

卫星与观测到的 2021 年 2 月 19 日和 2021 年 10 月 28 日的日降雨量空间比较表明，与仅使用 ARR 站相比，添加收割机合成降雨站的降雨分布模式更相似。

关键词：合成降雨，收割机模型，卫星，观测。

1. Introduction

The distribution of run-off in the stream and rainfall behavior because of some approaches by the unit hydrograph method and the engineering method has been promoted familiarly for recent years [1]. It is not too easy to understand the run-off process thoroughly [2]. The process of rainfall-induced runoff is usually given in a curve shape and shows the variation of runoff toward the time during a given rainfall event [2].

The rainfall data is the main component in providing the design, detail design, operation and maintenance of effective water resource infrastructure. Rainfall data are often used for analyzing flood balance [3], the flood frequency distribution [4], estimating the river discharge and water structure design [5]. The main constraint in the design of water resource infrastructure is less available rainfall data temporally and spatially. The limitation of rainfall station number that is available causes inaccuracy in analyzing the area mean rainfall [6, 7]. Therefore, sometimes the correlation between the recorded data in the rainfall station and water recorded station does not indicate a positive and strong correlation. This is due to less rainfall data that are spatially representative in the downstream of watershed [8]. Additionally, the usage of unit hydrograph as the rainfall-run-off model is often carried out in the practice of water resource infrastructure design [9, 10]. This method uses one value of the area mean rainfall, which will cause a potency of error between the simulation and observed discharge [12].

Based on the problem above, there is needed the synthetic rainfall that is used for correcting the area mean rainfall in a watershed, so the result of the simulation discharge can be close to the value of observed discharge. In this research, some flood hydrographs in the 10 watersheds in Indonesia are used to build an empirical equation for determining the synthetic rainfall. After the synthetic rainfall model is found, it is necessary to carry out the verification in the other watersheds that are not used for building the empirical model. In this research, we chose the Ciliwung Hulu watershed for conducting the verification.

2. Materials and Methods

The verification of ArRR equation is carried out in the Ciliwung Hulu watershed with the area of 150.55 km² and a flow length of 27.24 km, as presented in Fig. 1.

The analysis of the ArRR value is based on the following equation:

$$ArRR_i = \frac{0,026FB - 0,307Re_i + 1,184 \frac{Q_{i+lag}}{A} + 0,693}{C_{ArRR} \cdot K_{ArRR}}$$

for $A < 750 \text{ km}^2$.

The lag time is three hours based on the analysis of time to peak of the Nakayasu hydrograph. By assuming that the run-off coefficient is 0.35, the steps of finishing the research are as follows:

1. Collecting the technical data

The criteria of sample or data selection for the verification watershed are as follows:

a. There is a hydrometry station (automatic water level recorder (AWLR)), and, in the surrounding watershed, there are automatic rainfall recorder and the watershed area $< 300 \text{ km}^2$;

b. The watershed is not affected by the river cross-section structure like a dam. It intends to avoid the effect of storage on the flood discharge.

However, the secondary data needed are as follows:

a. Digital elevation model national (DEMNAS);

b. State Hydrograph from AWLR station including the rating curve;

c. Hourly rainfall from ARR.

A land cover map is used for determining the run-off coefficient. If there is no land cover map, it is changed by the satellite Landsat, which is classified using the forest random algorithm methodology.

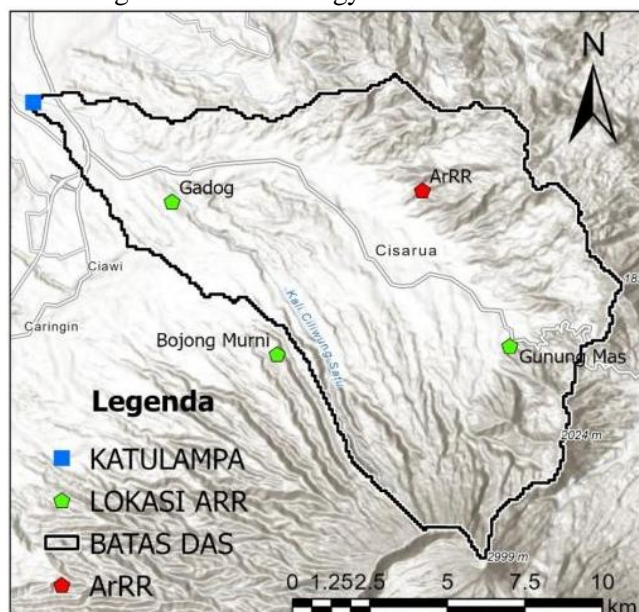


Fig. 1 Ciliwung Hulu watershed and the location of rainfall and discharge stations

