Rainfall-runoff Analysis Using Satellite Data in The Majalaya Watershed

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Abstract. Majalaya is a flood-prone area with a minimum of six flood events every year. There have been several efforts made by the government and residents for flood prevention and early warning efforts. One of them is the AWLR which was built to monitor the water level of the Upper Citarum River. However, the results of the recording of the AWLR itself are still in doubt because of the difference between the AWLR data and the observations of residents. Using the 2018 flood incident data as a reference, the hydrological analysis in this study was conducted by combining ground data and satellite data using the HEC-HMS application. The results of the modeling show that the difference between ground data and satellite data is quite significant. This is one of the validations of an error in the AWLR recording so that it gives different results.

Keywords: *satellite data; GSMaP; AWLR; water level; majalaya.*

1 Introduction

Majalaya is a small city located in the central part of the West Java Province (Figure 1). It is home to 169,000 people, more than 2000 medium, small, and micro-scale enterprises, as well as 2,200 ha of paddy fields [1]. Majalaya area is known for its textile industry since the 1960s [2]. Despite its significant role in West Java's economy, Majalaya experiences recurring floods from the Citarum river, where Majalaya is located at the first 13% (35 km) of the entire 270 km of Citarum River. The local flood mitigation community recorded at least six yearly flood events [3]. The local rainfall gauge shows that the recurring floods are typically caused by a maximum daily rainfall of around 70–90 mm. However, the 2017 and 2018 floods exceeded previous years' records. The 2017 flood paralyzed the city's road transportation network [4], while the 2018 flood, on top of making road transportation infeasible, the flood inundated the town to the extent of 5 square km, damaged dozens of houses, injured many, and claimed one life [5].

Despite its importance and severity, the flood characteristics in Majalaya are not well studied. On the Scopus indexing service, there were only eight publications discussing the topics related to the Majalaya flood [2], [3], [6], [11], with two of them explicitly discussing the Majalaya flooding problem [3], [7]. Junnaedhi et al. [3] discussed the general overview of the Majalaya flood and how the community organized themselves to anticipate and mitigate flood hazards. Safarina et al. [7], on the other hand, discuss the rainfall threshold characteristics that could lead to flood inundation in a larger study area where Majalaya is included. Although the study could be improved using a well-calibrated dataset, the study indicated Majalaya Area is prone to inundation should a minimum of 70.44 mm gauge rainfall occurs.

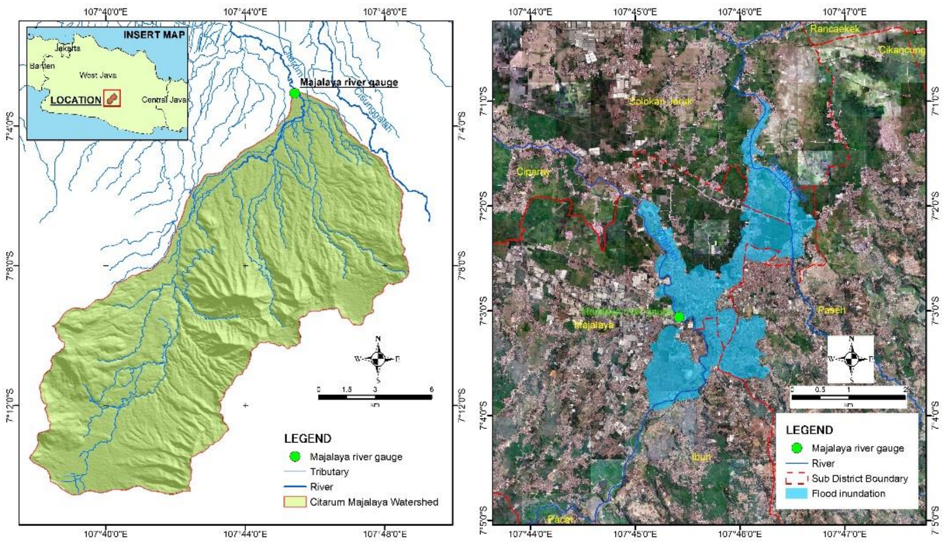

Figure 1 Majalaya catchment location with Majalaya stream gauge as the outlet (left figure); crowdsourced February 22nd, 2018, flood inundation map with Majalaya stream gauge as the reference location.

