Study of regional regulation on “Kawasan Bandung Utara” impact on flood discharges from the perspective of spatial variations of extreme precipitation in Bandung basin

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Abstract. This research was built from the probability of shifting urbanization patterns as a result of the Regional Regulation about Northern Bandung Region (Perda KBU). Moreover, extreme precipitation in the Bandung Basin not only happens in KBU but also varies spatially. The probability of urbanization shifting and spatial variation of extreme precipitation can increase flood discharge in other places. Three stages to understand how the spatial variations of extreme precipitation and land use affect flood discharge in Bandung Basin, namely: 1) Extreme precipitation data processing, 2) Land-use data processing, and 3) Hydrology Model simulation using HEC-HMS. Urbanization shifting to north non-KBU and east areas occurs as an impact of Perda KBU. It significantly affects flood discharge in the east area but relatively no impact in the north non-KBU area. Additionally, despite extreme precipitation frequency and volume, the south area has the biggest value. It opens the possibility that the South Bandung area has the potential to be the biggest contributor to Bandung Basin discharge. Therefore, flood study in the south area is needed as a priority.

1. Introduction

West Java Regional Regulation 2/2016 (Peraturan Daerah Jawa Barat Nomor 2 Tahun 2016) [1] is a regional regulation about Northern Bandung Region (Perda KBU). The regulation is intended to protect and ensure sustainable development in KBU with the realization of KBU’s hydrological function as its goals. It replaced former regional regulation, West Java Regional Regulation 1/2008 (Peraturan Daerah Jawa Barat Nomor 1 Tahun 2008).

A big city has a big probability to grow and develop itself [2]. So, with KBU’s exclusive protection, there is also a big probability of the urbanization pattern changing. One of the pattern changes that can happen is urbanization shifting to other areas beside KBU.

Extreme precipitation not only happens in KBU. Using the Probable Maximum Precipitation (PMP) method, Sibuea [3] shows that extreme precipitation varies spatially in the Bandung Basin. For precipitation durations of 6, 9, and 12 hours, the biggest PMP value is shown at Cimahi and Soreang (100 – 150 mm). For 24 hours of precipitation, the biggest PMP value is shown at Cimahi and Bandung Kota (250 mm).
With extreme precipitation that varies spatially and shifting urbanization to other areas beside KBU, other areas are expected to have an increase of flood discharge. This hypothesis is based on Hollis’s theory [4] that states urbanization higher than 5% could increase flood discharge. The flood discharge increases in other areas besides KBU could increase those area contributions to the Bandung Basin flood. That is why this study will show Perda KBU’s impact on flood discharge from the spatial variation of extreme precipitation’s point of view in the Bandung Basin.

2. Data and Methods

2.1. Study Area
Figure 1 shows Citarum Hulu Watershed (DAS) as the study area. It is located between 6°40′S to 7°15′S and 107°15′W to 107°60′W. To begin the research this study area will be divided into three areas. First, Northern Area (WU) will cover Cimahi Watershed until Cidurian Watershed. Second, the Eastern area (WT) will cover Cikeruh Watershed until Citarik Watershed. Third, the Southern area (WS) will cover Cirasea Watershed until Ciwidey Watershed.

Next, WU will be divided again into two areas. The area above 750 masl will be the KBU and the area under 750 masl will be the non-KBU northern area (WUn).

2.2. Precipitation Data
CHIRPS data from 1 January 1981 – 31 December 2017 are used as a yearly extreme precipitation data in this research. This dataset has a temporal resolution of one day and a special resolution of 0.05 x 0.05°.
To find the error of CHIRPS, data from 1 February – 31 March 2019 will be compared with BBWS Citarum’s 11 stations. These 10 minutes temporal resolution data can be downloaded at bbwscitarum.com. To be equally compared with CHIRPS, 11 stations with 10 minutes of temporal resolution data are processed to become daily data.

2.3. Precipitation Data Processing

Precipitation data processing has two purposes. First, it is processed to find the value of extreme precipitation recurrence interval from each area. Then, it will be used to find how many peak over threshold events are based on the value of extreme precipitation recurrence interval from each area.

