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Development of Unit Hydrograph Parameters Model Using Selected Watershed Parameters on Rivers in Central Sulawesi

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Abstract

This research aims to formulate hydrograph parameter equations using a larger number of highly correlated morphometric parameters on 8 watersheds in Central Sulawesi. There were 12 watershed parameters, namely area, main river length, main river slope, river length from centroid, the shape factor, order number, joint number, first-order river length, whole order river length, drainage density, reach number of first-order, and reach number of whole orders were used to construct the 3 main parameters of the unit hydrograph, namely peak time, peak discharge and base time. Regression analysis was applied to the watershed parameters to formulate the hydrograph parameters. The results showed that 5 of the watershed parameters showed a very large effect on the three hydrograph parameters with very low RMSE: 0.019, 0.098, and 0.014 for peak time, peak discharge, and time base, respectively. The low RMSE revealed that the three hydrograph parameter equations had very high performance.

Keywords: morphometric parameter, hydrograph of systemic unit, regression analysis, RMSE.

Abstrak

Penelitian ini bertujuan merumuskan persamaan parameter hidrograf menggunakan parameter morfometri berkorelasi tinggi lebih banyak pada 8 DAS terukur di Sulawesi Tengah. Ada 12 parameter DAS yaitu luas DAS, panjang sungai utama, kemiringan sungai utama, panjang sungai utama sampai titik terdekat titik berat DAS, faktor bentuk DAS, jumlah orde sungai, jumlah pertemuan sungai, panjang sungai orde 1, panjang sungai semua orde, kerapatan drainase, jumlah ruas orde 1, dan jumlah ruas semua orde digunakan untuk membangun 3 parameter utama hidrograf satuan yaitu waktu puncak, debit puncak dan waktu dasar. Regresi digunakan untuk memformulasikan ketiga parameter hidrograf tersebut. Hasil analisa menunjukkan 5 parameter DAS memiliki pengaruh yang sangat besar pada parameter hidrograf dengan RMSE yang sangat rendah: 0,019, 0,098, 0,014 secara berturut-turut untuk waktu puncak, debit puncak, dan waktu dasar. Rendahnya RMSE mengindikasikan bahwa ketiga persamaan parameter hidrograf berkinerja sangat tinggi.

Kata kunci: parameter morfometri, hidrograf satuan sistetik, analisis regresi, RMSE

1. Introduction

Discharge estimation using Synthetic Unit Hydrograph (SUH) approach is a topic that is still widely studied in hydrological analysis to date [1]. The limited amount and quality of the data used to derive the unit hydrograph is the main reason why SUH is the preferred alternative [2]. In general, especially in Indonesia, the limited number of discharges measuring instruments is not proportional to the number of rain gauges with a more even distribution. This is closely related to the high cost of investment, operation, and maintenance of discharge measurement instruments compared to the rain gauges with more diverse objectives [3]. The installation of discharge measuring instruments is only limited to the development and management of water resources, especially the utilization, preservation, and control of the destructive power of water in a watershed. Meanwhile, rain gauges are easier to find in various areas due to the various purposes of data utilization such as agricultural development, forest conservation, inland fisheries, navigation, and various other purposes [4] [5].

Three important parameters related to SUH are peak time (T_P), peak discharge (Q_P), and base time (T_b) as a representation of the hydrograph [6]. The ordinate of the hydrograph as an integral part of the hydrograph can be derived from these three parameters either by using a dimensionless unit hydrograph approach or by using one or more hydrograph curvature equations. Ideally, the best way to determine these three parameters is to average the data for each parameter from various hydrographs of measured units derived from flood hydrograph events recorded on discharge measuring instruments [7]. However, considering the limitations of the data as previously presented, other ways have been developed to determine these three parameters, either empirically, conceptually, and statistically [8].

A statistical and empirical approach is one of the most commonly applied ways to determine the three hydrograph parameters. The hydrograph parameter as a dependent variable is a function of various types of watershed parameters through a series of regression and dimensional analyzes [9]. The use of watershed parameters, especially watershed area, length and slope of the main river, watershed shape, and other morphometric parameters to determine hydrograph parameters is known as SUH, where the rain-flow transformation behavior is imitated by the morphometric characteristics of the watershed. The ease of obtaining watershed parameter data that can be accessed from various spatial-based free sources with adequate accuracy is the reason why statistics are widely used by a number of researchers.

