

Open Access Article

Time-Based Modeling of Unit Hydrograph Using the Radial Watershed Physical Parameters

M. Firman*, Mohammad Bisri, Ussy Andawayanti, Runi Asmaranto

Department of Water Resources, Faculty of Engineering, University of Brawijaya, Malang, Indonesia

Abstract: This study intends to develop a time-based (T_b) model using radial watershed physical parameters. The methodology consists of (1) determining the unit hydrograph time base (T_b), (2) identifying the characteristics of the physical radial watershed, (3) identifying the radial watershed physical parameters that have a significant effect on the time base and (4) developing a time-based (T_b) model. This research involves ten physical watershed parameters from ten radial watersheds spread across Java and Sulawesi islands to be tested. As a result, parameters of the main river slope (S) and factor of the main river length and the river length from outlet to the nearest to the center gravity of the watershed [L.Lc] together have significant ability to estimate the time base (T_b) variability. The resulting statistical indicator is Adj. $R^2 = 0.87$, standard error of the estimate (SEE) = 0.10, Sig. F = 0.00, and also the requirements of the model residual test are met. It has a good level of accuracy, with mean absolute error (MAE) = 0.07%, root mean square error (RMSE) = 0.09 and Nash-Sutcliffe Efficiency (NSE) = 0.89.

Keywords: radial watershed, physical parameters, time base, statistic, modeling.

使用径向流域物理参数的单位水位线时基建模

摘要: 本研究打算使用径向流域物理参数开发基于时间的 (结核病) 模型。该方法包括 (1) 确定单位水文过程线时基 (结核病), (2) 确定物理径向流域的特征, (3) 确定对时基有显著影响的径向流域物理参数和 (4)) 开发基于时间的 (结核病) 模型。这项研究涉及要测试的分布在爪哇岛和苏拉威西岛的十个径向流域的十个物理流域参数。因此, 主要河流坡度 (秒) 参数和主要河流长度因子以及从出口到最近流域重心的河流长度[L.Lc]共同具有显著的时基估计能力 (结核病) 变异性。由此产生的统计指标是调整。电阻 $2 = 0.87$, 估计的标准误差 (看) = 0.10, 信号。F = 0.00, 也满足模型残差检验的要求。它具有良好的准确度, 平均绝对误差 (MAE) = 0.07%, 均方根误差 (均方根误差) = 0.09, 纳什-萨特克利夫效率 (国家安全局) = 0.89。

关键词: 径向分水岭、物理参数、时基、统计、建模。

1. Introduction

Hydraulic structure planning and flood mitigation often require complete and realistic flood hydrograph data rather than just information on peak discharge and time to peak [1]-[4]. The absence or lack of rainfall-discharge data pairs triggered the idea of a synthetic unit hydrograph (SUH) concept [3], [5-7].

Based on the development of HSS theory, most experts agree to classify synthetic unit hydrographs (SUH) into four groups, namely (1) traditional; (2) conceptual; (3) probabilistic; and (4) geomorphology [3], [6], [8-10]. However, the reality is that practitioners in Indonesia are still very fanatical about using traditional SUH compared to other SUH. The reason for that is the advantage in terms of ease and practicality in its application.

Received: June 26, 2021 / Revised: August 21, 2021 / Accepted: September 28, 2021 / Published: October 30, 2021

About the authors: M. Firman, Doctoral Program at the Department of Water Resources, Faculty of Engineering, University of Brawijaya, Malang, Indonesia; Mohammad Bisri, Ussy Andawayanti, Runi Asmaranto, Department of Water Resources, Faculty of Engineering, University of Brawijaya, Malang, Indonesia

Corresponding author M. Firman, lilymont2001@gmail.com, mohammadfirman_gtlo@yahoo.co.id

Each watershed shape provides a unique response to the curve and the magnitude of its hydrographic elements [11]. According to [12], the use of the SUH model needs to consider the similarity between the characteristics of the watershed studied, and the watershed used when developing the SUH model. If the characteristics are different, it often results in estimates with significant deviations.