To begin the process, precipitation value from each area is needed. These values will be obtained from processing grid data using the arithmetic method in equation (1). This method calculates the average, from all precipitation value in each area’s grids, as the precipitation value from each area.

\[
\bar{R} = \frac{R_1 + R_2 + R_3 + \cdots + R_n}{n} = \frac{\sum_{i=1}^{n} R_i}{n}
\] (1)

After obtaining precipitation value from each area, finding the yearly annual maxima from each area's precipitation will be done as an extreme value. The period is one year, counted from June to June because the wet season in the Bandung Basin starts from November to April [5]. Then, plot 1-CDF of these yearly extreme precipitation is needed to show the probability of an extreme event and its value.

\[
T = \frac{1}{P(ch)}
\] (2)

Where recurrence interval (T) can be calculated from the probability of (1-CDF) plot (P(ch)) using equation (2), each area’s extreme precipitation will be chosen from theirs 1 year (probability 100%), 1.5 years (probability 66%), and 2 years (probability 50%) recurrence interval. It is because Hollis’s [4] theory that said low recurrence interval has the biggest impact on flood discharges. These values are an input for the hydrologic model and a threshold to find extreme event frequency form each area using peak over threshold method.

2.4. Producing Land Use Data

The production of land use data will show that the land use percentage differs from each period. As the year of regulation land use data is 2009, the pre-regulation period will be calculated from 1989 (using its land use data) and the post-regulation period will be calculated until 2019 (using its land use data).

Using Normalized Difference Vegetation Index (NDVI), near-infrared (NIR) and red Bands are needed. These are taken from Landsat 5 for 1989’s and 2009’s land use data and Landsat 8 for 2019’s land use data. NDVI has the index range of -1 to 1. From Goncalves et al [6] we can classify index near 1 as thick forest area, positive index near 0 as an urban area, and index under 0 as water area.

\[
NDVI = \frac{NIR-Red}{NIR+Red}
\] (3)

The land use data classification from each year uses the 2011 Bandung Basin’s land use data [7] as a benchmark. As its difference is only 2 years, 2009 is considered to have the same land use classification as 2011’s. At the same time, to classify the land use, 1989’s and 2019’s need to be normalized with 2009’s using a linear regression [8]. Because NDVI cannot distinguish between agriculture and paddy field area, satellite imagery of water is needed and is obtained from Rupa Bumi Indonesia. Last, the final correction to detail the classification from each year is done using google earth image.
The percentage of each classification from each area and year are calculated. These percentages are used to calculate the increase or decrease of each classification from each area, both on the pre-regulation period (1989 – 2009) and the post-regulation period (2009 – 2019).

2.5. Hydrology Model Simulation

The hydrology model simulation uses the Hydrologic Engineering Center’s Hydrologic Model System (HEC-HMS) produced by Nugraha [9]. This simulation has discharge and volume data as outputs.

To get discharge and volume outputs, there are two main inputs: extreme precipitation value and land use data that have been processed and produced. The method used to find each area’s discharge and volume is inserting the extreme precipitation data only on the area that is being sought. For example, if KBU’s discharge and volume are being sought, then only the extreme precipitation grid on KBU is filled. Then, with the input and this method, the discharge and volume on Nanjung outlet (Bandung Basin’s outlet) are the discharge and volume of area that is being sought.

2.6. Flood Discharges Analysis

Generally, discharges analysis uses a comparison ratio method. This ratio is a comparison between the present’s peak discharges and the past’s peak discharges. For more detail, this comparison ratio method is divided into three calculations.

\[ Q_r = \frac{Q_{2009}}{Q_{1989}} \]  

Equation (4) is a comparison ratio between 2009 and 1989, which is a pre-regulation comparison ratio. A ratio of more than 1 indicates an increase and less than 1 indicates a decrease.

\[ Q_r = \frac{Q_{2019}}{Q_{2009}} \]  

Equation (5) is a comparison ratio between 2019 and 2009, which is a post-regulation comparison ratio. A ratio of more than 1 indicates an increase and less than 1 indicates a decrease.

\[ \Delta Q = \frac{Q_{2019} - Q_{2009}}{Q_{1989}} \]  

Equation (6) is the difference between the value of post-regulation and pre-regulation comparison ratio using 1989 as a basis. A positive value indicates an increase and a negative value indicates a decrease in the post-regulation flood discharge ratio.