The initiation of the use of the watershed parameter was carried out by Snyder where the three hydrograph parameters were determined from three watershed parameters: the total length of the main river, main river length from centroid of watershed to outlet, and watershed area [10]. The first two parameters were variables to determine the time lag, which was an important parameter for SUH Snyder. Nakayasu used similar watershed parameters except for the main river length from centroid of watershed to outlet to determine the hydrograph parameters [11]. The main characteristic that distinguishes Snyder's SUH parameters is in the form of the equation. The two hydrograph parameter equations used a very limited number of watershed parameters. In Indonesia, Brotowiryatmo developed a hydrograph parameter equation known as SUH GAMA I using a relatively large number of watershed parameters. The watershed parameters applied included main river length, watershed symmetry factor, watershed area, the number of river confluences, main river slope, source frequency, and upstream watershed area. In some cases, this method had a fairly good performance and in other cases, it showed a fairly high deviation for both applications in Java and outside Java.

Similar to SUH GAMA I, Limantara developed SUH Limantara parameters using several watershed parameters including watershed area, main river length, and main river length from centroid of watershed to outlet, main river slope, and watershed surface roughness factor [12]. SUH Limantara was designed to improve SUH accuracy in watersheds outside Java. As a continuation to improve the performance of SUH applications on various watersheds, especially in Indonesia, Natakusumah proposed the ITB SUH parameter equation [13]. In this SUH, the parameters arranged were limited to peak discharge, while the other two parameters were not specifically formulated but could follow the equations of basic time and peak time that had been formulated by previous researchers. The peak discharge equation was determined from the mass conservation equation for the effective volume of rain that fell on the watershed surface and the volume of direct runoff.

Another approach using watershed morphometric parameters that were specifically related to watershed fractal characteristics was carried out at SUH ITS-2 [14]. The peak discharge equation adopted the same concept as SUH ITB [15]. The equations of the other two hydrograph parameters were based on the main river length, the density of the drainage network, the ratio of the river length, the watershed area, and the slope of the main river [1]. Based on the results of correlation and regression analysis, not all of the proposed watershed fractal parameters showed a strong relationship with the hydrograph parameters. Because the parameter equation of SUH ITS-2 was a combination function of the watershed morphometric and fractal parameters, taking into account the limitation of the application of the SUH parameters that had been developed previously, this paper accommodated more diverse watershed morphometric parameters. Basically, the rain-flow transformation process was not only influenced by the nature of the rain as input, but it was also greatly influenced by the various watershed parameters, either partially or simultaneously. The 12 watershed parameters proposed in this paper included watershed area, main river length, main river slope, main river length from the centroid of the watershed to outlet, shape factor of the watershed, number of river orders, number of river joints, river length of the first order, river length of the whole order, drainage density, reach number of 1st order, and reach number of the whole order. Accordingly, this paper aimed to improve the performance of the SUH parameters by involving a number of watershed parameters that were considered to have a high influence on the rain-flow transformation process.

2. Method

Research Materials

This study used 12 morphometric parameters from 8 measured watersheds in Central Sulawesi Province, Indonesia. The 12 watershed parameters were secondary data obtained from previous publications as shown in ***Table 1****. The locations of the 8 watersheds were scattered throughout the area representing topographic characteristics, land cover, soil type, and a highly complex river network system in Central Sulawesi Province. In general, the topography of the watershed in the study area was dominated by* *mountainous, hilly surfaces and a small part of it was a flat area. This condition caused most of the rivers in this area to be classified as high-slope rivers with relatively short river lengths compared to the watershed area.*

*In addition to watershed parameter data, this paper also used unit hydrograph parameter data, including peak time, peak discharge, and base time for 8 watersheds obtained from the same source as shown in **Table 2**.*

Research Stages

*This research began by examining the strength of the individual relationships of 12 watershed parameters with 3 hydrograph parameters with a coefficient of determination. This coefficient described how much the independent variable (watershed parameter) affected the dependent variable (hydrograph parameter) which was calculated by the **Eq. 1**.*

$$R^2 = \left[\frac{\Sigma(x-\bar{x})(y-\bar{y})}{\sqrt{\Sigma(x-\bar{x})^2}\sqrt{\Sigma(y-\bar{y})^2}}\right]^2 \qquad (1)$$

*where R2 = coefficient of determination, x = independent variable (watershed parameter) and x = dependent variable (hydrograph parameter). All watershed parameters that indicated the strength of individual relationships ranging from good to perfect categories above 50% (r = 0: no correlation between two variables, r > 0-0.25: very weak correlation, r > 0.25-0.5: moderate correlation, r > 0.5-0.75: strong correlation, r>0.75 - 0.99: very strong correlation and r =1: perfect correlation) could be accommodated in multiple linear regression analysis using SPSS software. The general equation for multiple linear regression could be expressed by **Eq. 2**.*

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 + \cdots + b_nx_n \qquad (2)$$

a = constant and b = regression coefficient.