Research on hydrograph elements in the peak discharge (Q_p) and time to peak (T_p) has been widely studied, as has been done in [13]-[15]. However, proceeding from the literature review for the time base (T_b), this research topic is still very rare. Time base (T_b) is one of the important elements in constructing a synthetic unit hydrograph (SUH). Several methods for estimating T_b were offered, but they still ignore the watershed shape factor in developing the model. Predominantly, they only focus on limiting the value of a particular watershed area and location.

Based on the description above, this research is more focused on developing a time-based model suitable for application to radial watersheds. The results are expected to provide benefits for increasing accuracy in determining SUH.

2. Materials and Method

2.1. Study Location

Two criteria were used to determine the research watershed. They are (1) the watershed shape is radial with a watershed area (A) $< 1,500 \text{ km}^2$; (2) The watershed has automatic rainfall-discharge data. The width factor (WF) and symmetry factor (SIM) are applied to determine the watershed shape. The watershed is radial if the parameter values are $WF > 1.00$ and $SIM > 0.50$. They are derived using Figure 1 and using the formula below.

- 1) The width factor (WF)

$$WF = W_u / W_l \quad (1)$$

- 2) The symmetry factor (SIM)

$$RUA = A_u / A \quad (2)$$

$$SIM = WF \cdot RUA \quad (3)$$

where:

WF - width factor (-);

W_u - watershed width at 0.75 L (Km);

W_l - watershed width at 0.25 L (Km);

RUA - upstream area of the watershed (-);

A_u - upstream watershed (km^2);

A - watershed area (km^2);

SIM - symmetry factor (-).

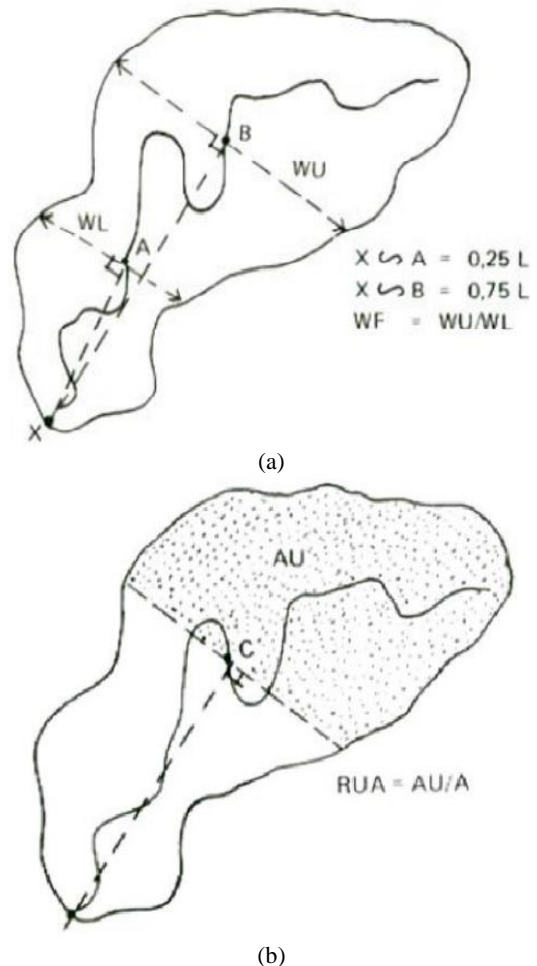


Fig. 1 WF and RUA parameters [16]

There are ten selected watersheds, with details as listed in Table 1. The selected watersheds are six from Sulawesi Island and the rest from Java Island.

Table 1 Study watersheds

No.	Watershed	Area (km^2)	Province	Width Factor (WF)	Symmetry Factor (SIM)
1.	Bontojai	277.96	South Sulawesi	2.50	1.37
2.	Daraha	26.01	South Sulawesi	4.08	2.36
3.	Jonggoa	128.62	South Sulawesi	1.43	0.74
4.	Kampili	630.43	South Sulawesi	1.67	0.81
5.	Macini Sombala	666.69	South Sulawesi	6.39	2.74
6.	Jenelata	222.95	South Sulawesi	1.62	0.85
7.	Pataruman	1.387.49	West Java	1.24	0.62
8.	Guwo	170.54	Central Java	1.19	0.60
9.	Lesti	378.85	East Java	1.41	0.70
10.	Gadang	692.65	East Java	1.46	0.71

2.2. Data Collection

The data requirements for this research are as follows:

- 1) Watershed Map derived from Topographic Map Scale 1: 50,000.
- 2) Discharge data obtained from automatic water level recording and rating curve.
- 3) Hourly rainfall data from rain recording stations of at least one and several daily rainfall data in the watershed.