3. Results and Discussion

3.1. Deciding Precipitation Value and Analysing

To find CHIRPS’ error, eleven BBWS stations at Bandung Basin are compared with the exact location of the CHIRPS grid of those stations. Both of those are averaged and then compared using the mass curve method. The comparison result of the mass curve shows 22% of volume error or about 0.22. This error value indicates that CHIRPS data is good enough to be used.
As annual maxima is a method to find the largest value in a time window, the result of searching precipitation’s annual maxima from each area shows each area’s extreme precipitation in a time window. The extreme precipitation value of each area (figure 3) varies spatially. It is seen from the differences in value in each area. This probably happens because Bandung Basin’s precipitation characteristic is dominated by local precipitation [10]. Although the value is different, every area tends to show the same fluctuation. The differences in fluctuations only happen at WS in 1987 and 1988.

To find the probability of extreme precipitation to happen and its value, these extreme precipitation data from each area are processed using (1-CDF) method. From (1-CDF) plot in figure 4, it can be seen that on the same probability, mostly the KBU’s extreme precipitation value is the largest. It is only less then other in 0.07 – 0.12 probability range where the WS extreme precipitation value is the largest. As the largest, KBU’s extreme precipitation value different from other areas on the 5 – 15 mm range. Equation 2 is used to seek for extreme precipitation value of its recurrence interval, while the
value is taken according to its probability. Probability 100% for 1-year recurrence interval, 67% for 1.5-year, and 50% for 2-year.

![Probability Distribution](image)

**Figure 4.** (1-CDF) plot of extreme precipitation from each area to see the probability of extreme precipitation incident. (Source: Analysis Result, 2020).

| Precipitation Value (mm) | Area | 1 Year | 1.5 Year | 2 Year |
|--------------------------|------|--------|----------|--------|
| KBU                      | 22.99| 54.51  | 62.88    |
| WU                       | 21.48| 50.41  | 58.25    |
| WT                       | 23.42| 48.3   | 54.58    |
| WS                       | 18.04| 47.76  | 56.41    |

**Table 1.** Precipitation value in each area according to their recurrence interval. (Source: Analysis Result, 2020).

Besides, the event frequency is also needed to analyze the extreme precipitation from each area. Therefore, the values from table 1 will be the input for the peak over threshold calculation. It will show how many events are equal to or greater than the extreme precipitation that happens in each area and period. As a result, figure 5 shows that WS tends to have the biggest frequency of events compared to the other areas. Except for the 2-year recurrence interval, the frequency of events in each area is not much different. Assumed that this was caused by the single convective cloud regeneration pattern that propagated to the south [10].

![Event Frequency](image)

**Figure 5.** Frequencies of extreme precipitation events for 1.5-year and 2-year recurrence interval. (Source: Analysis Result, 2020).

![Event Frequency](image)

**Figure 6.** Frequencies of extreme precipitation events for the 1-year recurrence interval. (Source: Analysis Result, 2020).
So, the spatial analysis of extreme precipitation of Bandung Basin, due to its flood impact, shows 2 results. First, if the extreme precipitation value point of view is used, KBU has the biggest contribution. But if the event frequency of extreme precipitation point of view is used, WS should be the biggest contributor.

3.2. Land Use Producing and Analysing
As land use data in 2009 became a reference to make a land use map data in 1989 and 2019, there were some errors. To calculate the error, each data in 1989 and 2019 are normalized with linear regression. Both of those year only has a little error seen from their \( R^2 \). The \( R^2 \) result from linear regression in 1989 is 0.93 and in 2019 is 0.83. This little error shows that the classification of land use is good enough to be used.

Figure 7. Bandung Basin land use map in a) 1989, b) 2009, and c) 2019 (Source: Analysis Result, 2020).
With fixed classification, table 2 shows two calculation results. First, the result of the calculation of the urban land use percentage in each area each year. Second, the result of the calculation of the urban land use percentage that shows an increase in each area and period (pre-regulation and post-regulation). The increase of WUn’s urban percentage is derived from assumptions that the increase in WU is the average of KBU’s and WUn’s. This assumption is based on the similarity of the total area from both KBU and WUn.