The recurring pattern of the Majalaya flood hazard necessitates a comprehensive study to understand the mechanism of the flood. While the prior studies are commendable, the need to assess Majalaya flood mitigation strategies requires studies to fill the gaps in its understanding. One of the fundamental components is to study the rainfall-runoff relationship in the area. This study will discuss the modeling of Majalaya rainfall-runoff model using GSMaP rainfall data and stream gauge using HEC-HMS. This study aims to serve as a baseline study for future works related to managing the Majalaya flood.

2 Materials and Methods

Data is one of the essential aspects of planning for the future in any area. Lack of completeness of data can affect any assessment such as development planning and evaluation of infrastructure. Various innovations have been carried out on how to complete the current shortcomings.

For water resource planning, rainfall record data is a crucial aspect. But unfortunately, there are still many areas in Indonesia that have inadequate facilities for recording rainfall regularly every year. Often empty data is obtained and there is not enough rain station in various areas.

The use of remote sensing data and the use of current technology is one of the means to complete the incomplete data on the manual ground data. An example of the benefits of satellite data is to simplify the calculation of the flood warning system, which estimates the time of flood and disseminated it to the public. This is evidenced by the results of research [12] which states that the concept of time lag is physically reasonable and consistent so that it gives reasonable results. So in this study, a hydrological analysis was carried out combining two types of data, namely ground data and satellite data. The advantage of combining the two types of data is that it can shorten the time of data calculation and fill in the blank data on the ground data.

3 Results

3.1 Hydrologic Data

In this study, two types of data are needed: water level data from the Paseh Rain Station and AWLR in Majalaya and satellite data. AWLR data can be accessed online on the website (http://103.110.9.91/) which is managed by the Citarum River Basin Agency (BWS), and GSMaP satellite data can be downloaded by accessing (https://sharaku.eorc.jaxa.jp/GSMaP/).

*Automatic Water Level Recorde*r (AWLR) or stream gauges is a tool to measure the water level in rivers, lakes, and irrigation flows and can automatically record water level records. Where this tool is used as a substitute for a conventional system that has to manually record data so that data storage is precise and accurate [14]. The available data are the water level (TMA) from the AWLR recording and the discharge which has several different periods, namely: 10 minutes, 1 hour, and 1 day.

GSMaP (Figure 2) data is a combination of several rainfalls taken from the Tropical Rainfall Measuring Mission satellite (TRMM), Aqua, DMSP, and

NOAA) and an algorithm so that it becomes one of the satellite data that has high resolution. GSMaP has a spatial scale of 11.06 x 11.06 km and can cover all regions in Indonesia [15]. Managed by Japan Science and Technology Agency (JST) and Japan Aerospace Exploration Agency (JAXA).

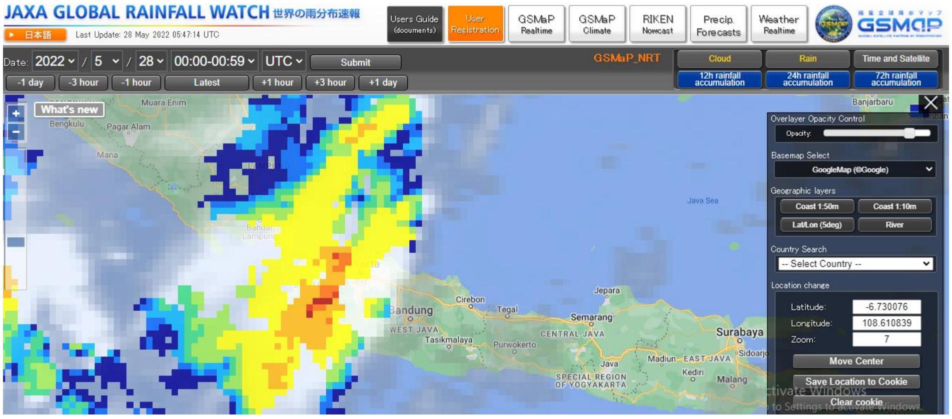

Figure 2 JAXA Global Rainfall Watch (GSMaP) Display.