2.3. Data Analysis

The calculation procedures and methods used are described below:

- 1) To obtain time base (T_b) by the following steps:
 - a. To transform stage hydrograph to discharge hydrograph using the rating curve for each watershed.
 - b. To select single peak flood cases, at least ten cases for each watershed.
 - c. To determine the base flow. Separation of the base flow from the discharge hydrograph is required to obtain a direct runoff (DRO) hydrograph. This study was selected using the straight-line method.
 - d. To determine water losses. Types of water losses include losses due to infiltration, evapotranspiration, interception, and basin storage. This study was selected using the phi index method. Phi-index is constant during the rainy period. The phi index is a method for analyzing infiltration due to the relationship between rainfall and watershed runoff.
 - e. To obtain the time base data (T_b). The time base is a period measured from zero time until direct runoff contribution ends. The time base is calculated with the formula: $T_b = n - 1 - j$, where (n) is the number of ordinates (excluding zero values at the beginning and ending hours) and (j) is the effective rainfall period (hour).
- 2) To determine the radial water physical parameters.

There are ten physical parameters to be tested, namely watershed area (A), watershed perimeter (P), the main river length (L), the main river length from outlet to nearest the center gravity of the watershed (L_c), river slope (S), topographic factors (T), drainage density (D_d), upstream area of the watershed (RUA), a factor of the main river length and the river length from outlet to nearest the center gravity of the watershed [L/L_c] and the ratio between the main river length and the river length from outlet to nearest the center gravity of the watershed [L/L_c].

The physical parameters of the watershed are derived from the Topographic Map scale of 1: 50,000 by using the Arc. GIS. Some physical watershed parameters (A , P , and L) could be directly obtained from the watershed map. The remaining physical watersheds parameters are obtained by taking into account the following criteria and formulas:

a. The L_c parameter is measured starting from outlet to nearest the center of gravity of the watershed. The grid method using Arc. GIS is applied to determine the center of gravity of the watershed.

b. The S parameter is calculated by the following formula:

$$S = \frac{\Delta E_r}{L} \quad (4)$$

where S is river slope (-); ΔE_r is a height difference between upstream and downstream of the river (m); and L is the main river length (m).

c. The T parameter is calculated using the Potten method [17].

$$T = \frac{L}{S^{0.5}} \quad (5)$$

where T is the topography factor (km), L is the main river length (m), and S is the river slope (-).

d. The D_d parameter is estimated by the formula below:

$$D_d = L_{tot}/A \quad (6)$$

where D_d is drainage density (km^{-1}), L_{tot} is total river length (km), and A is a watershed area (km^2).

e. Upstream area of the watershed (RUA) is defined as the ratio between the area of the upstream watershed (A_u) with the area of the watershed (A). The A_u parameter is obtained by referring to Figure 1(b). The RUA is estimated using Equation (2).

3) To identify the radial watershed physical parameters that significantly affect the time base and develop a time base (T_b) model.

a. The Pearson correlation method was applied to identify watershed physical parameters that significantly affect the time base. The correlation value (R) above 0.60 means that it indicates a significant relationship [18]. Table 2 is the correlation coefficient category. The direction of the relationship is indicated by a negative or positive sign. A positive correlation means that there is a linear relationship and vice versa.

Table 2 Correlation coefficient category [18]

Class of R	Relationship
0.000 – 0.199	Very low
0.200 – 0.399	Low
0.400 – 0.599	Medium
0.600 – 0.799	Strong
0.800 – 1.000	Very strong

b. A multivariate regression statistic procedure was applied to estimate the influential model parameters by following the form of the equation that was reported in [16], namely the exponential equation. In order to allow the use of multivariate regression, the time base (T_b) model is adjusted to the following equation:

$$T_b = aX_1^b \cdot X_2^c \cdot X_3^d \cdot X_4^e \quad (7)$$

where X_1 , X_2 , X_3 , and X_4 are the radial watershed physical parameters and a , b , c , d , and e are regression constants [19].