2. The methodology that is used in analyzing is as

follows:

- a. To select the serial data of hyetograph and hydrograph for the same time to be used as the basis of this research;
- b. To separate the direct run-off from the base-flow by using the straight-line method [11];
- c. To analyze the watershed physical parameters that consist of area (A), main river length (L), the river length until the closest point to the weight point of watershed (Lc), river slope (S), roughness coefficient (n);
- d. To determine the location of the synthetic rainfall station by using the help of Kagan Rodda method;
- e. To analyze Thiessen coefficient of each rainfall station (before and after there is synthetic rainfall station);
- f. To analyze the synthetic unit hydrograph by using Nakayasu Synthetic Unit Hydrograph;
- g. To conduct the verification of the model.

3. Results and Discussion

Based on the Nakayasu equation, time to peak in the Ciliwung Hulu watershed is 2.7 h. Fig. 1 shows the locations of the ARR rainfall station and AWLR station. According to the location, the coefficient of Thiessen can be determined, as presented in Table 1.

Table 1 Thiessen coefficient without ArRR

Station	Thiessen Coefficient	
	Without ArRR	With ArRR
Gadog	0.30	0.22
Bojong Murni	0.19	0.15
Gunung Mas	0.51	0.34
ArRR	0.00	0.29

The evaluation of ArRR analysis is carried out to the two hydrographs that are on 19th February 2021 and 21th October 2021. Data of rainfall and discharge on the two dates are presented in Table 2.

Table 2 Event data on February 19, 2021

Katulampa						Rainfall				
Date	Time	TMA PDA	Discharge m3/s	TMA Bendung	Discharge m3/s	Date	Time	Gunung Mas	Gadog	Bojong Murni
		Katulampa (m)	$(Q=22702(MA+0.21)^{2.464}$ Untuk $0.3 < MA < 3$ m	Katulampa (m)	$(Q=1.72*69.6*(H-0.275)^{3/2}$					
19-Feb-21	0.00	0.76	21.06	0.30	0.47	18-Feb-21	7.00	0.00	0.00	0.00
	1.00	0.75	20.53	0.30	0.47		8.00	0.00	0.00	0.00
	2.00	0.75	20.53	0.30	0.47		9.00	0.00	0.00	0.00
	3.00	0.75	20.53	0.30	0.47		10.00	0.00	0.00	0.00
	4.00	0.75	20.53	0.30	0.47		11.00	0.00	0.00	0.00
	5.00	0.79	22.7	0.30	0.47		12.00	0.00	0.00	0.00
	6.00	1.17	50.21	0.30	0.47		13.00	3.00	1.50	0.00
	7.00	1.41	74.53	0.60	22.18		14.00	41.00	11.50	0.00
	8.00	1.25	57.68	0.80	45.54		15.00	8.00	4.00	16.00
	9.00	1.35	67.91	1.00	73.9		16.00	1.00	1.50	0.00
	10.00	1.25	57.68	0.70	33.17		17.00	1.00	1.00	0.00
	11.00	1.07	41.71	0.40	5.29		18.00	0.00	0.50	0.00
	12.00	1.03	38.57	0.60	22.18		19.00	0.00	0.00	0.00
	13.00	0.99	35.58	0.60	22.18		20.00	1.00	0.50	0.00
	14.00	0.98	34.85	0.50	12.78		21.00	0.00	0.00	0.00
	15.00	0.97	34.13	0.50	12.78		22.00	0.00	0.00	0.00
	16.00	0.95	32.73	0.50	12.78		23.00	0.00	0.00	0.00
	17.00	0.93	31.35	0.50	12.78	19-Feb-21	0.00	0.00	0.00	0.00
	18.00	0.91	30.01	0.50	12.78		1.00	0.00	0.00	2.00
	19.00	0.9	29.36	0.50	12.78		2.00	0.00	0.00	0.00
	20.00	0.89	28.71	0.40	5.29		3.00	0.00	0.00	0.00
	21.00	0.87	27.44	0.40	5.29		4.00	0.00	1.00	1.00
	22.00	0.85	26.21	0.40	5.29		5.00	6.00	1.50	0.00
	23.00	0.85	26.21	0.40	5.29		6.00	6.00	31.50	8.00
							7.00	11.00	21.00	2.00
							8.00	2.00	0.00	1.00
							9.00	7.00	1.00	0.00
							10.00	3.00	0.00	0.00
							11.00	2.00	0.00	0.00
							12.00	4.00	0.00	0.00
							13.00	0.00	0.00	0.00
							14.00	3.00	0.00	0.00
							15.00	0.00	0.50	0.00
							16.00	1.00	0.00	0.00
							17.00	0.00	0.00	0.00
							18.00	0.00	0.00	0.00
							19.00	0.00	0.00	0.00
							20.00	0.00	0.00	0.00
							21.00	0.00	0.00	0.00
							22.00	0.00	0.00	0.00
							23.00	0.00	0.00	0.00