*The selection of the best regression equation that represented the selected hydrograph parameter equation was based on hypothesis significance testing which consisted of hypothesis testing (F-Test) and Partial Regression Coefficient Test (t-Test). The F-test aimed to assess whether the watershed parameters selected based on the correlation coefficient simultaneously had a significant effect on the hydrograph parameters. The F-test recommended whether the proposed hypothesis could be accepted or rejected, by comparing F_{hit} and F_{tab}, where F_{hit} could be calculated by **Eq. 3**.*

$$F_{hit} = \frac{R^2(n-k-1)}{k(1-r^2)} \qquad (3)$$

*where n = the number of watershed data, k = the number of watershed parameters (independent variable). Furthermore, the t-test is known as the individual significance test aimed to assess whether all watershed parameters in the formed regression equation partially had a significant effect on the hydrograph parameters. This test was applied by comparing T_{hit} and T_{tab}, where T_{hit} for each watershed parameter was calculated by **Eq. 4**.*

$$T_{hit} = \frac{b_i-\beta_i}{S_{b_i}} \qquad (4)$$

where: bi=coefficient of the i^{th} independent variable in the regression equation, βi = regression constant and S_{bi}= standard error of estimator.

3. Results and Discussions

Correlation of Watershed Parameter and Hydrograph Parameter

*As mentioned in the previous section, the correlation analysis was applied to 12 watershed parameters with 3 hydrograph parameters. This analysis aimed to identify the linear relationship between the two types of variables as a consideration for determining the selected watershed parameter. Based on the results of the analysis, of the 12 watershed parameters assessed, most revealed the strength of the relationship in a good to a very good category (**Table 3**). However, there were 3 watershed parameters that performed a weak relationship, namely: S, F_B, and D. Conceptually, the three watershed parameters ideally greatly affected the hydrograph parameters. As an illustration, high-sloping rivers tended to produce shorter hydrograph peak times than low-sloping rivers, and subsequently also had an impact on peak discharge and hydrograph bottom time. The watersheds with an elongated shape gave a longer peak time than watersheds with a wide shape. Likewise, a watershed with a high density of drainage network could trigger an increase in the concentration of flow at the outlet**.***

Some SUH equations used one of the three watershed parameters to set the hydrograph parameters. SUH GAMA I employed the symmetry factor as a representation of the watershed shape factor to determine T_p. In addition, the number of river outlets that described the drainage density was used as one of the variables in determining Q_p. Furthermore, the S parameter was also accommodated in determining T_b. In line with that, SUH Limantara also used one of the three parameters in setting the hydrograph parameters. The low correlation coefficient in this study was thought to be closely related to the nature of the 8 watersheds evaluated which were located in areas with steep topography and with high variability in 3 watershed parameters and *indicated inconsistency with hydrograph parameters. Other rain-discharge pair data needed to be accommodated to verify this assumption.*

*The relationship between the 12 watershed parameters and each hydrograph parameter could be expressed graphically as shown in **Figure 1** (watershed parameters and T_p), **Figure 2** (watershed parameters and Q_p), and **Figure 3** (watershed parameters and T_b). It was interesting to observe that the weakest relationship of the three watershed parameters was given by T_p (**Figure 1**), followed by T_b (**Figure 3**), and Qp (**Figure 2**). Furthermore, the two-way correlation that stated the nature of the two variables influencing each other could be expressed by the coefficient of determination as in **Table 4**, **Figure 4**, **Figure 5**, and **Figure 6**. Given that the correlation coefficient of the 3 watershed parameters to the 3 hydrograph parameters tended to be closer and centered to 0 (zero), then the determination number also tended to be low and showed a very weak relationship for both T_p (**Figure 4**, Q_p (**Figure 5**) and Tb (**Figure 6**).*

Watershed Parameter Selection

*The reference for setting the selected watershed parameter was based on the number of determinations provided that $R^2>0.5$. Referring to **Figure** 7, the number of watershed parameters with R2>0.5 to the T_p parameter was 5 consecutive parameters from high to low R^2: L, A, J_N, and R_1 (black graph). Furthermore, for the Q_p parameter, there were 9 watershed parameters with R2 above 50%, namely: A, L_t, L_1, R_1, J_N, R_t, n, L_c, and L from large to small (**Figure 8**). Meanwhile, 9 watershed parameters were indicated with a coefficient of determination R^2 in a good category was a very good category for T_b, namely: A, J_N, L_t, R_t, R_1, L, L_1, and L_c (**Figure 9**). In detail, the number of determinations that met the requirements associated with each hydrograph parameter is shown in **Table 5**, **Table 6**, and **Table** 7.*