3. Results and Discussion

There were 100 cases of single peak flooding in the entire study watershed. They were obtained after extracting the collected rainfall-discharge data. Baseflow separation using the straight-line method is applied to each flood hydrograph to produce a direct runoff hydrograph. The individual time base is determined based on each direct runoff hydrograph.

The time base representing the watershed is obtained by averaging the individual time-based values in the watershed. Radial watershed physical parameters tested were obtained using a watershed map with a scale of 1: 50,000 and the software Arc. GIS and apply equation (4) to equation (6). The values of each physical parameter of the radial watershed and average base time (T_b) are presented in Table 3.

Table 3 Summary of physical parameters (X_i) and time base (Y_i)

No.	Watersheds	Physical parameters (X_i)									Y_i	
		A (km ²)	P (km)	L (km)	Lc (km)	S (-)	T (km)	Dd (km ⁻¹)	RUA (-)	[L.Lc] (km ²)	[L/Lc] (-)	Tb (hour)
1	Bontojai	276.26	117.99	36.14	21.88	0.04	177.62	0.90	0.55	790.62	1.65	3.70
2	Daraha	25.99	36.56	11.81	7.93	0.10	37.25	3.12	0.58	93.60	1.49	4.80
3	Jonggoa	128.53	73.89	21.26	12.81	0.06	86.06	1.76	0.52	272.34	1.66	5.10
4	Macini Sombala	661.49	252.95	79.21	54.76	0.02	553.21	0.80	0.51	4,337.27	1.45	15.50
5	Jenelata	222.95	104.30	34.70	21.43	0.02	221.25	1.50	0.52	743.61	1.62	15.40
6	Pataruman	1398.14	297.39	101.97	52.03	0.01	1,185.33	0.96	0.50	5,304.78	1.96	23.10
7	Guwo	250.29	140.35	47.93	23.27	0.02	310.05	0.41	0.50	1,115.38	2.06	9.80
8	Lesti	378.88	151.96	44.20	21.24	0.04	234.90	0.19	0.49	938.66	2.08	5.20
9	Gadang	719.31	216.33	40.40	15.74	0.03	250.04	0.20	0.48	635.70	2.57	15.60
10	Kampili	630.10	193.33	60.53	36.43	0.03	371.15	0.78	0.49	2,205.00	1.66	8.00

Statistical analysis of correlation has been carried out. It is to assess the level of relationship between the time base and the physical parameters of the watershed and between the physical parameters themselves

individually. The parameter values in Table 3 need to be log-transformed (base 10) prior to analysis. The correlation matrix is presented in Table 4.

Table 4 Correlation matrix

	A	P	L	Lc	S	T	Dd	RUA	L.Lc	L/Lc	Tb
A	1										.797**
P	.936**	1									.767**
L	.901**	.934**	1								.739*
Lc	.768**	.849**	.950**	1							.647*
S	-0.630	-.755*	-.748*	-.674*	1						-.677*
T	.927**	.853**	.944**	.846**	-0.632	1					.802**
Dd	-0.441	-0.630	-0.490	-0.364	.773**	-0.301	1				-0.262
RUA	-0.547	-.670*	-0.526	-0.382	.735*	-0.391	.843**	1			-0.447
L.Lc	.849**	.862**	.963**	.969**	-0.596	.933**	-0.269	-0.333	1		.721*
L/Lc	0.342	0.347	0.098	-0.173	-0.325	0.121	-.638*	-.649*	-0.105	1	0.274
Tb	.797**	.767**	.739*	.647*	-.677*	.802**	-0.262	-0.447	.721*	0.274	1

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Correlations above 0.60 are considered significant [18]. The time base (T_b) is positively correlated with topographic factors (T), watershed area (A), watershed perimeter (P), the main river length (L), a factor of the main river length, and the river length from the outlet to nearest the center gravity of the watershed [L.Lc], the main river length from outlet to nearest the center gravity of the watershed (Lc). As for the negative correlation with only one parameter, namely river slope (S).