Table 3 Event data on October 28, 2021

28-Feb-21	9.00	0.56	11.54			28-Feb-21	9.00	0.00	0.00
	10.00	0.54	11.17				10.00	0.00	0.00
	11.00	0.60	13.51				11.00	0.00	54.00
	12.00	1.45	79.14				12.00	19.00	1.00
	13.00	1.70	111.82				13.00	14.00	106.00
	14.00	1.54	90.14	1.10	89.71		14.00	0.00	27.00
	15.00	1.35	67.91	1.10	89.71		15.00	0.00	38.00
	16.00	1.25	57.68	1.30	124.23		16.00	0.00	18.00
	17.00	1.11	44.99	0.90	59.15		17.00	0.00	1.00
	18.00	1.05	40.12	0.80	45.54		18.00	0.00	0.00
	19.00	1.00	36.31	0.70	33.17		19.00	0.00	0.00
	20.00	0.93	31.35	0.50	12.78		20.00	0.00	0.00
	21.00	0.87	27.44	0.50	12.78		21.00	0.00	0.00
	22.00	0.76	21.06	0.40	5.29		22.00	0.00	0.00
	23.00	0.75	20.53				23.00	0.00	0.00
	0.00	0.75	20.53				0.00	0.00	0.00
	1.00	0.74	20.01				1.00	0.00	0.00
29-Okt-21	2.00	0.74	20.01			29-Feb-21	2.00	0.00	0.00
	3.00	0.74	20.01				3.00	0.00	0.00
	4.00	0.74	20.01				4.00	0.00	0.00
	5.00	0.74	20.01				5.00	0.00	0.00
	6.00	0.74	20.01				6.00	0.00	0.00
	7.00	0.74	20.01				7.00	0.00	0.00
	8.00	0.74	20.01				8.00	0.00	0.00
	9.00	0.74	20.01				9.00	0.00	0.00
	10.00	0.74	20.01				10.00	0.00	0.00
	11.00	0.74	20.01				11.00	0.00	70.00
	12.00	0.74	20.01				12.00	0.00	0.00
	13.00	0.74	20.01				13.00	1.00	0.00
	14.00	0.71	18.49				14.00	0.00	0.00
	15.00	0.69	17.51				15.00	0.00	0.00
	16.00	0.69	17.51				16.00	0.00	1.00

However, analysis of ArRR is based on the equation as follows (for $A < 750 \text{ km}^2$):

$$ArRR_i = \frac{0,026FB - 0,307Re_i + 1,184 \frac{Q_{i+lag}}{A} + 0,693}{C_{ArRR} \cdot K_{ArRR}}$$

The time lag that is used is 3 h. It is based on the analysis of time to peak from the Nakayasu Synthetic Unit Hydrograph. Assuming that the run-off coefficient is 0.35, the analysis result of the ArRR value is presented in Table 4. Fig. 2 presents the flood hydrograph and comparison by ARR and ArRR rainfall on February 19, 2021. Fig. 3 and 4 present the spatial comparison between satellite and observed daily rainfall on February 19, 2021, each with and without ArRR.

Table 4 Analysis result of ArRR on February 19, 2021

Date	Time	A	FB	Q_{i+lag}/A	Re_i	ArRR
19/02/2021	9	150.55	0.20	0.00	0.15	0.00
	10	150.55	0.20	0.01	0.00	4.91
	11	150.55	0.20	0.19	0.00	6.37
	12	150.55	0.20	0.49	0.19	8.45
	13	150.55	0.20	0.53	1.19	6.65
	14	150.55	0.20	0.78	5.11	0.40
	15	150.55	0.20	0.44	4.35	0.00
	16	150.55	0.20	0.15	0.34	5.29
	17	150.55	0.20	0.23	1.30	3.97
	18	150.55	0.20	0.21	0.51	5.46
	19	150.55	0.20	0.14	0.34	5.23
	20	150.55	0.20	0.13	0.68	4.44
	21	150.55	0.20	0.12	0.00	5.78
	22	150.55	0.20	0.10	0.51	4.59
	23	150.55	0.20	0.09	0.06	5.45
	24	150.55	0.20	0.08	0.17	5.14
	25	150.55	0.20	0.02	0.00	5.02
	26	150.55	0.20	0.01	0.00	4.92

