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Evaluation of Satellite-based Rainfall Data in Flood Prediction

Bayu Krisna Wisnulingga*, Joko Sujono, Rachmad Jayadi
Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada

Jalan Grafika No. 2, Mlati, Sleman, Yogyakarta, Indonesia

* Corresponding author email: bkrisnaw15@mail.ugm.ac.id

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Abstract
Rainfall-runoff transformation is a solution to the difficulty of obtaining observed discharge data in flood prediction analysis. Rainfall-runoff transformation requires observed rainfall data with a high rate of accuracy spatially. However, observed rainfall data is also often not available. Satellite rainfall data is commonly used to replace observed rainfall data. However, the accuracy of satellite rainfall data still needs to be tested. This study applied rainfall-runoff transformation to the observed rainfall data and the PERSIANN, GPM, and GSMaP satellite rainfall data in the Opak Watershed using GAMA I SUH method, which were then compared with the observed hydrograph at the AWLR Kretek during the flood event that occurred in Yogyakarta Province due to Cyclone Cempaka to evaluate their accuracy. The results showed that the GPM data generated a hydrograph that is the closest to the observed hydrograph, both the shape and the peak of the hydrograph.

INTRODUCTION

Yogyakarta City is the economic center of the Yogyakarta Province. Yogyakarta Province has quite high rainfall and several major rivers in the Opak Watershed flow through the Yogyakarta City. With high rainfall and many rivers that flow into the Opak Watershed, flooding will be more prone to occur. Considering that the level of vulnerability to flooding is quite high and some of the water flows through the Yogyakarta City, it is necessary to monitor and observe the behavior of the rivers in the Opak Watershed to overcome the adverse effects that can be caused by the flow of these rivers. Saputra et al. (2019) in their research stated that the Cempaka Cyclone event 27-30 November 2017 caused a maximum flood discharge of 2,185 m^3/s and resulted in overflow in the Opak River at several points from the Opak-Oyo River confluence to Kretek.

One of the observations that needs to be made in the Opak Watershed is the observation of river flow discharge, but this often causes problems due to the unavailability of observed discharge data over a long time at the Automatic Water Level Recorder (AWLR) station. This problem can be overcome by utilizing observed rainfall data from rainfall gauge stations (ARR) in the watershed, which are usually available for a long period using certain analytical approaches to estimate unavailable discharge data. The transformation of rainfall data into an estimate of discharge can be done by constructing a flood hydrograph using a Unit Hydrograph (UH).

However, sometimes rainfall data is not always available or the rainfall gauge station is too far from the watershed. Therefore, a solution is needed to be able to overcome this problem. Due to their large coverage, high spatial resolution, and temporal frequency, satellite weather radars produce observations that adequately represent precipitation structure and evolution (Pidwirny, 2006 as cited in Mohamad et al., 2021). There are many types of satellite rainfall data that can be utilized in constructing a hydrograph. Gunawan (2008) and Natadiredja et al. (2018) states that satellite rainfall data has the potential to be used to fill in empty observed rainfall data.

However, in general, satellite rainfall data has figures that tend to br different from actual precipitation due to the satellite radar beam blockage by obstacles, overshooting and partial beam filling, clutter, and the attenuation of the radar signals (Ryzhkov & Zrkić, 2019 as cited in Mohamad et al., 2021). So that the discharge data from the transformation of satellite rainfall data also does not match the observed discharge data in the field. From the results of his research on the GSMaP (Global Satellite Mapping of Precipitation), CHIRPS (Climate Hazards Group InfraRed Precipitation with Station), and GPM (Global Precipitation Measurement) satellite rainfall data in South Lampung Regency, Pratama et al. (2022) state that for rainfall intensity, the three satellite rainfall data still have quite a large error over the observed data even though the ability to detect rainfall is good. From the results of research conducted by Trisantikawaty & Sepriando (2015), the Tropical Rainfall Measuring Mission (TRMM) satellite rainfall data is not good enough to be used for estimating daily rainfall, but good enough to be used for estimating monthly rainfall.

