

DIMENSIONLESS SYNTHETIC UNIT HYDROGRAPH AT GEMBONG WATERSHED, PASURUAN REGENCY-EAST JAVA PROVINCE OF INDONESIA

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ABSTRACT: This study aims to establish the model of Dimensionless Synthetic Unit Hydrograph at Gendong Watershed, Pasuruan Regency-East Java Province of Indonesia. The observed data of Automatic Water Level Recorder at Gembong Warungdowo was used in this research and the Automatic Rainfall Recorder at P3GI (Sugar Factory Central Research of Indonesia) from 2008 until 2011. The model was differentiated by using the Collins Method. The result showed that the suitable model at Gembong watershed is as follow: the rising limb curve is $Q_n = Q_p + 0.615 (t - T_p)$ and the recession line curve is $Q_t = Q_p \times e^{0.30 (T_p - t)}$. This result was based on the regression statistical analysis with the highest correlation of $R^2=0.993$ and the standard error minimum of $SEY=1.143$ for the rising limb curve, however, for the recession line curve is $R=0.906$ and $SEY=0.415$. The model is as follow: the rising limb is $Q_n = Q_p + 0.615 (t - T_p)$ and the recession line is $Q_t = Q_p \times e^{0.30 (T_p - t)}$.

Keywords: *Dimensionless Synthetic Unit hydrograph, Collins Method*

1. INTRODUCTION

Hydrology science was practically started from 1608 such as since Pierre Parrult who carried out the measuring of rainfall and run-off during three years in the Seine watershed. Then, it was followed by Edme Mariote (1620) and Edmund Hally (1656) [1]. Hydrology science is an earth science which studies the behavior, characteristic, event, distribution, and the flow of water [2]. The phenomena of hydrology are too complex and it may be difficult to be overall understood. To be able to understand the phenomena in nature, it is needed an abstraction and to simplify the phenomena of the abstraction for understanding the hydrological cycle. The abstraction means to place the phenomena into a model. In other words, the model is an estimation or simplification from the reality [2]. Water traveling in a watershed can be assumed as the total run-off which consists of the direct run-off and the base flow. Direct run-off consists of the surface run-off and the prompt sub-surface flow. However, base flow consists of the groundwater flow which enters through the percolation and delayed the sub-surface flow that cannot enter into the channel, but it is together with the water percolation to enlarge the base flow. By the end, the base flow and the direct flow is together towards the river [3].

The available models of Synthetic Unit Hydrograph (SUH) which have been founded before the SUH of Snyder (research location in

USA, 1938), SUH of Nakayasu (research location in Japan, 1948), SUH of Gama I (research location in Java Island, 1985) and in 2006, SUH of Limantara was founded by Lily Montarich Limantara which was produced an Indonesian Specific Synthetic Unit Hydrograph (research locations in Java, Bali, Lombok, and East Borneo). However there are the limitation of technical specification as follow [4][5]: 1) the area of watershed (A) is in the range of 0.325-1667.50 km²; the length of the main river is in the range of 1.16-62.48 km; the distance between weight point to outlet is in the range of 0.50-29.386 km; the slope of the main river is in the range of 0.00040-0.14700; and the roughness coefficient of watershed is in the range of 0.035-0.070. All of the models as above are differentiated from the development of Sherman, 1932 [6].

The watershed shape factor gives the good hope for the next development in the Synthetic Unit Hydrograph Modeling [7]. By observing the observed hydrograph and the previous research that produced the synthetic model, it can be estimated that 1) the rising limb and the recession line of hydrograph can be approached with an arch equation; 2) the model of peak discharge can be implemented from the watershed physical factor which is exactly defined as the length of the main river (L), the area of watershed (A), the mean of river slope (S), the roughness coefficient of watershed (n), the river length from weight point of watershed to the outlet (Lc), etc. [8]; 3) the formulation of model is based on the

correlation among the watershed factors; 4) the Synthetic Unit Hydrograph model of Nakayasu that is applied, nowadays produces the big enough error especially for flood peak discharge. For the ideal cases, there is needed to calibrate some model parameters based on the watershed characteristic [9].