Hydrograph Parameter Equation

*The watershed parameter which contributed a good category determination to the hydrograph parameter was then used as an independent variable in the regression model, in this case, multiple linear regressions with respect to the number of independent variables more than 1. The results of the analysis of determination showed that there were 4, 9, and 8 watershed parameters simultaneously adequate as a hydrograph parameter. However, in the subsequent analysis for the Q_p and T_b parameters, the number of watershed parameters used was 7, considering that there was insufficient data available to describe the n parameters, so these parameters had not been accommodated in the regression model. Regression analysis of selected watershed parameters using the SPSS statistical tool produced 3 equations of hydrograph parameters as in **Eq. 5** for Tp, **Eq. 6** for Q_p, and **Eq.** 7 for T_b.*

$$\mathrm{Tp} = 0.180892 + 0.003854\mathrm{A} + 0.122305\mathrm{L} - 0.03719\mathrm{JN} + 0.018962\mathrm{R1} + 0.005301\mathrm{Rt} \tag{5}$$

$$\mathrm{Qp} = 0.874097 + 0.059385\mathrm{A} - 0.06623\mathrm{L} + 0.100429\mathrm{Lc} - 0.08982\mathrm{JN} + 0.017964\mathrm{L1} - 0.03094\mathrm{Lt} + 0.046081\mathrm{Rt} \tag{6}$$

$$\mathrm{Tb} = 14.52214 - 0.11437\mathrm{A} + 0.354516\mathrm{L} - 1.69674\mathrm{Lc} + 1.262664\mathrm{JN} + 0.333477\mathrm{L1} - 0.03278\mathrm{Lt} - 1.14135\mathrm{R1} \tag{7}$$

*The three hydrograph parameter equations gave a determination number of more than 70%. This meant that the three hydrograph parameters could be represented by all selected watershed parameters as much as 70%, and the rest were represented by other watershed parameters that were not accommodated in the model. Statistically, the resulting regression equation was very satisfactory, considering that the error between prediction and observation was relatively very low with RMSE below 10% (**Table 8**). Graphically, it appeared that the predicted and observed values for the parameters T_p (**Figure 10**), Q_p (**Figure 11**), and T_b (**Figure 12**) were relatively very similar. The best performance was given by T_b with RMSE = 1.4% and followed by Q_p and T_b with RMSE of 1.9% and 9.8%, respectively. When it was further examined, the effect of each watershed parameter varied on the hydrograph parameters. In the T_p equation, two watershed parameters, namely L and J_N, had a dominant influence compared to other watershed parameters. Meanwhile, in the other 2 hydrograph parameters, there were 2 watershed parameters that dominantly affected Q_p and T_b. However, almost all of the selected watershed parameters showed good determination.*

The use of various watershed parameters in the formulation of hydrograph parameters was basically to accommodate as many factors as possible that affect the hydrograph. The complexity of the process of transforming rain into discharge could be described by the various watershed parameters which simultaneously form a hydrograph. Ideally, the more parameters involved in the formulation of the hydrograph parameters, the higher the performance of the model should be. However, there was a limit where this condition was difficult to achieve considering the dominance of the influence of certain watershed parameters on other watershed parameters so that the other *watershed parameters seemed to have no real contribution. In this paper, as mentioned in the previous section, high performance was given to the respective equations T_p, Q_p and T_b limited to 5, 7, and 7 watershed parameters, consecutively. This was in line with previously published research which accommodated 5 watershed parameters for the Q_p formulation, while the other hydrograph parameters could follow SUH GAMA I parameters where T_p and T_b each used 3 watershed parameters [7], [12].*

The important thing to note was that this paper was very successful in accommodating the watershed parameters as much as possible with a very low error rate. There was no significant difference between the observed hydrograph parameters and the simulation parameters, and statistically, this indicator showed that the behavior of the three hydrograph parameters could be well represented by the transformation parameters which were presented by the watershed parameters. However, the basic principle that must be understood was that this condition would be achieved if the conditions in the unit hydrograph were met especially the first assumption that rain was evenly distributed over the entire surface of the watershed with constant intensity over a certain time interval reviewed [7], [14]. The fact on the spot displayed that idealization was difficult to be achieved, where generally the nature of rain in Indonesia tended to be of irregular intensity with uneven distribution. The installation of higher density automatic rain gauges that could record minute rain data could be applied to accommodate this assumption.