From the problems above, it is necessary to evaluate the accuracy of the satellite rainfall data. In previous studies, Ginting et al. (2019) analyzed the relationship between GPM and PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) satellite rainfall data and the observed rainfall data reviewed at the ARR Kalibawang. In addition, Harsanto et al. (2021) compared direct runoff hydrographs from GPM 3IMERGHH satellite rainfall data in the upstream Winongo sub-watershed and observed data from other sub-watershed with similar characteristics.

This study evaluated the accuracy of observed and satellite rainfall data, namely PERSIANN, GPM, and GSMaP, compared to the observed discharge of the Opak Watershed, reviewed at the AWLR Kretek. In this research, the analysis of rainfall-runoff transformation using the GAMA I SUH method was carried out for the Opak Watershed, which is divided into several sub-watersheds. The hydrograph resulting from the rainfall data is compared with the AWLR Kretek hydrograph to see the level of accuracy of observed and satellite rainfall data.

RESEARCH METHODS

Research Location

The location of this research is the Opak Watershed, which is administratively located in Yogyakarta Province, covering Sleman Regency, Bantul Regency, Yogyakarta City, and Gunung Kidul Regency as can be seen in Figure 1. The Opak Watershed empties into the south coast of Yogyakarta, precisely in Bantul Regency.

The location point for the review in this study is the AWLR Kretek, which is placed on southwest (downstream) of the Glondong (Kretek) Bridge and northeast (upstream) of the Kretek Weir, to be precise at 110°18’52.9” E and 7°59’25.9” S. The total area of the Opak Watershed studied at the AWLR Kretek location is ±1248 km^2.

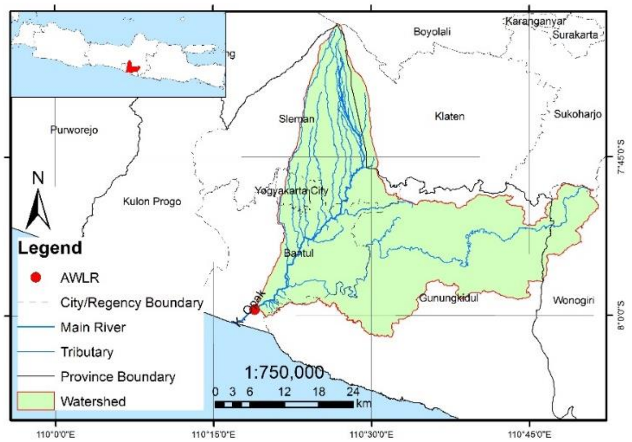

Figure 1. Research Location (BBWSO, 2020)

Research Steps

In general, the research steps that will be carried out in the evaluation of satellite rainfall data in the Opak Watershed are as follow. (1) Collecting sub-watersheds map data in the Opak Watershed and characteristics of the sub-watersheds. (2) Generating the average rainfall of the watershed and sub-watersheds for observed rainfall data using the Thiessen Polygon method. (3) Generating the average rainfall the watershed and sub-watersheds for satellite rainfall data based on the area of influence of the grid. (4) Processing land use data obtained from Regional Development Planning Agency of Yogyakarta (Bappeda DIY) and the Indonesian Topographical Map (RBI) using ArcMap 10.5 software to obtain the area of each land use for each sub-watershed. (5) Determining the type of soil in each sub-watershed using the Harmonized World Soil Database (HWSD) v 1.2 soil type map provided by the Food and Agriculture Organization (FAO) by entering boundary data for each sub-watershed in shapefile (shp) format. (6) Processing land use data and soil type data into CN (Curve Number) values and $CN_{composite}$ values. (7) Determining the baseflow discharge for each sub-watershed based on the area of influence of the sub-watershed on the Opak Watershed. (8) Generating unit hydrographs using the GAMA I method for each sub-watershed. (9) Creating the sub-watershed and river model into the HEC-HMS 4.7.1 software from the upstream of the Opak River to the AWLR Kretek, with the river routing method using the Lag method, and the loss method using SCS-CN, and baseflow using constant flow. (10) Entering data into the HEC-HMS 4.7.1 software, these data include characteristic data for each sub-watershed such as data on sub-watershed area, river length, hourly rainfall data, unit hydrograph, CN value, and baseflow. (11) Conducting simulation/running after creating the watershed and river models. (12) Obtaining the simulation results in the form of flood hydrograph data. (13) Comparing the hydrographs of rainfall data to the hydrograph of AWLR Kretek.