Yue *et.al* [10] has carried out the method development study to illustrate the statistical variables for the flood hydrograph shape such as the variable of mean shape (S_m) and the variance shape (S_v) which was defined as the random shape illustration of flood hydrograph. They used the observed data from Asuapmushuan watershed in Quebec Province-Canada. It showed that the approached method presented the statistical parameter for the shape of flood hydrograph. Bunya *et.al*. [11] developed the empirical relation for estimating β and λ as the factors that regulated the unit hydrograph dimension shape of Nash parameter (n = number of storage). The algorithm of Marquardt was used to develop the nation linear relation. At the end of hydrograph unit of Shusil was obtained by using the methods of Snyder, SCS, and Gray based on the standard of error. This research intends to obtain a model of Dimensionless Synthetic Unit Hydrograph at Gembong Watershed, Pasuruan Regency-East Java of Indonesia based on the observed data of Automatic Water Level Recorder (AWLR) at

Gembong-Warungdowo and Automatic Rainfall Recorder (ARR) at P3GI-Pasuruan City from 2008 until 2011.

2. MATERIALS AND METHODS

This research is conducted at Gembong Watershed with the characteristic as follow: area (A) is 58.71 km², the length of the main river (L) is 24.03 km, the mean of river slope is 0.00196, and the roughness coefficient of river (n) is 0.035, because there is no forest in the upstream. The mean of river width is 50.00 m on the downstream and there is mangrove crop in surrounding coast and in the left and right side of the estuary, and a little of the fishpond. In surrounding river estuary, there is used for the sailing route of the traditional fishermen, because there are the tidal effects so their boats can be reclined in and out of the coast until 500 m towards the river upstream. However, in the middle of Gembong river is crowded of population residents which enter to the Pasuruan city. In the upstream area, the resident is diminished and there are more paddy field and moor but there is no forest in the Pasuruan Regency. Generally, the topography condition of Gembong watershed is relatively plain with the slope is in the range of + 1,00 – 55,00 m DPL. Map of location is presented as in the Fig. 1.

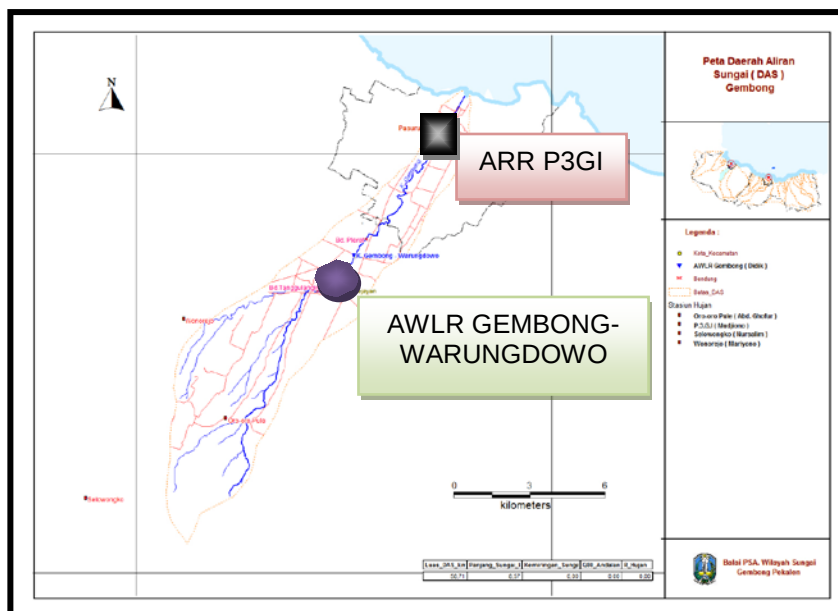


Fig. 1 Map of Gembong Watershed
Source: UPT Balai Gembong-Pekalen Sampean Pasuruan

Secondary data are used in this study which consists of 1) Data of the Automatic Water Level Recorder (AWLR) from UPT Balai Gembong-Pekalen Sampean Pasuruan from 2008 until 2011; 2) Rainfall data of the Automatic Rainfall

Recorder (ARR) from P3GI of Sugar Factory Research Central of Indonesia in Pasuruan; and 3) Topography map with the scale of 1 : 25,000.

The dimensionless Synthetic Unit hydrograph (SUH) at Gembong Watershed is

differentiated by using Collins Method with the assumptions as follow: a) The separation of direct run-off hydrograph from the base flow uses the Straight Line Method [6]; b) The effective rainfall is analyzed with the phi (ϕ) index; c) The observed unit hydrograph is differentiated from the observed discharge hydrograph by using the Collins Method; d) The peak discharge of observed unit hydrograph is used for analysis the watershed physical factor, and e) The watershed is assumed as a linear system with the time invariant so the happened input every time will cause the same flow [6].

