Rainfall distribution in relation to flooding in upper Citarum watershed, Indonesia

Syifa Hanifa¹, Mangapul Parlindungan Tambunan¹, Kuswantoro Marko¹

¹Department of Geography, Universitas Indonesia Margonda Raya Street, 16424 Depok, West Java, Indonesia

e-mail: syifahnfa@yahoo.com

Abstract. Disasters caused by weather, such as flood, have become more frequent since the late 1990s. Compared to the previous decade, there are more than twice the number of floods in the world. Essentially, flood often occurs in lowland area with compact river systems. Unlike the case that often happened in the area around the Upper Citarum Watershed, floods occur because of the physical characteristics of the basin in the bowl-like form. In addition, rain that occur consecutively for a certain period of time in a day can result a surplus runoff water falling to the surface of the earth. Observation of rainfall has actually been carried out quantitatively since the 19th century. Satellite-based rainfall observation has the main advantage of being quite accurate in spatial and temporal coverage. This research is intended to see the pattern of rainfall distribution in relation to flooding in the Upper Citarum Watershed using remote sensing methods to process satellite images of PERSIANN CCS in obtaining rainfall data in each sub-watershed. Spatial results show six areas of rainfall distribution as of sub-watershed. Meanwhile, temporal results are analyzed with a graph that shows the pattern of hourly rainfall behaviour.

1. Introduction

Weather-caused disasters, such as flood, commonly occurred since late 90s. Compared to the latest decade, it is reported to be increasing twice in the world [1]. Flood occurred because of the water flow is exceed its storage. The problem is that surplus water is in high volume and appear in long-term period and disturbing human activities. Human activities take place in urban area which are many assets and population can be impacted by flood, as well as in Upper Citarum Watershed [2]. This area has high-risk damage in social-economic activities [3].

Essentially, flood happens in lowland area with the compact river system [4]. Different case happens in Upper Citarum Watershed, the causes of flood in there are its physical character which form a bowl-like basin and river condition which is silting up and constricting because of sedimentation. In addition, a consecutive raining which affect atmospheric system to become stronger to produce water is also the cause of flood happened there [5]. This condition makes runoff water exceed its storage and overflowed.

Quantitively, rainfall observation has been done since 19th century [6]. Satellite-based rainfall observation has main advantage which is spatially and temporally quite accurate [7]. Moreover, satellite-based rainfall observation had been proved its application in climate and hydrological study. In this research, Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks Cloud Classification System (PERSIANN CCS) satellite data with 4x4 kilometres resolution are used as satellite-based rainfall data [8]. Because of its high resolution, spatially and temporally, this satellite-rainfall data can explain rainfall in detail and are very useful to analyze a short-term disaster such as flood.
This research aims to prevent short-term disaster which is very rare to be done in Indonesia. By analysing rainfall distribution in correlation to flooding in Upper Citarum Watershed, this research is done to see rainfall characteristics in two different period of flood occurrence which has different flood characteristics. In the paper the question is addressed, how is the spatial and temporal rainfall distribution based on PERSIANN CCS satellite in correlation to flooding in Upper Citarum Watershed?

2. Study Area

Upper Citarum Watershed is a part of Citarum Watershed in upper area (plateau). This upper area formed basin which is surrounded by mountains such as Tangkubanperahu mount in North, Patuh-Malabar, Krenceng, Mandalawangi mount in South. The area of Upper Citarum Watershed is 1,762.55 km² with slope of 0 – 2%. Its rivers flow through some administrative area such as Bandung City, Cimahi City, Bandung District, and Sumedang District. In Bandung District, there are 29 sub-districts and 26 sub-districts in Bandung City which passed through by Upper Citarum rivers. Upper Citarum Watershed is divided into six sub-watersheds: Cikapundung, Cikeruh, Cirasea, Cisangkuy, Citarik, and Ciwidey sub-watershed. Also, Upper Citarum Watershed has a reservoir in west-side which is named as Saguling reservoir. It also has nine water level recorders which is: Citarum-Nanjung, Cikeruh-Jatinangor, Citarum-Dayeuh Kolot, Citarum-Majalaya, Ciwidey-Cibeureum, Ciburadul-Kertajaya, Cidurian-Sukapada, Cigede-Komplesks Radio, and Cikeruh-Cikuda station.

Astronomically, Upper Citarum watershed is in 6° 43’ – 7° 15’ S and 107° 30’ – 108° E. It has geographical border with:
- Surakarta district and Subang district in North.
- Cianjur district dan Kabupaten Garut in South.
- Bandung district in West.
- Sumedang district dan Garut in East.