Data Collection

Administrative and topographical data

Administrative and topographical data for the Opak Watershed were obtained from the Serayu-Opak River Basin Center (BBWSSO, 2020). The land use map was obtained from Regional Development Planning Agency of Yogyakarta (Bappeda DIY, 2016). Indonesian Topographical Map data (RBI Map) obtained from the Geospatial Information Agency (BIG), which is provided online (BIG, 2019). The soil type and texture map was obtained from the Harmonized World Soil Database (HWSD) v 1.2 map provided by the Food and Agriculture Organization (FAO), which is provided online (FAO, 2013). Then the data is processed using ArcMap 10.5 software.

Observed discharge data

The observed discharge data uses hourly water level recording data from AWLR Kretek obtained from Serayu-Opak River Basin Center (BBWSSO, 2021). The selected flood event is flood event on 27-30 November 2017 when Cyclone Cempaka occurred in Yogyakarta Province.

Observed rainfall data

The observed rainfall data in this study used hourly automatic rainfall recording data from rainfall stations around the Opak Watershed obtained from Serayu-Opak River Basin Center. 19 rainfall stations data available around the Opak Watershed on 27-30 November 2017. The 19 rainfall stations are shown in Figure 3 (BBWSSO, 2021).

Satellite rainfall data

Satellite rainfall data and the provider's website in this study are as follows. (1) PERSIANN rainfall data are downloaded from https://chrsdata.eng.uci.edu/, (2) GPM rainfall data are downloaded from https://giovanni.gsfc.nasa.gov/giovanni/, and (3) GSMaP rainfall data are downloaded from https://sharaku.eorc.jaxa.jp/GSMaP/.

The satellite rainfall data devide into grids with specific spatial resolution, where each grid has a different precipitation value from the others. The grids of PERSIANN satellite rainfall data have a spatial resolution of 0.25°×0.25°. The grids of GPM and GSMaP satellite rainfall data have a spatial resolution of 0.1°×0.1°.

GAMA I Synthetic Unit Hydrograph

This study uses GAMA I for the analysis of the rainfall-runoff transformation. GAMA I was developed based on the hydrological behavior of 30 watersheds in Java Island in 1985 by Prof. Dr. Ir. Sri Harto Brotowiryatmo, Dip. H. (Brotowiryatmo, 2009).

The data needed in the analysis of GAMA I are.

- Watershed area (A), (km^2)
- Main river length (L), (km)
- Number of order 1 ($O1$)
- Number of all orders (O)
- Total length of order 1 (L_{O1})
- Total length of all orders (L_O)
- Watershed width at $0.75L$ from the control point (W_U), (km)
- Watershed width at $0.25L$ from the control point (W_L), (km)
- Upstream watershed area (A_U), (km^2)
- River bed slope (S)
- Number of river confluence (JN)
- Source factor (SF) $= \frac{L_{O1}}{L_O}$ (1)
- Source number (SN) $= \frac{O1}{O}$ (2)
- Width factor (WF) $= \frac{W_U}{W_L}$ (3)
- Relative upstream area (RUA) $= \frac{A_U}{A}$ (4)
- Symmetry factor (SIM) $= WF \times RUA$ (5)
- Drain network density (D) $= \frac{L_O}{A}$, (/km) (6)

The determination of the river order used in GAMA I is the Strahler method. Equations of peak time and peak discharge in GAMA I are.

- Peak time (T_R)

$$T_R = 0{,}43\left(\frac{L}{100\ SF}\right)^3 + 1{,}0665\ SIM + 1{,}2775 \quad \text{, (hour)} \qquad (7)$$

- Peak discharge (Q_P)

$$Q_P = 0{,}1836\ A^{0{,}5886} TR^{-0{,}4008} JN^{0{,}2381} \quad \text{, (m}^3\text{/s)} \qquad (8)$$

- Recession coefficient (K)

$$K = 0{,}5617\ A^{0{,}1798} S^{-0{,}1446} SF^{-1{,}0897} D^{0{,}0452} \qquad (9)$$

The HSS GAMA I hydrograph curve equations are.