The time base model is based on the use of the seven physical watershed parameters above. The

modeling analysis has used the multivariate regression method with several alternatives based on the number of independent variables used. In this analysis, the time base (T_b) is the dependent variable, while the physical watershed parameters (T, A, P, L, [L.Lc], S and Lc) are the independent variables. The selection of the time base model is based on (1) statistical criteria: the Adj. $R^2 \geq 0.70$, Sig. $F < 0.05$, the smallest standard error (SEE) and passed the residual test; (2) The accuracy test is good (MAE and RMSE are close to zero and $NSE \geq 0.65$); (3) model rationalization: regardless of

the value of the independent variable does not produce a negative value for the time base.

In stage 1 regression analysis, the time base model with Adj. R^2 , the largest (0.67), was obtained by involving the parameters S and $[L.L_c]$. The model has also passed the model residual test (normality, autocorrelation, heteroscedasticity, and multicollinearity test) and has a good level of accuracy. Model improvement is made by eliminating one data set from the Macini Sombala watershed. As a result, the selected base time model can meet all of the above criteria, as follows:

$$T_b = 2,037 \cdot S^{-1.734} \cdot [L.L_c]^{-0.690} \quad (8)$$

where T_b is the time base (hour), S is river slope (-); $L.L_c$ is a factor of the main river length and the river length from outlet to nearest the center gravity of the watershed (km^2).

The time base (T_b) model (Eq. 8) has Adj. $R^2 = 0.87$; Sig. $F = 0.00$ (<0.05), $SEE = 0.10$ and passed the residual test. In addition, the model has also shown good accuracy, namely with $MAE = 0.07$ $RMSE = 0.09$ and $NSE = 0.89$. That model has Adj. $R^2 = 0.87$. It means that the time base (T_b) models involving two radial watershed physical factors (S and $[L.L_c]$) can simultaneously explain the time base (T_b) variability of 87%, and the rest is influenced by other parameters.

The main river slope parameter (S) has a dominant influence on the time base (T_b) model based on the magnitude of the exponential value (1.720) and then followed by the parameter of a factor of the main river length and the river length from outlet to nearest the center gravity of the watershed $[L.L_c]$ (0.690). The negative sign on the exponential value only shows the direction of the relationship with the time base (T_b) parameter. The appearance of parameters S and $[L.L_c]$ in the time base (T_b) model is in line with the theory and strengthens the findings of previous researchers, which have been documented in [20] and [21]. They have mentioned that these two parameters (S and $L.L_c$) are responsible for the duration of peak and recession time.

The time base duration is mainly determined by the flow velocity factor. Referring to Manning's equation, the flow velocity is controlled by the hydraulic radius (R) and the river slope (S). If we assume that the hydraulic radius of the watershed is the ratio of the watershed area and the watershed perimeter and the watershed radius is $0.5 L$ (river length) or close to the value of L_c . Based on that, the parameter $[L.L_c]$ is proportional to the hydraulic radius parameter of the watershed. Thus, the dominant parameter in the time base (T_b) model is analogous to the parameter that affects the flow velocity in Manning's equation.

The river slope parameter has a significant effect on the hydrograph section, mainly on the recession section. This effect describes the rate of decline in the magnitude of the flood. The greater river slope increases the rate of decreasing the higher flood

discharge. The implication of this situation is to produce a steeper hydrograph recession or a shorter time base duration [22]. Likewise, for the process and effects caused by the parameter $[L.L_c]$. The greater the parameter value, the more implications for the relatively shorter flood drain time. In addition, the results of this study have also provided evidence that this research can support the results of previous studies and theoretical principles, especially on flood characteristics in radial watersheds.

The limitations of the time base (T_b) model produced in this research are (1) it is only suitable for radial watersheds ($WF > 1$ and $SIM 0.5$); (2) The river is not affected by tidal factors and perineal; (3) the main river slope (S) is between 0.01 to 0.10; (4) the main river length (L) is between 11.81 to 101.97 km; (5) the main river length from outlet to nearest the center gravity of the watershed (L_c) is between 7.93 to 54.76 km.