The formula of Φ index is as follow [12]:

$$\Phi = (\sum R - \text{DRO})/T_d \dots\dots\dots(1)$$

Where:

- Φ = infiltration (mm)
- R = rainfall depth (mm)
- DRO = direct run-off (mm)
- T_d = time duration (hour)

The unit hydrograph is defined as the direct run-off which is produced by a unit of 1 mm effective rainfall depth that is dropped at a watershed on the certain period. The unit of 1 mm effective rainfall depth is usually used for controlling the unit hydrograph volume which if it is divided by the area of the watershed, there will

be obtained a unit depth of 1 mm effective rainfall depth. The definition of unit hydrograph indirectly is as follow: 1) Unit hydrograph presents a response of effective rainfall which is dropped at the watershed for producing the direct run-off hydrograph, so if the water volume of unit hydrograph is divided by the area of watershed, the result has to be the same as 1 mm of the effective rainfall depth; 2) The dropped rainfall is considered as the average of the effective rainfall intensity; 3) The distribution of heavy rain which is dropped in a watershed is assumed uniform.

The estimation of flood discharge by using unit hydrograph is the best carrying out if there is the available record of the Automatic Water Level Recorder (AWLR) which is enough to represent the pattern of flood (discharge) hydrograph at the watershed, so the flood discharge can be accurately differentiated. The unit hydrograph which follows the principal of linearity, the direct run-off is produced by the effective rainfall consecutively in a certain period with the output is the same as the direct run-off by calculating each of the direct run-offs happening time. However, to analyze the volume of the direct run-off is carried out by using the super-position of the direct run-off as presented in the Fig. 2.

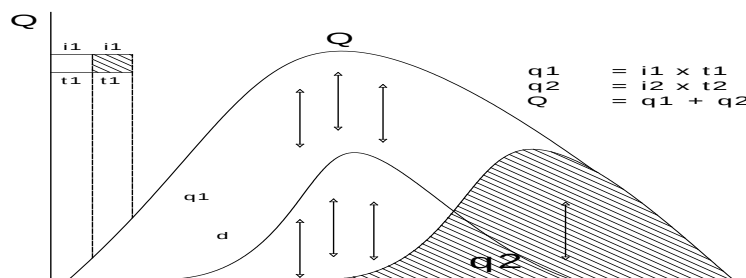


Fig. 2 Determination of unit hydrograph

The unit hydrograph which is analyzed from a case of the flood has not been as a hydrograph that represents the watershed. Therefore, it is needed a unit hydrograph which is differentiated from many cases of flood and then there is to be averaged. However, there is no guidance for the number of flood cases that are needed to produce the unit hydrograph [13][14]. In the flattening process, there is not allowed to average the ordinate of each unit hydrograph, because it will be produced the unit hydrograph with the peak discharge is less than the average of each unit hydrograph peak discharge. The flattening is carried out by averaging the peak discharge as well as the time to peak. Then, the recession line is obtained by drawing the line from the average recession line to the volume base of unit hydrograph and it is the same as the remained volume unit [6]. In the analysis, it is necessary to

be selected an advantaged case such as to select the isolated hydrograph that has single peak discharge and having enough rainfall and the record of hourly rainfall distribution. However, to produce the observed unit hydrograph, there is carried out by using the numerical method. In this case, there is used the Polynomial Equation or the Collins Method. The polynomial equation has some weakness, however, the Collins Method can be used on the whole condition and it generally can often be solved and giving the best and rational result [6]. The last estimation of unit hydrograph ordinate is as follow [15]:

$$Use = (V \times U^{**})/(3600 \times \sum U^{**}) \dots\dots\dots(2)$$

Where:

$$U^{**} = (U_i + F \times U^*)/(1 + F) \dots\dots\dots(3)$$

$$U^* = dQ/Re_{marks} \dots\dots\dots(4)$$

Use = initial ordinate of hydrograph ($m^3/s/mm$)

V = volume of run-off (m^3)
 U_i = ordinate an-i ($m^3/s/mm$)
 F = factor of calibration
 U^* = ordinate of hydrograph after correction ($m^3/c/mm$)
 DQ = ordinat of observed hydrograph ($m^3/s/mm$)
 Re_{maks} = maximum effective rainfall (mm)