- On peaking curve ($0 < t < T_R$)

$$Q_t = \frac{Q_P \times t}{T_R} \quad \text{, (m}^3\text{/s)} \qquad (10)$$

- On recession curve ($t > T_R$)

$$Q_t = Q_P\ e^{-t/K} \quad \text{, (m}^3\text{/s)} \qquad (11)$$

Lag Time

The simplest method for flood tracing is the lag method provided by HEC in HEC-HMS 4.7.1 software. The Lag method is generally represented by the lag time equation as below.

$$lag = 0{,}6 t_c \quad \text{, (hour)} \qquad (12)$$

t_c is the concentration time, which is the time required for water to flow from the upstream point of the river to the control point of the river. The equation of Kirpich concentration time is shown below (Lydia & Mutia, 2015).

$$t_c = 0{,}0663 L^{0.77} S^{-0{,}385} \qquad , \text{(hour)} \qquad (13)$$

HEC-HMS 4.7.1

HEC-HMS (Hydrologic Center – Hydrologic Modeling System) is a model that can be used to transform rainfall into event flow or continuous flow through a watershed system and can perform flow routing analysis facilitated by hydrologic routing models (Scharffenberg, 2016).

The main components in the HEC-HMS 4.7.1 model are as follows. (1) Basin model; contains elements found in a watershed such as sub-watershed, watershed control points, river segments, reservoirs. (2) Meteorologic model; contains rain and evaporation data. (3) Control specipications; contains the start and end time of the calculation or simulation. (4) Time series data;contains input data such as time series of rainfall data and discharge. (5) Paired data; contains data pairs such as unit hydrographs.

Rainfall-runoff simulation in each sub-watershed requires several model components: (1) Precipitation; an input to the watershed system, (2) Loss method; to calculate run-off volume (effective rain), (3) Transform model; to transform the effective rain which is the difference between the amount of rain and loss into surface flow/runoff, and (4) Baseflow model; to calculate the amount of baseflow.

RESULTS AND DISCUSSION

*Sub-wateshed*s

From the generating and merging of sub-watersheds using ArcMap 10.5 software, 27 sub-watersheds were obtained which were then modeled in HEC-HMS 4.7.1 software. The sub-watersheds map is shown in Figure 2. The area (*A*) of each sub-watershed is shown in Table 1.

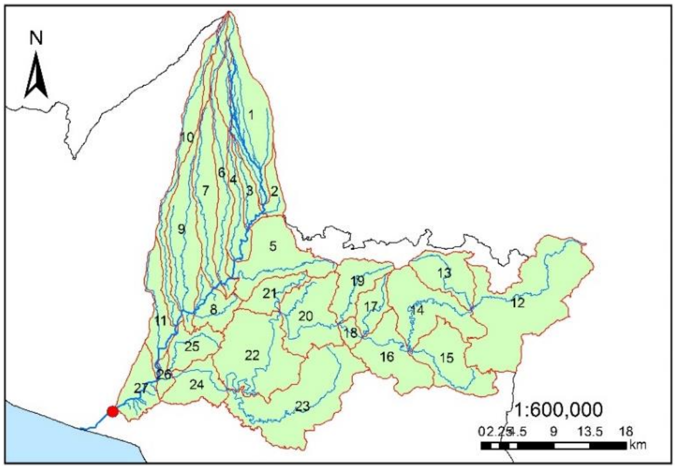

Figure 2. Sub-watersheds map

Curve Number

The Curve Number (*CN*) values are calculated as a $CN_{composite}$ values based on the types of land use and soil textures. The types of land use are divided per sub-watershed so that the *CN* value of each sub-watershed is obtained as shown in Table 1.

Baseflow

Estimating the baseflow is important in order to predict the discharge that has the potential to generate flood. The baseflow (Q_B) data used in the input for flood routings in the Opak Watershed are shown in Table 1 (BBWSSO, 2021).