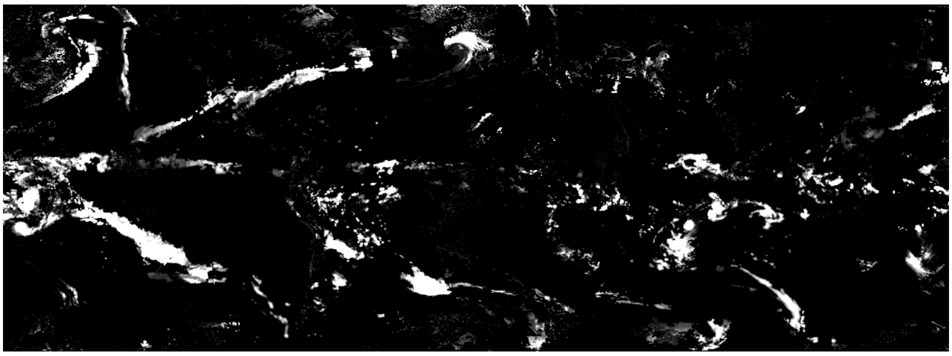

Figure 3 Cloud Pattern Map from GSMaP.

The website shows the movement or pattern of clouds and rain around the world. And in this study using GSMaP v.7 data from March 2014 to May 2022 per hour that has been calibrated, then access the data using the FileZilla application. The downloaded image still has to be extracted from the GEO format into a TIF format file so that it can be processed to get hourly rainfall data (Figure 3). To change the format of the data use the Format Conversion Tool application. The GSMaP map is on a World Map scale but what is needed is rainfall data in the area of the Majalaya watershed. In processing the GSMaP map into rainfall data, the R Studio programming language is used. The required input data are GSMaP maps and Majalaya watershed maps in SHP format. Some results that are important to note are that GSMaP data has a time unit of 00:00 GMT so it must be changed to West Indonesia Time (WIB). And the results will be in the form of hourly rainfall data in mm.

4 Hydrology Analysis

The analysis is carried out to see the accuracy of the AWLR data and satellite data. For AWLR data, it is known that there are differences between the data recorded by AWLR and events in real time. Taking the case of the flood in Majalaya on February 22, 2018, at that time the local community recorded the water level seen on the river measuring board at the time of the peak of the flood. It can be seen in Figure 4 that the difference between the AWLR water level and the actual incident is about ± 1 m. Therefore, it is suspected that the results of the AWLR data are not exactly like the actual event.

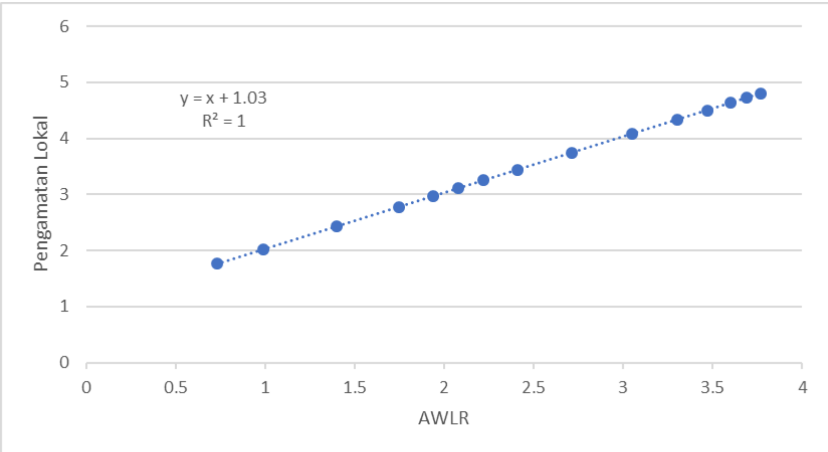

Figure 4 Comparison of AWLR Results with Observation Data.