4. Conclusion

The time base modeling of the unit hydrograph is based on radial watershed physical parameters. There are ten radial watershed physical parameters to be tested. As a result, parameters of the main river slope (S) and factor of the main river length and the river length from outlet to nearest the center gravity of the watershed $[L.L_c]$ together have significant ability to estimate the time base (T_b) variability. The resulting statistical indicator is Adj. $R^2 = 0.87$, standard error of the estimate (SEE) = 0.10, Sig. $F = 0.00$ and also met the requirements of the model residual test. It has a good level of accuracy, with mean absolute error (MAE) = 0.07%, root mean square error ($RMSE$) = 0.09 and Nash-Sutcliffe Efficiency (NSE) = 0.89.

References

- [1] ROY A, and THOMAS R. A Comparative study on the derivation of unit hydrograph for Bharathapuzha River. *Procedia Technology*, 2016, 24: 62-69.
- [2] PRIYANTORO D, and LIMANTARA LM. Conformity evaluation of synthetic unit hydrograph (case study at upstream Brantas subwatershed, East Java Province of Indonesia). *Journal of Water and Land Development*, 2017, 35: 173–183. <https://doi.org/10.1515/jwld-2017-0082>.
- [3] SINGH PK, MISHRA SK, and JAIN MK. A review of the synthetic unit hydrograph: from the empirical UH to Advanced Geomorphological Methods. *Hydrological Sciences Journal*, 2014, 59(2): 239-261
- [4] PRADIPTA AG, and NURHADY S. The representative synthetic unit hydrograph in Juana Watershed. *IOP Conference Series: Earth and Environmental Science*, 2019.
- [5] BHUNY PK, BERNDTSSON R, OJHA CSP, and MISHRA SK. Suitability of Gamma, Chi-square, Weibull, and Beta Distributions as synthetic unit hydrographs. *Journal Hydrology ELSEVIER*, 2006, 334(1-2): 28-38.
- [6] ONKAR C. A review study of different methods of synthetic unit hydrograph. *International Journal of Creative Research Thoughts*, 2020, 8(5): 2666-2671.