Table 1. Sub-watersheds parameter values

No.	**Code**	***A* (km^2)**	**Q_B (m^3/s)**	***CN***	***S***	**I_a (mm)**
1	WS-1	69.987	0.507	57.854	185.033	37.007
2	WS-2	12.980	0.094	58.080	183.324	36.665
3	WS-3	16.191	0.117	59.770	170.964	34.193
4	WS-4	38.834	0.282	59.622	172.016	34.403
5	WS-5	64.818	0.470	61.873	156.520	31.304
6	WS-6	47.828	0.347	55.885	200.502	40.100
7	WS-7	49.220	0.357	58.626	179.252	35.850
8	WS-8	26.367	0.191	62.347	153.396	30.679
9	WS-9	69.409	0.503	56.069	199.011	39.802
10	WS-10	47.033	0.341	54.847	209.106	41.821
11	WS-11	31.791	0.231	57.991	183.997	36.799
12	WS-12	140.454	1.018	84.759	45.673	9.135
13	WS-13	36.907	0.268	82.706	53.113	10.623
14	WS-14	63.516	0.461	85.158	44.269	8.854
15	WS-15	51.867	0.376	84.132	47.908	9.582
16	WS-16	50.291	0.365	85.697	42.393	8.479
17	WS-17	20.126	0.146	87.129	37.520	7.504
18	WS-18	7.523	0.054	85.221	44.049	8.810
19	WS-19	32.869	0.238	88.190	34.014	6.803
20	WS-20	57.348	0.416	85.059	44.617	8.923
21	WS-21	22.599	0.164	87.420	36.551	7.310
22	WS-22	86.462	0.627	84.107	47.996	9.599
23	WS-23	108.293	0.785	83.427	50.457	10.091
24	WS-24	32.002	0.232	84.848	45.359	9.072
25	WS-25	26.717	0.194	62.107	154.970	30.994
26	WS-26	7.168	0.052	61.678	157.816	31.563
27	WS-27	29.655	0.215	72.201	97.794	19.559
Total		1248.253	9.051			

Rainfall Data

Observed rainfall data for each sub-watershed that has been processed based on the Thiessen polygon method as shown in Figure 3. The PERSIANN, GPM, and GSMaP rainfall data for each sub-watershed which has been processed based on the coefficient of the area of influence of the grid on the sub-watersheds as shown in Figure 4 and Figure 5.