3. Methodology

The main variable of this research is rainfall. The variable is used to see rainfall distribution in a different characteristics of flood occurrence. The data are PERSIANN CCS satellite rainfall data with 4x4 km per hour resolution. Its type is secondary data which is processed and analysed the spatial and temporal rainfall distribution based on satellite data in correlation to flooding in Upper Citarum Watershed. The data are collected as below.
Table 1. Research data.

| DATA TYPE | DATA TYPE | INDICATOR | SOURCE |
|-----------|-----------|-----------|--------|
| Upper Citarum Watershed area | Upper Citarum Watershed border | Watershed Modelling System results |
| Upper Citarum Sub-Watershed area | Upper Citarum Sub-Watershed border | Watershed Modelling System results |
| Administrative area | Administrative border | Ina Geoportal (http://tanahair.indonesia.go.id/) |
| Flood Occurrence (2016 & 2018) | Flood characteristics | BNPB and BPBD of West Java |
| PERSIANN CCS satellite rainfall (2016 & 2018) | Hourly rainfall data (a day before flood day) | CHRS Data Portal (www.chrsdata.eng.uci.edu) |

3.1. Data processing
PERSIANN CCS satellite rainfall data which are downloaded can be open directly in ArcMap software. The data processing is divided into flood characteristics and rainfall distribution. Flood characteristics are processed in tabular data and rainfall distribution is made into rainfall distribution map and graphic of rainfall behaviour.

3.1.1. Flood Characteristics
Flood characteristics are collected from main station of Citarum Watershed. It is explained in table of flood characteristics below.

Table 2. Characteristics of flood in Upper Citarum Watershed.

| FLOOD | FLOOD DEPTH | DISCHARGE |
|-------|-------------|-----------|
| March 13th, 2016 | 50 – 300 centimeters | Citarum-Nanjung: 136.21 m³/s |
| | | Cikeruh-Jatinangor: 0.35 m³/s |
| | | Citarum-Dayeuh Kolot: 333.11 m³/s |
| | | Citarum-Majalaya: 11.77 m³/s |
| | | Ciwidey-Cibeureum: 7.51 m³/s |
| | | Ciburadul-Kertajaya: 0.56 m³/s |
| | | Cidurian-Sukapada: 1.59 m³/s |
| | | Cigede-Komp. Radio: 9.9 m³/s |
| | | Cikeruh-Cikuda: 1.3 m³/s |
| March 4th, 2018 | 100 – 150 centimeters | Citarum-Nanjung: 364.75 m³/s |
| | | Cikeruh-Jatinangor: 2.28 m³/s |
| | | Citarum-Dayeuh Kolot: 115.12 m³/s |
| | | Citarum-Majalaya: 19.33 m³/s |
Ciwidey-Cibeureum: 31.62 m³/s
Ciburadul-Kertajaya: 1.28 m³/s
Cidurian-Sukapada: 1.38 m³/s
Cigede-Komp. Radio: 8.32 m³/s
Cikeruh-Cikuda: 2.79 m³/s

3.1.2. Rainfall Distribution
The downloaded raster rainfall data is processed to divide it into sub-watershed. The step is using Spatial Analyst Tools ➔ Extraction ➔ Extract by Mask in ArcMap software. Manually count every pixel in sub-watershed area to get average rainfall of each sub-watershed. The provided rainfall intensity in every sub-watershed are classified into rain type as table below [9].

Table 3. Classification of rain type.

| RAIN TYPE      | RAINFALL INTENSITY (mm) |
|----------------|-------------------------|
|                | 1 HOUR      | 24 HOURS   |
| Very Light Rain| < 1         | < 5        |
| Light Rain     | 1 – 5       | 5 – 20     |
| Normal Rain    | 5 – 10      | 20 – 50    |
| Heavy Rain     | 10 – 20     | 50 – 100   |
| Very Heavy Rain| > 20        | > 100      |

Each sub-watershed is visualized by adding colours from lighter to darker to make a gradation that represent the rainfall intensity level from lower to higher.

It is made into hourly rainfall table, then create a graphic of rainfall to see the rainfall behaviour. Select Table ➔ Insert Charts ➔ Column Type.

The results are hourly rainfall distribution map that present rainfall spatial pattern and hourly rainfall graphic that present rainfall behaviour a day before flood occurrence.

4. Results and Discussion
This research used two periods of flood which represent two different flood characteristics as explained in table 2. Flood characteristics are focused on flood depth and water discharge in each sub-watershed. Water discharge of Cirasea sub-watershed in 2016 has the highest volume as of 333.11 m³/s, whereas in 2018 the highest volume of water discharge is in Cikapundung sub-watershed.

![Water discharge map](image-url)
Flood occurrence in 2016 has heterogeneous flood depths, from the lowest of 50 centimeters to the highest of 300 centimeters. In 2018, flood depths are homogenous in average level above 100 centimeters.

Figure 3. Flood occurrence map.

As the map below, in 2016, it was raining all around Upper Citarum Watershed which happened for consecutive seven hours. The four out of seven hours have average rainfall of more than normal rain. For the rest 18 hours, there are no rain. In 2018, it was unevenly raining in the area of Upper Citarum Watershed. Although there are 15 hours of rain, the average rainfall intensities are between very light rain and normal rain. The highest intensity only happened at 10.00 WIB as of heavy rain in Cikapundung, Cikeruh, and Cisangkuy sub-watershed.