4. Conclusions

The linear regression analysis had been applied to build a 3-parameter synthetic unit hydrograph equation based on 12 measured 8-watershed morphometric parameters. The twelve selected watershed parameters indicated high correlation with 3 watershed parameters, namely: watershed area (A, km^2), main river length (L, km), main river slope (S), main river length from centroid of watershed to outlet (Lc, km), shape factor of watershed (F_B), number of order (n), number of joint (J_N), river length of first-order (L_1), river length of whole order (L_t), drainage density (D), reach a number of 1st order (R_1), reach number of whole order (R_t). The results of the regression analysis showed very high performance on the three hydrograph parameter equations with a very low error rate based on the RMSE indicator below 0.1. This RMSE indicator indicated that at least 5 of the 12 tested watershed parameters showed a very good sign to the hydrograph, especially in the 8 watersheds as a model constructor. This study was conducted in watersheds in Central Sulawesi Province with the characteristic of small watershed, high slope and land cover is mostly forest. Therefore, in the future this method needs to be validated using other watersheds that have different characteristic so that the model can be used in a wider wathershed and has various characteristic. Futher research will also be carried out to simplify the equation of hydrograph parameter by reducing the number of watershed parameters but the results still have an acceptable performance.

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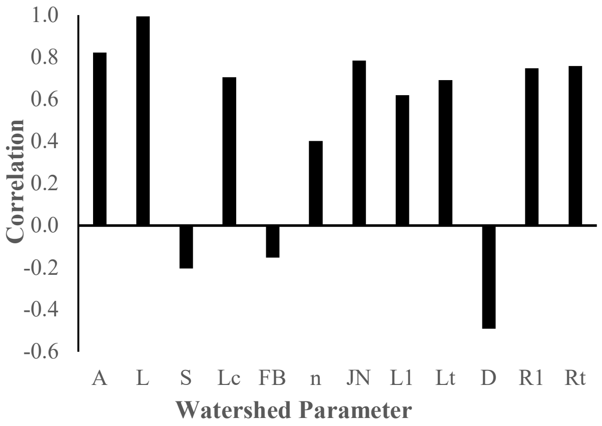

Figure 1. *Correlation of watershed parameters to T_p*

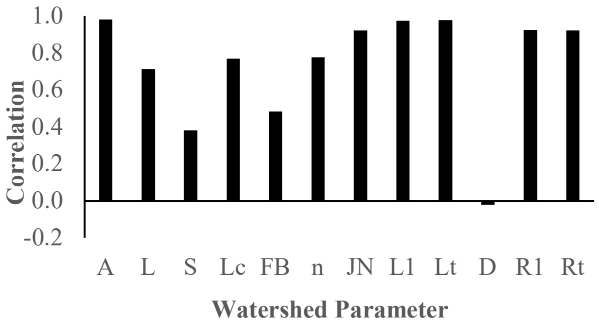

Figure 2. *Correlation of watershed parameters to Q_p*

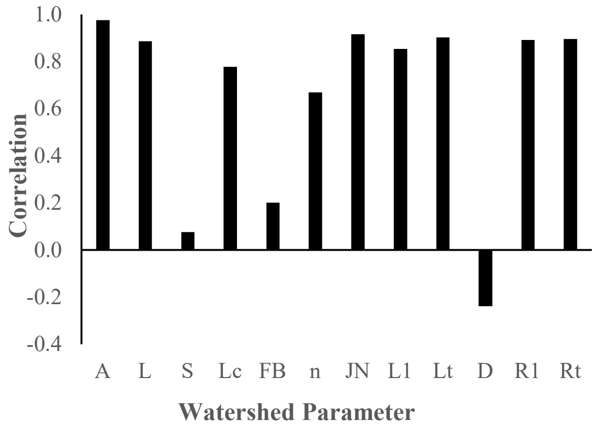

Figure 3*. Correlation of watershed parameters to T_b*

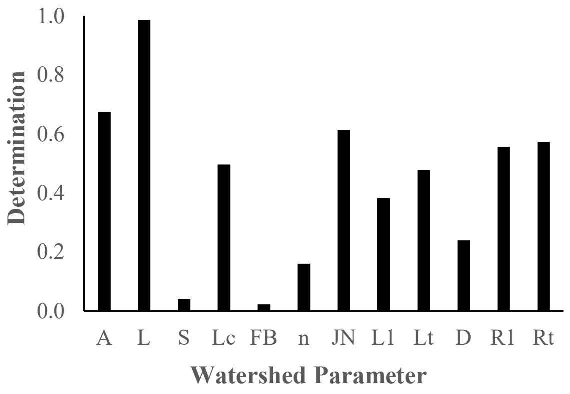

Figure 4. *Coefficient of determination (R^2) between watershed and T_p parameters*