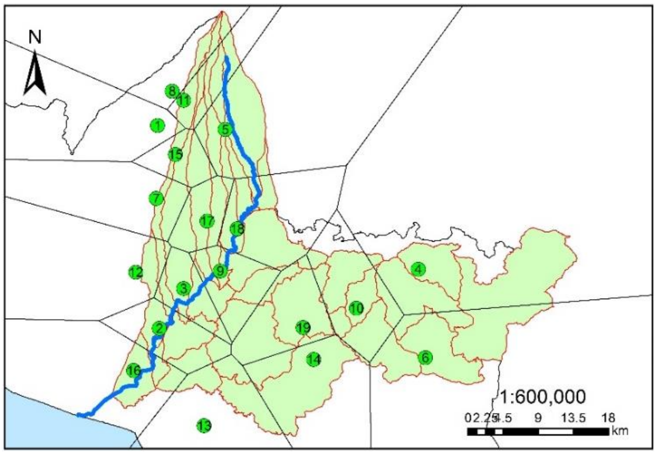

Figure 3. Location points of rainfall stations

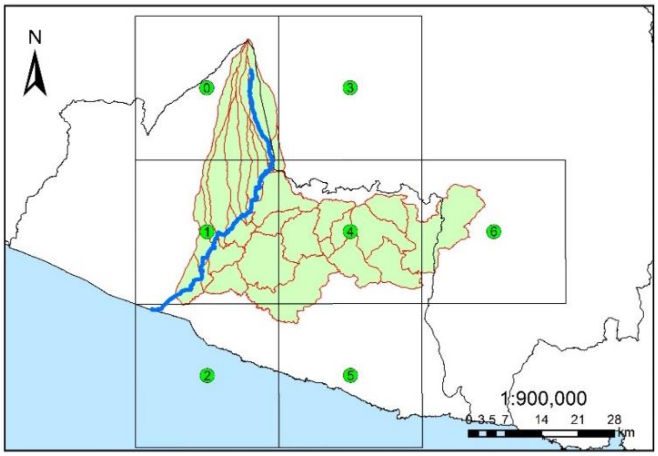

Figure 4. PERSIANN grid with spatial resolution of 0.25°×0.25°

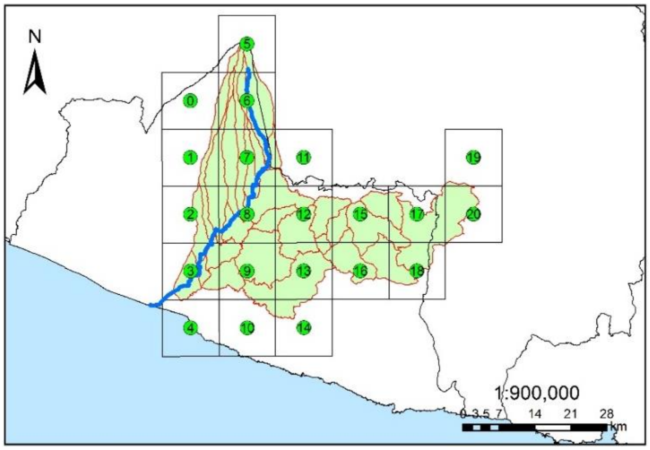

Figure 5. GPM and GSMaP grid with spatial resolution of 0.1°×0.1°

Rainfall-runoff Modeling in HEC-HMS 4.7.1

Rainfall-runoff tranformation was performed using HEC-HMS 4.7.1 software. The Opak Watershed that is modeled consists of 27 input sub-watersheds as well as each river from each sub-watershed as shown in the basin model scheme of the Opak Watershed in Figure 6.

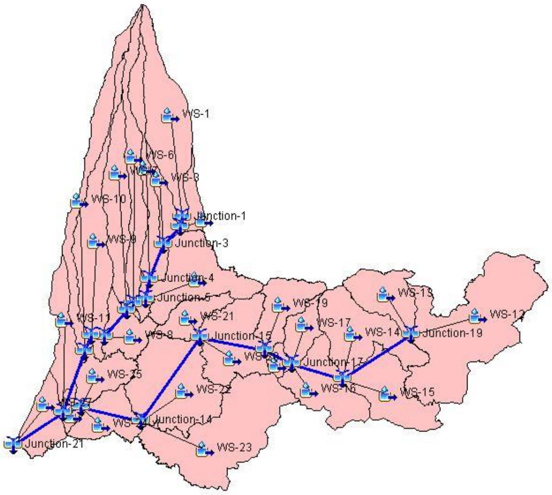

Figure 6. Opak Watershed model in HEC-HMS 4.7.1

Rainfall-runoff tranformation analysis was carried out by modeling using the HEC-HMS 4.7.1 software, which is the result of input data for each sub-catchment that had been prepared previously. These data include sub-watershed area, *CN* values, baseflow, rainfall data, and unit hydrographs. In addition, there is also input data in the form of lag time derived from the concentration time (t_c) of the Kirpich method for several sub-DAS where there are flood routings as presented in Table 4.

Table 2. Lag time values for some sub-watersheds

No.	Code	Reach length (km)	Slope	t_c (hour)	*lag* (minute)
1	WS-2	1.239	0.010	0.459	16.517
2	WS-3	3.689	0.003	1.618	58.250
3	WS-4	6.560	0.006	2.061	74.189
4	WS-5	2.301	0.004	1.022	36.801
5	WS-6	1.793	0.001	1.307	47.052
6	WS-7	1.251	0.005	0.606	21.806
7	WS-8	4.237	0.001	2.480	89.263
8	WS-9	1.844	0.007	0.727	26.157
9	WS-10	1.922	0.001	1.416	50.979
10	WS-11	9.275	0.002	3.742	134.729
11	WS-14	25.019	0.001	9.672	348.197
12	WS-16	9.258	0.001	4.683	168.590
13	WS-18	4.325	0.003	1.944	69.988
14	WS-20	12.892	0.001	6.865	247.125
15	WS-22	28.075	0.002	9.076	326.747
16	WS-24	9.503	0.001	4.826	173.750
17	WS-26	2.426	0.005	0.997	35.893
18	WS-27	7.748	0.017	1.542	55.510