The Collins method needs the gradual procedures such as at first, to separate the average distributed run-off depth and it needs the calibration of unit hydrograph gradually as follow [15]: a) To prepare the direct run-off hydrograph; b) To prepare the effective rainfall and separating it from the maximum rainfall; c) To calculate the direct run-off volume; d) To carry out the trial and error for the initial unit hydrograph ordinate regarding to the direct run-off; e) To calculate the multiplication between effective rainfall (exception the maximum one) and the trial hydrograph ordinate ($\sum Re \times U$); f) To calculate the calibration factor (F) for the next step; g) To calculate the estimation of unit hydrograph ordinate; h) To calculate the ordinate deviation at the beginning and last trial. If there has not been accurate (almost the same), so the initial ordinate

has to be trial with the ordinate in the previous trial, and then it is carried out the return process until it is obtained the less enough deviation; and i) Based on the observed unit hydrograph, it can be determined the peak discharge (Q_p), time to peak (T_p), time base (t_b), and then there are to be averaged.

3.RESULTS AND DISCUSSION

Study about the food or the discharge hydrograph with the peak discharge from the Automatic Water Level Recorder (AWLR) at Gembong-Warungdowo and effective rainfall from Automatic Rainfall Recorder (ARR) at P3GI Pasuruan City since 2008 until 2011, is carried out for obtaining the dimensionless Synthetic Unit Hydrograph. In addition, there is needed the physical parameter of the Gembong Watershed such as the area of the watershed (A) and the length of the main river (L). These data as above are conducted for obtaining the average of observed unit hydrograph and it is presented as in Table 1.

Table 1 Observed Unit Hydrograph (HSO) at Gembong Watershed.

Observed Unit Hydrograph (HSO)	Time to peak (T_p)	Peak discharge (Q_p)	Time base (T_b)	Time recession (T_r)
HSO-1	4.00	1.12	20.00	16.00
HSO-2	6.00	1.68	35.00	24.00
HSO-3	5.00	3.43	30.00	25.00
HSO-4	2.00	4.29	23.00	21.00

The coordinates of Dimensionless Synthetic Unit hydrograph at Gembong Watershed is presented as in Table 2.

Table 3 presents the result of the rising limb curve and the recession line equation based on the analysis of gradient

Table 2 Coordinate of Dimensionless Synthetic Unit Hydrograph at Gembong Watershed.

t/T_p	Q/Q_p	T (hour)	Q (m^3/s)
0.000	0.000	0.000	0.000
0.083	0.000	0.554	0.000
0.178	0.086	0.756	0.227
0.383	0.336	1.629	0.883
0.442	0.397	1.877	1.045
0.721	0.593	3.064	1.561
1.000	1.000	4.250	2.630
1.279	0.810	5.436	2.130
1.558	0.629	6.623	1.654
1.838	0.531	7.809	1.397
2.117	0.470	8.996	1.236
2.396	0.393	10.182	1.035
2.675	0.367	11.369	0.965
2.954	0.341	12.555	0.896
3.233	0.313	13.742	0.823
3.513	0.286	14.928	0.751
3.792	0.268	16.115	0.706

4.071	0.244	17.301	0.642
4.350	0.226	18.488	0.593
4.629	0.210	19.674	0.554
4.908	0.203	20.860	0.533
5.188	0.193	22.047	0.508
5.467	0.048	23.233	0.125
5.911	0.036	25.122	0.096
6.200	0.031	26.350	0.051
6.489	0.023	27.578	0.059
6.778	0.017	28.806	0.045
7.067	0.014	30.033	0.037
4.033	0.019	21.392	0.049
5.217	0.017	22.171	0.015
5.400	0.017	22.950	0.045
5.583	0.017	23.729	0.045
5.333	0.025	22.667	0.066
5.500	0.019	23.375	0.049
5.667	0.019	24.083	0.049
5.833	0.006	24.792	0.016

Table 3 Result of gradient analysis on the rising limb curve (m_1) and the recession curve (m_2) .