- [7] SHARMA RL. Development of synthetic unit hydrograph for ungauged catchments – A review. *International Journal of Research and Analytical Reviews*, 2018, 5: 1190-1196.
- [8] PATIL SK, and BHAGWAT TN. A review of synthetic hydrograph method for design storm. *International Research Journal of Engineering and Technology*, 2019, 06: 2413-2418
- [9] NADARAJAH S. Probability Models for Unit Hydrograph Derivation. *Journal of Hydrology*, 2007, 344: 185-189.
- [10] SARKA S, and RAI R K. Flood inundation modeling using Nakagami-m Distribution based GIUH for a partially gauged catchment. *Water Resource Management*, 2011, 25: 3805-3835.
- [11] SOEWARNOW. *Hidrometeri dan teknosabo dalam pengelolaan sum ber daya air (Hydrometric and techno-sabo in managing water resources) (Edisi Pertama)*. Yogyakarta: Graha Ilmu, 2013
- [12] LIMANTARA LM. Evaluation of roughness constant of river in synthetic unit hydrograph. *World Applied Sciences Journal*, 2009, 7(9): 1209-1211.
- [13] DEWI Y T, LIMANTARA L M, SUHARTANTO E, and WAHYUNI S. Analysis of the time to peak modelling. *Journal of Technology Report of Kansai University*, 2021, 63(01): 6797-6804.
- [14] LIMANTARA LM. The limiting physical parameters of synthetic unit hydrograph. *World Applied Sciences Journal*, 2009, 7(6): 802-804.
- [15] SAEFULLOH D F, HADIHARDAJA I K, and HARLAN D. Modeling of triangular unit hydrograph using Artificial Neural Network in a Tropical River Basin. *International Journal of GEOMATE*, 2018, 15(51): 69-76.
- [16] HARTO S. *Analisis hidrologi (Analysis of hydrology)*. Jakarta: Gramedia Pustaka Utama, 1983.
- [17] SEYHAN and ERSIN. *Dasar-dasar hidrologi (Base of hydrology)*. Yogyakarta: Gadjah Mada University Press, 1977.
- [18] SUGIYONO. *Metode penelitian kuantitatif, kualitatif, dan R&D (Research method in quantitative, qualitative, R&D)*. Bandung: CV. Alfabeta, 2017.
- [19] BAYUADJI G. Model pengurangan (*Decay*) berbasis faktor retardasi Daerah Aliran Sungai. *S-3 Disertasi*, Universitas Brawijaya Malang, 2020.
- [20] SNYDER F F. Synthetic unit hydrographs. *Transactions of the American Geophysical Union*, 1938, 19: 447-454.
- [21] TAYLOR AB, and SCHWARZ HE. Unit hydrograph lag and peak flow related to basin characteristics. *Transactions of the American Geophysical Union*, 1952, 33: 235-46.
- [22] SUBRAMANYA. *Engineering hydrology*. New Delhi: Tata McGraw-Hill Publishing Company Limited, 1995.
- 域上游案例研究)。水土发展杂志, 2017, 35: 173-183。
。 <https://doi.org/10.1515/jwld-2017-0082>。
- [3] SINGH PK、MISHRA SK 和 JAIN MK。合成单位水文线综述: 从经验呃到高级地貌方法。水文科学学报, 2014, 59(2): 239-261
- [4] PRADIPTA AG 和 NURHADY S. 胡安娜流域的代表性合成单元水文过程线。眼压会议系列: 地球与环境科学, 2019。
- [5] BHUNY PK、BERNDTSSON R、OJHA CSP 和 MISHRA SK。伽玛, 卡方、威布尔和测试版 分布作为合成单位水位线的适用性。期刊水文学 爱思唯尔, 2006, 334(1-2): 28-38。
- [6] ONKAR C. 不同合成单元水位图方法的综述研究。国际创意研究思想杂志, 2020, 8(5): 2666-2671。
- [7] 夏尔马 RL。未测量流域的合成单位水文过程线的开发——综述。国际研究与分析评论杂志, 2018 年, 5: 1190-1196。
- [8] PATIL SK 和 BHAGWAT TN。设计风暴综合水位图方法综述[J].国际工程技术研究学报, 2019, 06: 2413-2418
- [9] NADARAJAH S. 单位航道图推导的概率模型。水文学杂志, 2007, 344: 185-189。
- [10] SARKA S 和 RAI R K. 使用基于 中神分布的国际卫生研究院的洪水淹没建模, 用于部分测量的集水区。水资源管理, 2011, 25: 3805-3835。
- [11] SOEWARNOW。水资源管理中的水文测量和技术萨博 (第一版)。日惹: 格拉哈-伊尔穆, 2013。
- [12] LIMANTARA LM. 综合单位水文线中河流粗糙度常数的评价。世界应用科学杂志, 2009, 7(9): 1209-1211。
- [13] DEWI Y T、LIMANTARA L M、SUHARTANTO E 和 WAHYUNI S. 达到峰值建模的时间分析。关西大学技术报告, 2021, 63(01): 6797-6804。
- [14] LIMANTARA LM. 合成单元水位线的极限物理参数。世界应用科学杂志, 2009, 7(6): 802-804。
- [15] SAEFULLOH D F、HADIHARDAJA I K 和 HARLAN D. 在热带河流域中使用人工神经网络对三角形单位水文进行建模。国际地理杂志, 2018, 15(51): 69-76。
- [16] HARTO S. 水文学分析。雅加达: 语法主图书馆, 1983。
- [17] SEYHAN 和 ERSIN。水文学基础。日惹: 加札马达大学出版社, 1977。
- [18] SUGIYONO. 定量、定性、研发的研究方法。万隆: 简历。阿尔法贝塔, 2017。
- [19] BAYUADJI G. 基于分水岭延迟因子的排水模型布。S-3 论文, 拉维贾亚大学玛琅, 2020。
- [20] SNYDER F F. 合成单位流量图。美国地球物理联合会汇刊, 1938, 19: 447-454。
- [21] TAYLOR AB 和 SCHWARZ HE。与流域特征相关的单位水文过程线滞后和峰值流量。美国地球物理联合会汇刊, 1952, 33: 235-46。
- [22] SUBRAMANYA。工程水文学。新德里: 塔塔麦格劳-希尔出版有限公司, 1995。

参考文献:

- [1] ROY A 和 THOMAS R. 巴拉塔普扎 河单位水位线推导的比较研究。继续技术, 2016, 24: 62-69。
- [2] PRIYANTORO D 和 LIMANTARA LM。合成单位水文线的一致性评估 (印度尼西亚东爪哇省布兰塔斯分流