Hydrographs

Rainfall-runoff tranformation was carried out on observed rainfall data and GPM, PERSIANN, and GSMaP rainfall data that occurred in the Opak Watershed during the flood event on 27-30 November 2017. The results of the rainfall-runoff tranfomation reviewed at the AWLR Kretek produced hydrographs for each -respective data shown in Table 3 and Figure 7. Each hydrograph in Figure 7 is the accumulation of all sub-watersed hydrographs that are derived from each rainfall data using GAMA I SUH method and are flood-routed to AWLR Kretek point with HEC-HMS 4.7.1 software.

Table 3. Discharge table on 27-30 November 2017

Time	AWLR	Observed rainfall	PERSIANN	GPM	GSMaP
	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
11/27/17 18:00	59.7	20.6	9.1	16.5	12.6
11/27/17 19:00	59.7	29.9	9.1	15.7	12
11/27/17 20:00	63.0	39.3	9.1	14.8	11.4
11/27/17 21:00	69.9	38.4	9.1	14.7	11.1
11/27/17 22:00	75.4	32	9.1	15.9	17.7
11/27/17 23:00	81.3	27.1	9.1	19.8	31.2
11/28/17 0:00	87.4	51.8	9.1	24.1	40.8
11/28/17 1:00	91.8	108	9.1	25.1	42.4
11/28/17 2:00	94.0	182.4	9.1	33	53.9
11/28/17 3:00	94.0	247.1	9.1	55.3	74.8
11/28/17 4:00	98.5	292.3	9.1	87.1	88.3
11/28/17 5:00	115.7	368.9	9.1	134.3	105.9
11/28/17 6:00	170.3	474.2	9.1	244.7	130.6
11/28/17 7:00	241.9	562.9	16.4	449	159.5
11/28/17 8:00	295.5	631.8	41.2	693.8	206.6
11/28/17 9:00	375.9	699	77	952	266.4
11/28/17 10:00	494.2	770.3	99.9	1110	320.7
11/28/17 11:00	715.6	830.5	116.8	1169.6	373.3
11/28/17 12:00	1111.7	868.2	157.4	1225.5	414.9
11/28/17 13:00	1228.2	875.2	192.3	1243.1	424.7
11/28/17 14:00	844.8	870.3	191.2	1181.4	411.5
11/28/17 15:00	550.1	853.3	177	1092.5	398.1
11/28/17 16:00	408.2	808.9	164.7	1019.5	387.2
11/28/17 17:00	339.7	752.6	153.3	973.7	369.2
11/28/17 18:00	328.2	703.3	141.1	980.7	344.5
11/28/17 19:00	357.5	666.5	125.7	1056.3	324.8
11/28/17 20:00	357.5	648	111.2	1163.3	318.4
11/28/17 21:00	375.9	653.2	115.9	1262.6	320.1
11/28/17 22:00	357.5	673.1	142.3	1360.2	325.3
11/28/17 23:00	375.9	684.6	172.4	1403.5	333
11/29/17 0:00	509.7	673.7	178.6	1335.1	337.5
11/29/17 1:00	725.8	640	185.1	1207.3	328.8
11/29/17 2:00	1043.1	600.4	212.9	1099.6	305.5
11/29/17 3:00	1305.5	577.9	217.1	1038.3	282.1
11/29/17 4:00	977.8	582.8	199.6	1008.2	277.5
11/29/17 5:00	746.4	602.9	185.1	970.9	293.9
11/29/17 6:00	558.5	611.2	178.3	901.7	312.2
11/29/17 7:00	408.2	590.5	181.1	816	312.3
11/29/17 8:00	317.0	546.3	186.5	734.3	291.3
11/29/17 9:00	260.5	490.8	180.4	659.5	258.6
11/29/17 10:00	220.1	430	174.2	591.9	223.2
11/29/17 11:00	195.9	368.1	179.1	527.5	188.9
11/29/17 12:00	177.3	309	186.2	459.1	158.1
11/29/17 13:00	184.6	259.1	200	388.1	136.3
11/29/17 14:00	173.8	220	219.1	322.4	129
11/29/17 15:00	188.3	187.5	220.1	267	129.9
11/29/17 16:00	211.8	158.7	222.8	221.4	125.2