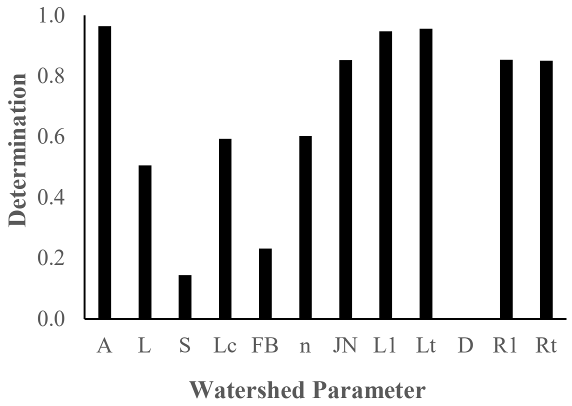

Figure 5. *Coefficient of determination (R^2) between watershed parameters and Q_p*

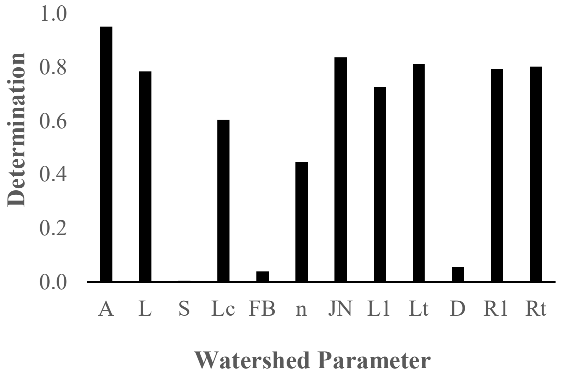

Figure 6. *Coefficient of determination (R^2) between watershed parameters and T_b*