No	Item	Curve model	R	R ²	SEY
1	Linear raising limb	$Q_{n1} = Q_p + 0.615(t - T_p)$	0.993	0.986	1.143
2	Polynomial rising limb	$Q_{n2} = Q_p [t/T_p]^{2.9}$	0.905	0.819	1.568
3	Exponential rising limb	$Q_{n3} = Q_p \times e^{1.5(t - T_p)}$	0.817	0.668	1.783
4	Linear recession line	$Q_{t1} = Q_p + 0.103(T_p - t)$	0.936	0.875	0.648
5	Polynomial recession line	$Q_{t2} = Q_p [T_p/t]^{3.0}$	0.827	0.684	0.552
6	Exponential recession line	$Q_{t3} = Q_p \times e^{0.30(T_p - t)}$	0.906	0.822	0.415

Based on the result as in Table 3 above, there is selected the rising limb linear curve is $Q_n = Q_p + 0.615(t - T_p)$ and the recession line is $Q_t = Q_p \times e^{0.30(T_p - t)}$. The result is due to the regression statistical analysis with the high correlation coefficient of (R) 0.993 and the minimum deviation (SEY) of 1.143 for the rising limb curve,

however for the recession line is the correlation coefficient (R) of 0.906 and the minimum deviation (SEY) of 0.415.

The comparison between Observed Unit Hydrograph and the Laksono-UB Synthetic Unit Hydrograph at Gembong Watershed is presented as in Figure 3 below.

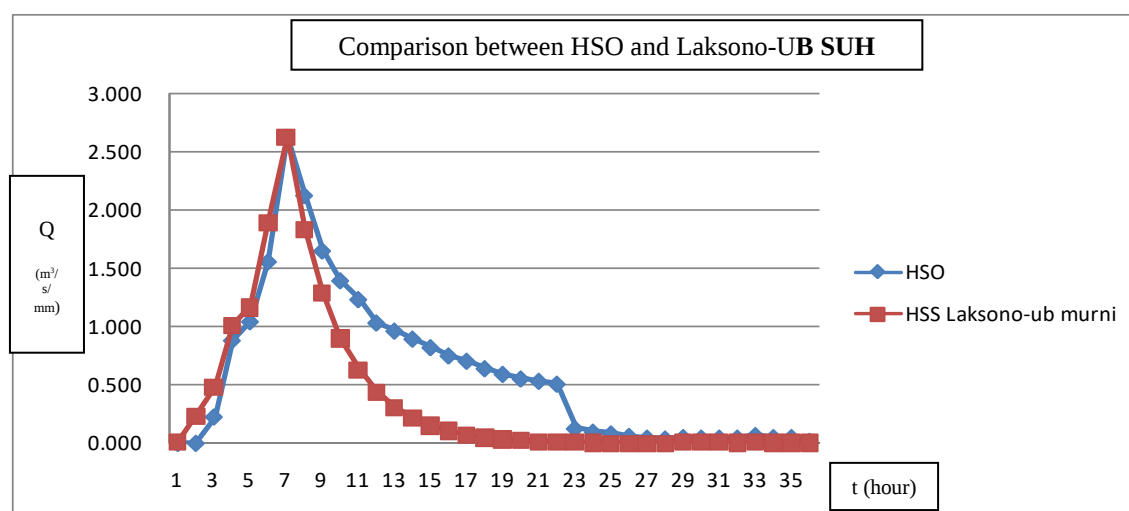


Figure 3 Comparison between Observed Unit Hydrograph (HSO) and Laksono-UB Synthetic Unit Hydrograph (SUH) at Gembong Watershed

The recession line of the observed hydrograph as in the Fig. 3 has the sharp decreasing between 22nd and 23th hour. It indicates that on the time duration there is extreme rainfall in a short time. Even though the recession line of dimensionless Synthetic Unit Hydrograph (HSS-Laksono UB murni) has the coefficient correlation (R) = 0.906 and SEY = 0.415 due to the observed hydrograph.

4.CONCLUSION

Based on the analysis as above, the suitable model of dimensionless Synthetic Unit Hydrograph (SUH) at Gembong watershed is as follow: the rising limb is $Q_n = Q_p + 0.615 (t - T_p)$ and the recession line is $Q_t = Q_p \times e^{0.30 (T_p - t)}$ with the highest correlation of $R^2=0.993$ and the standard error minimum of SEY=1.143 for the rising limb curve, however, for the recession line curve is $R=0.906$ and SEY=0.415 to the observed hydrograph.

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