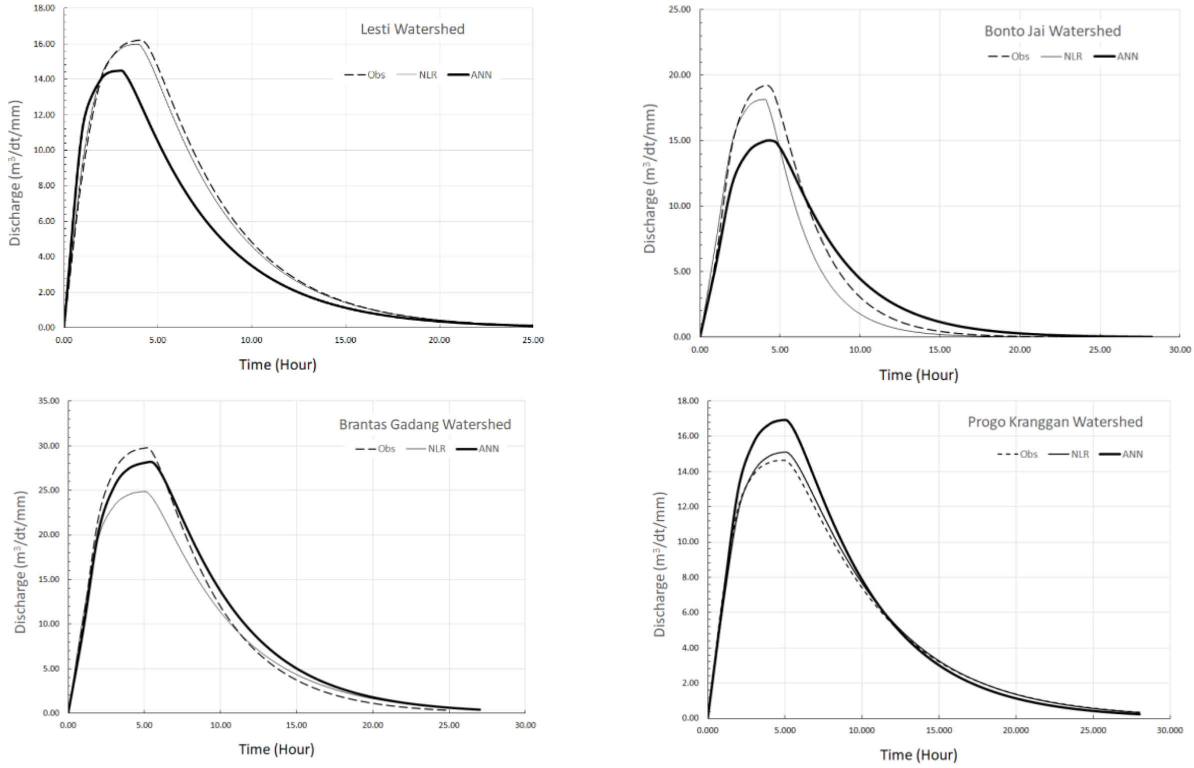

Figure 4. Comparison of hydrograph observation data, modification of Snyder SUH with NLR, modification of Snyder SUH with ANN (Verification) (Source: own study)

4. Conclusion

Based on the above analysis and discussion, we can conclude that the modification result of the Snyder SUH model is as follows: a) $T_p = C_t.\ Lc^{0.325}$ (R^2 = 89.3% and C_t= 0.680 ($W_r^{0.153}$ / $S^{0.143}$); b) Q_p= C_p. (1 / $T_p^{2.969}$) (R^2 = 91.6% and C_p = 0.537 $K^{1.624}$; c) T_b = 3.919 $A^{0.569}$ / $Q_p^{0.562}$ (R^2 = 72.7%)

The reliability of the modification of the Snyder SUH model using the NLR and ANN methods produces the following calibration results: a) model of time to peak (T_p), KN = 89.2% and 92.0%; b) model peak discharge (Q_p), KN = 91.6% and 94.0%; c) model time base (T_b), KN = 72.7% and 80.7%, respectively.

The verification results of the modification of Snyder SUH model by using NLR and ANN methods is as follows: a) The model accuracy of T_p as the result of NLR: Lesti Watershed (94.6%), Bonto Jai Watershed (93.9%), Brantas Gadang Watershed (96.7%), Progo Kranggan Watershed (94.2%); b) The model accuracy of Q_p as the result of NLR: Lesti Watershed (98.5%), Bonto Jai Watershed (94.4%), Brantas Gadang Watershed (83.4%), Progo Kranggan Watershed (96.7%); c) The model accuracy of T_b as the result of NLR: Lesti Watershed (94.9%), Bonto Jai Watershed (83,1%), Brantas Gadang Watershed (97.8%), Progo Kranggan Watershed (97.3%); d) The model accuracy of T_p as the result of ANN: Lesti Watershed (94.2%), Bonto Jai Watershed (93.9%), Brantas Gadang Watershed (95.9%), Progo Kranggan Watershed (96.0%); e) The model accuracy of Qp as the result of ANN: Lesti Watershed (90.1%), Bonto Jai Watershed (78.1%), Brantas Gadang Watershed (94.8%), Progo Kranggan Watershed (84.3%); f) The model accuracy of T_b as the result of ANN: Lesti Watershed (98.7%), Bonto Jai Watershed (71.3%), Brantas Gadang Watershed (94.5%), Progo Kranggan Watershed (95.0%).

This new model can be developed by adding more research locations; therefore, the model can be generally applied to many types of watersheds.

Declarations

Author Contributions

Conceptualization, R. and M.B.; methodology, R., M.B. and P.T.J.; formal analysis, R. and M.B.; writing—original draft preparation, all authors contributed equally; writing—review and editing, R.; visualization, A.M.; project administration, R. and M.B. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data presented in this study are available in this article.

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Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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