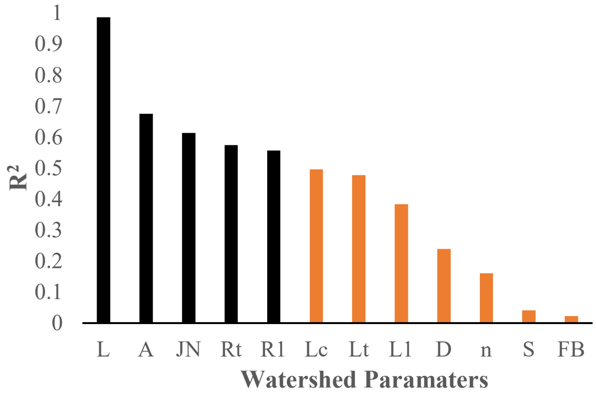

Figure 7. *R^2 of watershed parameters with respect to T_p*

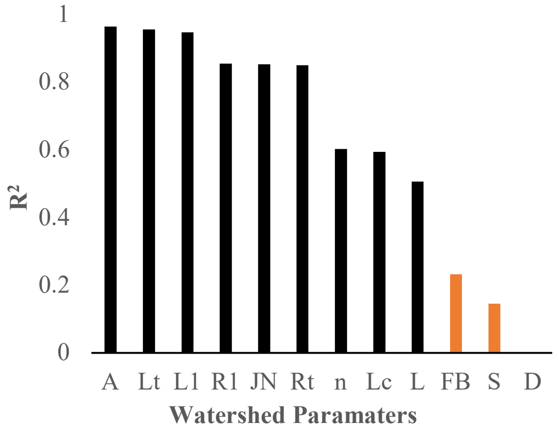

Figure 8. *R^2 of watershed parameters with respect to Q_p*

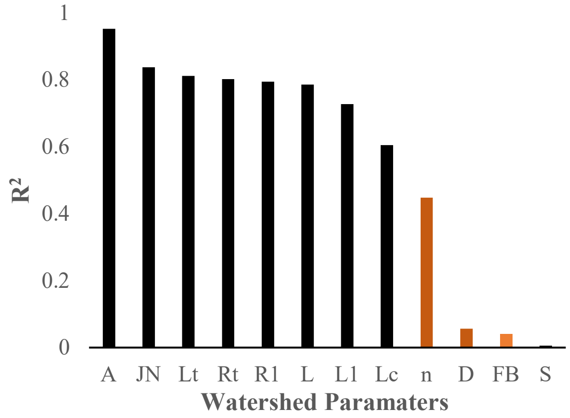

Figure 9. *R^2 of watershed parameters with respect to T_b*

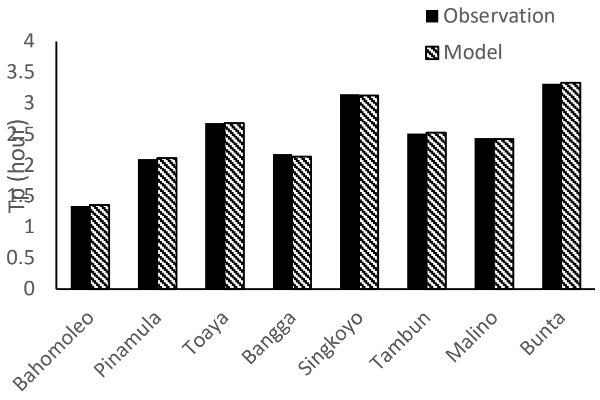

Figure 10. *Comparison of T_p values between observations and models*

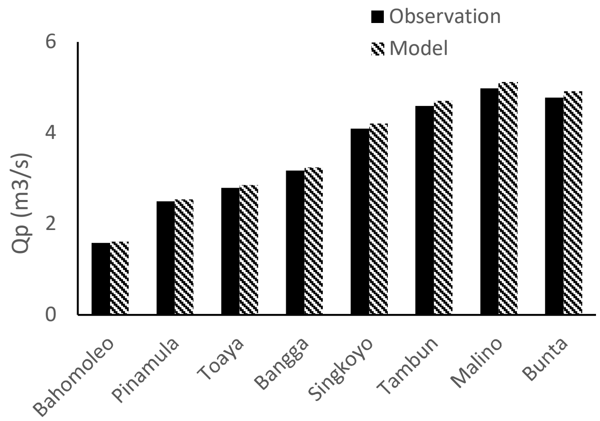

***Figure 11**. Comparison of Q_p values between observations and models*

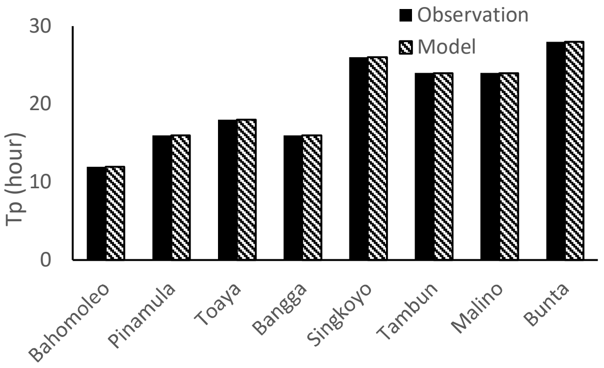

***Figure 12**. Comparison of Tb values between observations and models*

***Tabel 1**. Data for 12 parameters 8 measured watersheds [14], [15]*

No	*Parameters*	*Watersheds*							
		Bahomoleo	*Pinamula*	*Toaya*	*Bangga*	*Singkoyo*	*Tambun*	*Malino*	*Bunta*
1	*Watershed area (A, km^2)*	*23.88*	*49.35*	*65.51*	*68.19*	*116.05*	*118.19*	*128.75*	*144.73*
2	*Main river length (L, km)*	*10.32*	*15.64*	*21.82*	*16.48*	*26.81*	*19.99*	*19.19*	*28.7*
3	*Main river slope (S)*	*0.0763*	*0.0342*	*0.065*	*0.0894*	*0.0456*	*0.0975*	*0.1081*	*0.0635*
4	*Main river length from centroid of watershed to outlet (L_c, km)*	*6.11*	*6.07*	*9.3*	*7.65*	*10.16*	*10.94*	*9.22*	*8.83*
5	*Shape factor of watershed (F_B)*	*0.3*	*0.39*	*0.21*	*0.37*	*0.22*	*0.5*	*0.49*	*0.36*
6	*Number of order (n)*	*4*	*3*	*4*	*4*	*4*	*5*	*5*	*5*
7	*Number of joint (J_N)*	*32*	*32*	*65*	*81*	*105*	*113*	*124*	*168*
8	*River length of first order (km)*	*20.18*	*36.85*	*48.96*	*68.9*	*76.86*	*122.93*	*118.69*	*113.15*
9	*River length of whole order (km)*	*43.06*	*61.36*	*88.94*	*116.96*	*144.69*	*199.39*	*205.68*	*222.6*
10	*Drainage density (D)*	*1.8*	*1.24*	*1.36*	*1.72*	*1.25*	*1.69*	*1.6*	*1.54*
11	*Reach number of 1st order (R_1)*	*34*	*34*	*67*	*92*	*106*	*125*	*137*	*182*
12	*Reach number of whole order (R_t)*	*70*	*71*	*137*	*180*	*211*	*242*	*267*	*356*