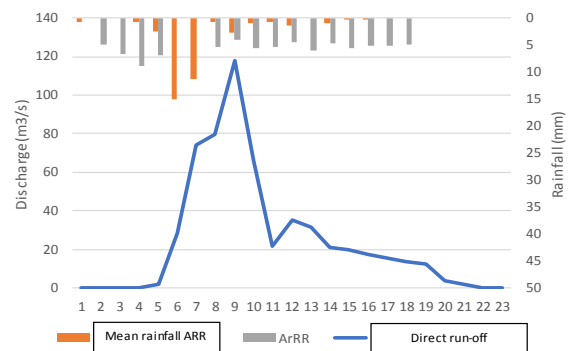


Fig. 2 Flood hydrograph and comparison by ARR and ArRR rainfall on February 19, 2021

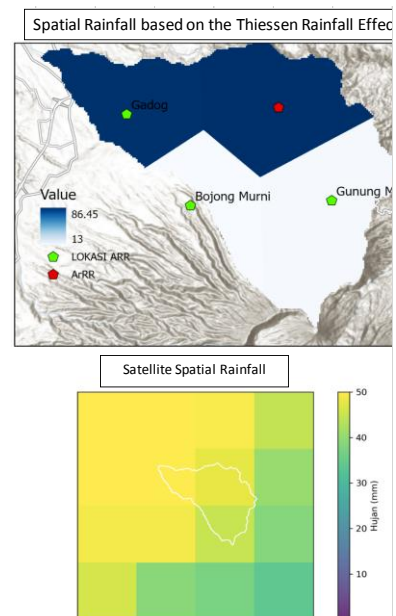


Fig. 3 Spatial comparison between satellite and observed daily rainfall on February 19, 2021

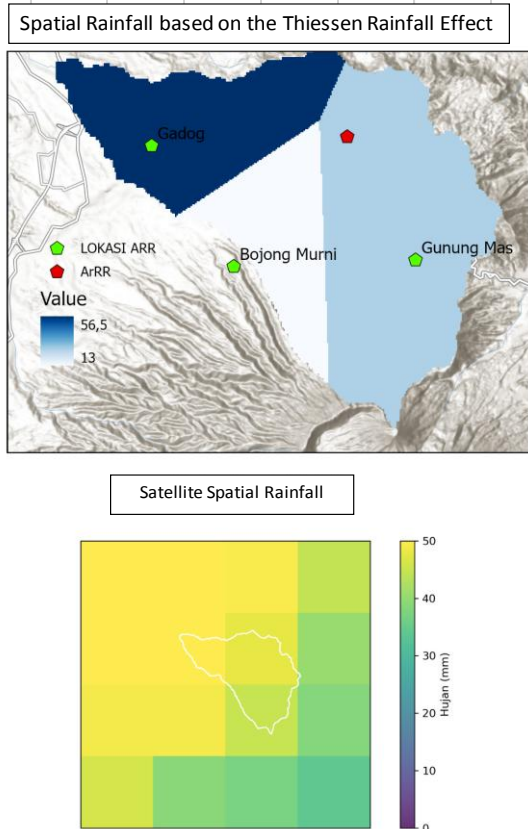


Fig. 4 Spatial comparison between satellite and observed daily rainfall on February 19, 2021, without ArRR

The spatial comparison between satellite and observed daily rainfall on February 19, 2021, shows that the rainfall distribution pattern is more similar with adding the synthetic rainfall station (ArRR) than only using the ARR. Table 5 presents the analysis result of ArRR on October 28, 2021. Fig. 5 presents the Flood Hydrograph and Comparison by ARR and ArRR Rainfall on February 28, 2021. Fig. 6 and 7 present the spatial comparison between satellite and observed daily rainfall on February 28, 2021, each with and without the ArRR.

Table 5 Analysis result of ArRR on October 28, 2021

Date	Time	A	FB	Q_{i-lag}/A	Re_i	ArRR
28/10/2021	9	150.55	0.20	0.66	0.00	14.61
	10	150.55	0.20	0.11	5.59	2.90
	11	150.55	0.20	0.96	3.35	7.91
	12	150.55	0.20	1.11	13.38	0.00
	13	150.55	0.20	0.59	2.80	5.35
	14	150.55	0.20	0.47	3.94	0.41
	15	150.55	0.20	0.35	1.86	5.38
	16	150.55	0.20	0.18	0.10	8.70
	17	150.55	0.20	0.15	0.00	8.66
	18	150.55	0.20	0.05	0.00	7.53
	19	150.55	0.20	0.01	0.00	7.03
	20	150.55	0.20	0.01	0.00	6.98
	21	150.55	0.20	0.00	0.00	0.00
	22	150.55	0.20	0.00	0.00	0.00
	23	150.55	0.20	0.00	0.00	0.00
	24	150.55	0.20	0.00	0.00	0.00
	25	150.55	0.20	0.00	0.00	0.00
	26	150.55	0.20	0.00	0.00	0.00