4.1 Data Calibration

To use the GSMaP data calibrated with ground data or direct measurements. Calibration is done by looking at the results of linear graph equations so that the GSMaP data times factor is known to resemble soil data or direct measurements.

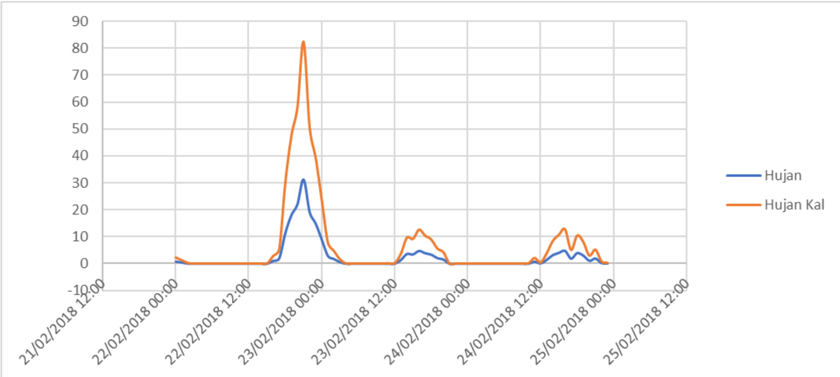

Figure 5 GSMaP Calibration Data Results.

In Figure 5, it can be seen that the GSMaP data after being calibrated produces a value that is too large so that it cannot be used. Because it is too far from the actual events that occurred during the 2018 floods. GSMaP rainfall data is closer to direct measurement rainfall data. So, we use GSMaP data without recalibration.

For this reason, the modeling using HEC-HMS was carried out. Where the rainfall input data used is from GSMaP data and debit data is calculated from AWLR data.

To calculate the discharge, based on the water level from the AWLR by using the debit equation, the results of the Neo Perdas Program Package Analysis are:

$$Q = 3{,}52(H - 0{,}03)^{2{,}355} \quad (1)$$

Description:

Q = discharge (mm^3/second)

H = water level (mm)

The discharge equation above is a curved formula resulting from the rating curve for flow measurement data from 2006 to 2012.

4.2 HEC-HMS Modelling

Next is the HEC-HMS modeling by taking the 2018 Flood event from February 22, 2022 at 00:00 WIB to February 24, 2022 at 23:00 WIB (Figure 6).

To calculate the Hydrograph Unit on HEC-HMS using the Snyder Equation [16], where:

$$tp = C1.Ct(L.L_c)^{0,3} \quad (2)$$

Description:

t_P = time peak

C_1 = coefficient

Ct = time coefficient

L = main channel length (km)

Lc = length of the main stream channel from the outflow point of a watershed to a point opposite the centroid of the watershed (km)

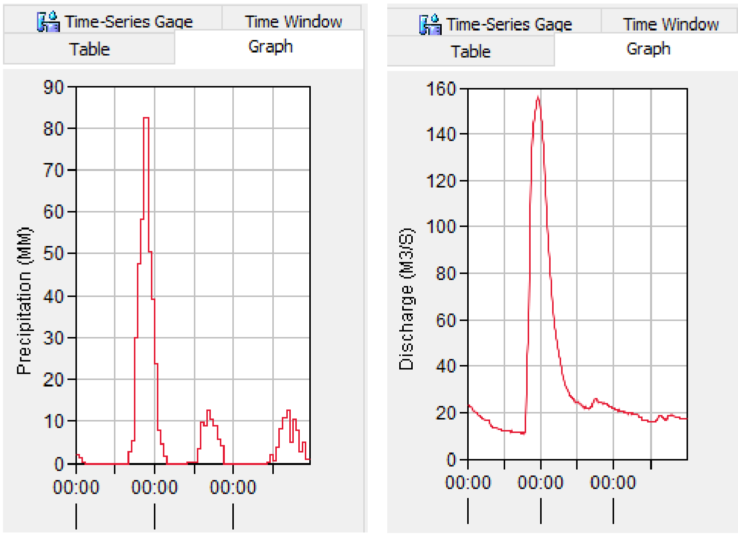

Figure 6 (left) GSMaP time graph (right) Majalaya AWLR time graph.