***Table 2**. Parameter of Unit Hydrograph*

No	*Parameters*	*Watersheds*							
		Bahomoleo	*Pinamula*	*Toaya*	*Bangga*	*Singkoyo*	*Tambun*	*Malino*	*Bunta*
1	*T_P (hour)*	*1.35*	*2.1*	*2.68*	*2.18*	*3.15*	*2.51*	*2.44*	*3.32*
2	*Q_P (m^3/s)*	*1.58*	*2.49*	*2.79*	*3.17*	*4.09*	*4.59*	*4.98*	*4.77*
3	*T_B (hour)*	*12*	*16*	*18*	*16*	*26*	*24*	*24*	*28*

***Table 3**. Correlation of watershed parameters with T_p, Q_p and T_b*

Hydrograph Parameter	*Parameter watershed*											
	A	*L*	*S*	*L_c*	*F_B*	*n*	*J_N*	*L_1*	*L_t*	*D*	*R_1*	*R_t*
T_p	*0.821*	*0.994*	*-0.204*	*0.705*	*-0.152*	*0.402*	*0.784*	*0.620*	*0.691*	*-0.490*	*0.747*	*0.758*
Q_p	*0.982*	*0.712*	*0.381*	*0.770*	*0.482*	*0.776*	*0.923*	*0.973*	*0.978*	*-0.021*	*0.924*	*0.922*
T_b	*0.976*	*0.887*	*0.077*	*0.778*	*0.201*	*0.670*	*0.915*	*0.853*	*0.901*	*-0.238*	*0.891*	*0.896*

Table 4. *Coefficient of determination (R^2) of the relationship between the watershed parameter and the hydrograph parameter*

UH Parameters	A	L	S	L_c	F_B	n	J_N	L_1	L_t	D	R_1	R_t
T_p	0.68	0.99	0.04	0.50	0.02	0.16	0.61	0.38	0.48	0.24	0.56	0.57
Q_p	0.96	0.51	0.15	0.59	0.23	0.60	0.85	0.95	0.96	0.00	0.85	0.85
T_b	0.95	0.79	0.01	0.61	0.04	0.45	0.84	0.73	0.81	0.06	0.79	0.80

***Table 5**. Watershed parameters selected as input for the Tp model*

Parameter	L	A	J_N	R_t	R_1
R^2	0.9876	0.675	0.6144	0.5746	0.5574

Table 6. *Watershed parameters selected as input for the Q_p model*

Parameter	A	L_t	L_1	R_1	J_N	R_t	n	L_c	L
R^2	0.9634	0.9559	0.9473	0.8541	0.8525	0.8504	0.6025	0.5934	0.5068

Table 7. *Watershed parameters selected as input for the Tb model*

Parameter	A	J_N	L_t	R_t	R_1	L	L_1	L_c
R^2	0.953	0.8376	0.8127	0.8026	0.7947	0.7861	0.7283	0.6056

Table 8. *Calculation of error and RMSE between observations and models*

	T_p			Q_p			T_b		
Catchment	*Observasi*	*Model*	*Error*	*Observasi*	*Model*	*Error*	*Observasi*	*Model*	*Error*
Bahomoleo	1.35	1.36	-0.01	1.58	1.60	-0.02	12	12.00	0.00
Pinamula	2.1	2.11	-0.01	2.49	2.54	-0.05	16	1.99	0.01
Toaya	2.68	2.68	0.00	2.79	2.86	-0.07	18	18.00	0.00
Bangga	2.18	2.15	0.03	3.17	3.24	-0.07	16	15.99	0.01
Singkoyo	3.15	3.13	0.02	4.09	4.21	-0.12	26	26.00	0.00
Tambun	2.51	2.53	-0.02	4.59	4.71	-0.12	24	23.97	0.03
Malino	2.44	2.43	0.01	4.98	5.11	-0.13	24	23.98	0.02
Bunta	3.32	3.34	-0.02	4.77	4.92	-0.15	28	28.00	0.00
RMSE		0.019			0.098			0.014	

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