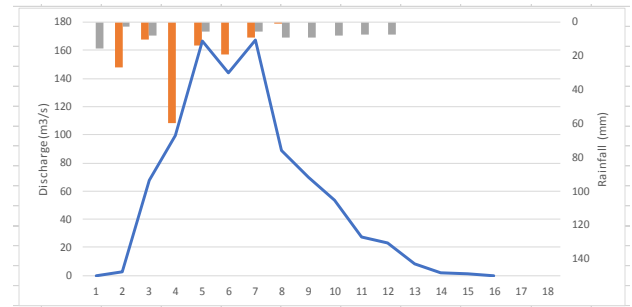


Fig. 5 Flood hydrograph and comparison by ARR and ArRR rainfall on October 28, 2021

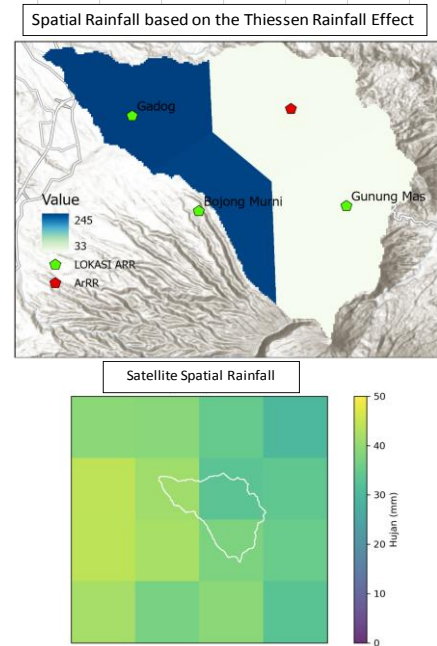


Fig. 6 Spatial comparison between satellite and observed daily rainfall on October 28, 2021

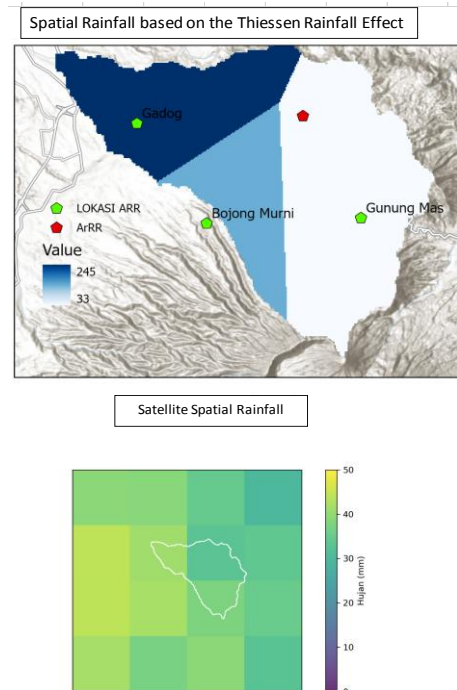


Fig. 7 Spatial comparison between satellite and observed daily rainfall on October 28, 2021, without the ArRR

The spatial comparison between satellite and observed daily rainfall on February 28, 2021, shows that the rainfall distribution pattern is more similar with adding a synthetic rainfall station (ArRR) than only using the ARR.

4. Conclusion

The limitation of rainfall station number causes inaccuracy in the analysis of area mean rainfall. Therefore, sometimes the correlation between the recorded data in the rainfall station and water recorded station does not indicate a positive and strong correlation. This is caused by less rainfall data that are spatially representative in the downstream of watershed. The verification of ArRR equation is carried out in the Ciliwung Hulu watershed with the area of 150.55 km² and a flow length of 27.24 km. The analysis of ArRR is based on the equation as follows:

$$ArRR_i = \frac{0,026FB - 0,307Re_i + 1,184 \frac{Q_i + lag}{A} + 0,693}{C_{ArRR} - K_{ArRR}}$$

This equation is for $A < 750$ km². Lag time that is used is 3 h based on the analysis of time to peak by using the Nakayasu equation by assuming the run-off coefficient is 0.35. The spatial comparison between satellite and observed daily rainfall on October 19, 2021, and February 28, 2021, shows that the rainfall distribution pattern is more similar when adding the synthetic rainfall station (ArRR) than when only using the ARR.

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