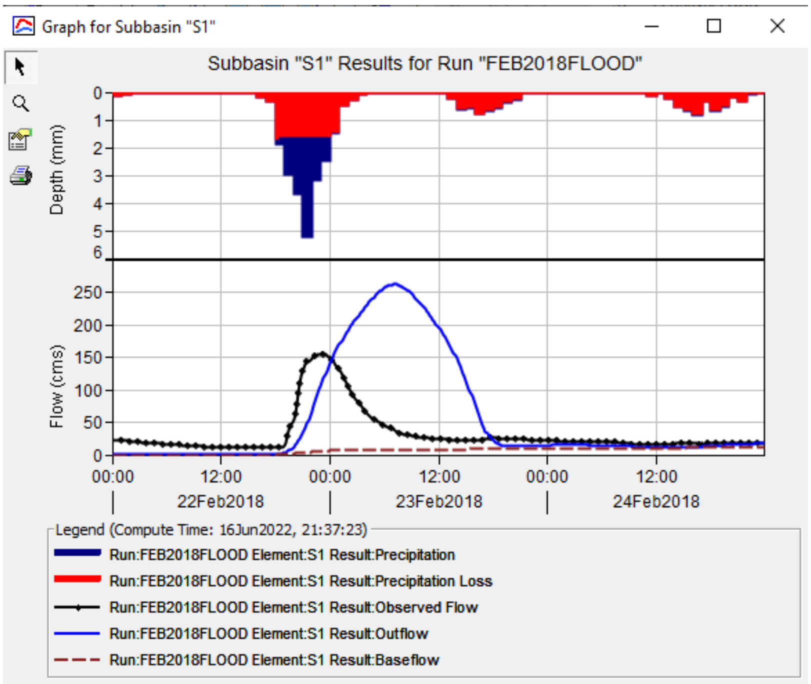

Figure 7 Running Program HEC-HMS Result.

In Figure 7, it can be seen that the hydrographs of the two types of data, namely soil and satellite data, give significantly different results. Even the peak times of both data are also different.

4.3 Discussion

Due to the density of settlements and the textile industry, the Majalaya area is one of the contributors to river pollution due to its effluent and inefficient IPAL. Of the 600 existing textile industries, only 10% operate standard IPALs [17]. Meanwhile, the upstream area of the Citarum river is an area for cattle farming and agriculture, which causes river pollution due to the dumping of cow dung waste into the river. Then the excess fertilizer (nitrogen and phosphorus) is not absorbed by plants [17].

Annual floods almost always occur in Majalaya, flooding has occurred since 2008 and occurs several times a year. The number of flood events in a year is at least six times, namely in 2012 and the most is 20 events occurring in 2008. One of the influencing factors is serious land subsidence, where Majalaya is one of the areas where groundwater extraction has exceeded the ideal limit. [17].

Precipitation assessment carried out, shows that extreme rainfall has increased over the years. And the impact of climate change is the worsening of flooding. Generally, the depth of the flood ranges from ankle-deep to one meter, caused by sedimentation, and the build-up of garbage, the effect of uncontrolled urbanization [3], [13].

5 Summary

This research uses GSMaP satellite data as an alternative to ground data. Which ground data tends to have a lot of blank or unrecorded data. And there are also allegations of inaccuracies in the recording of the AWLR compared to ground data so that satellite data is expected to be used as a substitute for ground data in the future.

In the HEC-RAS modeling results, it can be seen that the two hydrographs of satellite data and AWLR data have significant differences. Where the water level results from satellite data and the resulting ground data are far different that the resulting hydrograph is different as well. It is estimated that there was an error in the rating curve which could be caused by several factors. Among them are the differences in water level used with events in real time, so that there is an error in the value of the graph curve in the rating curve. Thus, it is concluded that the water level data from the AWLR is underestimated and still needs to be reviewed further.

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