Figure 4. Rainfall distribution map.

4.1. Cikapundung sub-watershed
In 2016, graph showed an up-down-up-down-up-down pattern for seven hours of raining. Rainfall formed a two-peak graph with the highest intensity of 30.24 millimeters. The average rainfall of the day is 2.69 millimeters which is categorized as light rain. In 2018 graph, it showed three-peak pattern with the highest intensity of 18.47 millimeters at 10.00 WIB. Rain happened for 15 hours and interspersed by 5 hours with no rain. A day before flood has average rainfall of 1.78 millimeters and categorized as light rain. There were many flood occurrence in Cikapundung sub-watershed in 2018, different case happened in 2016.
4.2. Cikeruh sub-watershed

In 2016, graph showed an up-down-up-down pattern for 8 hours of raining. Rainfall formed a two-peak graph with highest intensity of 18.67 millimeters. The average rainfall is 2.04 millimeters which is light rain. In 2018, graph showed a three-peak and two-valley pattern which happened for 13 hours and interspersed by 3 hours of no rain condition. The highest intensity of rainfall happened at 10.00 WIB of 14.25 millimeters. Average of rainfall is 1.76 millimeters. Eventhough it is categorized as light rain, the rainfall is still lower than in 2016. There was a flood occurrence in 2018.

4.3. Citarik sub-watershed

Hourly rainfall graph of 2016 showed a one-peak pattern of 8 hours of raining. Its rainfall made an up-up-down graph. The highest intensity of 13.17 millimeters happened at 11.00 WIB. The rainfall is 2 millimeters in average which is light rain. In 2018, it is a fluctuative graph with three-peak and two-valley for 14 hours of raining. The highest intensity is 7.83 millimeters. Even so, there are 3 hours of
no rain condition. The average is light rain which has intensity of 1.17 millimeters. Citarik sub-watershed has a different pattern of flooding. While other sub-watershed had been flooding in 2018, it had been flooding near the main river in 2016.

4.4. Cirasea sub-watershed

Figure 8. Rainfall behaviour of Cirasea sub-watershed

In 2016, graph showed a straight line pattern since the first hour of the day. It starts increasing at 07.00 WIB and reached its peak with the intensity of 13.14 millimeters at 11.00 WIB. Followed by decreasing intensity for the next three hours and stopped at 14.00 WIB. In 2018, rain started at 00.00 WIB and was experiencing fluctuation. The graph showed five-peak and four-valley. It was having three peak with an approaching intensity. Though, the highest intensity is still 4 millimeters as of light rain. There was not flood occurrence in both year.

4.5. Cisangkuy sub-watershed

Figure 9. Rainfall behaviour of Cisangkuy sub-watershed

In 2016, it is shown a two-peak and one-valley graph for 6 hours of raining. Rainfall formed an up-down-up-down pattern with the highest intensity of 18.94 millimeters. In 2018, graph showed for the first six hours of having a decreasing pattern until it stopped at 06.00 WIB. Rain continued at 08.00 WIB for consecutive 8 hours and reached its peak at 10.00 WIB with the intensity of 13.50 millimeters. Although, the next 5 hours after reaching its peak, it is only light rain. There were so many flood occurrence in 2016, while there was not flood occurrence in 2018. Flood occurred near the main river of Citarum.
4.6. Ciwidey sub-watershed

Figure 10. Rainfall Behaviour of Ciwidey Sub-Watershed

In 2016, graph showed a peak pattern for 8 hours of raining. Its rainfall reached the peak at 09.00 WIB with intensity of 12.86 milimeters. At the very most, rain is only classified as normal rain. In 2018, graph showed the first six hours in Ciwidey sub-watershed experienced light rain. The peak rainfall happened at 07.00 WIB with intensity of 14.57 milimeters. The next 9 hours, it experienced normal rain and interspersed by 2 hours of no rain condition which are at 09.00 WIB and 15.00 WIB. In Ciwidey sub-watershed, flood occurred far from the main river and it was only happened in 2018.

5. Conclusion

In 2016, Upper Citarum Watershed had similar rainfall pattern. There are Cikapundung and Cikeruh sub-watershed with a two-peak graph, Citarik and Cirasea sub-watershed with a peak graph, and Cisangkuy and Ciwidey sub-watershed with the highest intensity at the 9th hours of a day before flood occurrence. In 2018, it has different pattern as in 2016. Cirasea sub-watershed has a striking fluctuation pattern, although the rest 5 sub-watersheds have an almost similar pattern.

At least, 7-hours consecutive of raining in the morning caused flooding in the next day. The homogeneity of flood depth can be measured based on the term of raining. The high intensity of rainfall which happened in short-term caused a heterogeneous flood depth in some area. On the contrary, in long-term period of raining with low rainfall intensity caused a homogenous flood depth in every area.

6. References

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