Time	AWLR	Observed rainfall	PERSIANN	GPM	GSMaP
	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
11/29/17 17:00	228.7	136.5	239.3	184	116.1
11/29/17 18:00	233.0	123.3	258.3	152.9	108.5
11/29/17 19:00	246.5	116	267.8	126.9	102.4
11/29/17 20:00	260.5	109.5	264.1	106.2	98.5
11/29/17 21:00	251.1	101.1	252.5	91.9	94.2
11/29/17 22:00	233.0	90.8	230.7	83.4	85.4
11/29/17 23:00	216.0	79.3	197	77.5	74
11/30/17 0:00	199.8	67.6	162.9	73.1	65.8
11/30/17 1:00	184.6	56.5	141.5	71.9	61.5

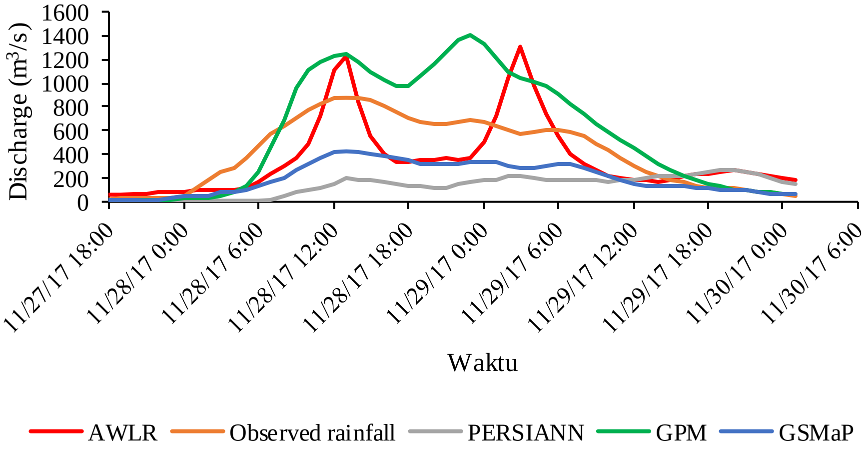

Figure 7. Hydrographs on 27-30 November 2017

From visual observations in Figure 7, it can be seen that the GPM hydrograph has a peak discharge value that almost matches the peak discharge value of the AWLR Kretek hydrograph. In addition, the GPM hydrograph also forms 2 (two) peaks like the AWLR Kretek hydrograph, while hydrographs from other rainfall data do not form 2 (two) peaks. To be more precise in seeing the difference in the peak discharge value of each hydrograph of rainfall data to the AWLR Kretek hydrograph, the difference values are presented in Table 4.

Table 4. Hydrograph peak discharge values

Peak discharge (m^3/s)				
AWLR	**Observed Rainfall**	**PERSIANN**	**GPM**	**GSMaP**
1228.2	**875.2**	**192.3**	**1243.1**	**424.7**

From Table 4, it can be seen that the difference in the value of the peak discharge from the hydrograph of the observed rainfall data analysis to the peak discharge of the AWLR Kretek is 353.0 m^3/s. The difference in the peak discharge value from the PERSIANN hydrograph to the the peak discharge of the AWLR Kretek is 1035.9 m^3/s. The difference in the peak discharge value from the GPM hydrograph to the peak discharge of the AWLR Kretek is 14.9 m^3/s. While the difference in the value of the peak discharge from the GSMaP hydrograph to the peak discharge of AWLR Kretek is 164.4 m^3/s.

CONCLUSION

From the results of this study, it can be concluded that from the analysis of the rainfall-runoff tranformation of observed rainfall data, PERSIANN rainfall data, GPM rainfall data, and GSMaP rainfall data, the GPM rainfall data produces a hydrograph that is closest to the shape and the peak discharge of the AWLR Kretek hydrograph during the flood event on 27-30 November 2017.

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