Table 2. (Left) Urban land use percentage in each area and (right) their increases in the pre-regional regulation period (1989-2009) and post-regional regulations period (2009-2019). (Source: Analysis Result, 2020).

| Area | Urban Land Use Percentage | An Increase in Urban Land Use Percentage |
|------|---------------------------|----------------------------------------|
|      | 1989 (%) | 2009 (%) | 2019 (%) | Area | Pre-Perda (%) | Post Perda (%) |
| WU   | 37.6     | 47.7     | 59.7     | WU   | 10.1         | 12           |
| KBU  | 14.0     | 24.9     | 33.6     | KBU  | 10.9         | 8.7          |
| WT   | 13.2     | 27.0     | 36.4     | WUn  | 9.3          | 15.3         |
| WS   | 11.7     | 22.8     | 26.3     | WT   | 13.8         | 9.4          |
|      |          |          |          | WS   | 11.1         | 3.5          |

Based on Hollis [4], almost all areas in all periods will have an increasing flood discharge. It is seen from almost all areas in all periods that have more than 5% increases in urban percentage. Only WS in the post-regulation period is not expected to have an increase in flood discharge. This is because its urban percentage only increases by up to 3.5%.

To find out if there is any shifting in urbanization patterns, it is necessary to compare some data that spatially and temporally the same. It can be seen from Table 2 that both periods do not have the same range of time. Therefore, it needs to be transformed into the same temporal scale which is shown as the rate of urban growth percentage in Table 3.

This rate of urban growth percentage shows urbanization shifting to WUn and WT. It is shown in two things. First, it because of an increase in the rate of urban growth percentage which is shown in WUn and WT. Second, even as KBU also shows an increase in urban growth percentage rate, WUn and WT have a bigger rate than KBU.

Table 3. Urban growth percentage rate in every area on all periods. (Source: Analysis Result, 2020).

| Rate of Urban Growth Percentage |
|--------------------------------|
| Wilayah | Pre-Regulation | Post-Regulation |
| KBU     | 0.5            | 0.8             |
| WUn     | 0.4            | 1.5             |
| WT      | 0.6            | 0.9             |
| WS      | 0.5            | 0.3             |

So, spatiotemporal analysis of land-use data also shows two results. First, according to Hollis [4], almost all areas in all periods will have an increasing flood discharge. Only WS in the post-regulation period is not expected to have an increase. Second, urbanization shifting occurs because of KBU regulation. It shifts to WUn and WT in the post-regulation period.

3.3. Flood Discharge Response on Spatial Variation of Extreme Precipitation and Land Use

Precipitation data in all recurrence intervals and land use that are already processed are used as input in the HEC-HMS model to get a discharge (figure 7 and 8) and volume output (figure 10 – 12). In
figure 7 and 8, two theories of Hollis [4], that said urbanization over 5% will affect flood with a return period of 1 year or more and the effect of urbanization decline in relative terms as flood recurrence are fulfilled. Moreover, the value of the ratio is approximately the same as Hollis’s. However, if two of the periods are compared, it shows different increasing ratios even with the value of urban growth that approximately the same. It can be explained using Farid [11] opinion that says the increasing peak discharge is not just affected by the urban growth percentage, but it is also affected by the large decrease of forest percentage. This theory is supported by Bathrust [12] which states that 20%-30% of forest change in land cover is needed to have a significant impact on the hydrological response.

Focus on table 4 that shows and compares the decreases of forest percentage between two periods, where the influence of forests on flood discharge according to Farid [11] and Bathrust [12] is clearly seen in two ways. First, only the WUn area has a bigger urban growth percentage on the post-regional regulation period rather than the pre-regulation period. But the increase in the flood discharge ratio is more or less the same as the WS which should not have increased. It is because, during the post-regional regulation period, WUn did not have a decrease in forest percentage (0%). Second, WT and WS have a large increase in flood discharge ratio in the pre-regional regulation period. It is also caused by the loss of forest percentage. Table 4 shows that these areas have the biggest decrease in forest percentage on the pre-regulation period compared with other areas and even with themselves on the post-regulation period.

![Figure 8](image1.png)

**Figure 8.** The ratio of flood discharge increase in the Pre-regional regulations period (20 years). (Source: Analysis Result, 2020).

![Figure 9](image2.png)

**Figure 9.** The ratio of flood discharge increase in the Post-regional regulations period (10 years). (Source: Analysis Result, 2020).
Table 4. Percentage of forest land cover changes in each area in each period.
(Source: Analysis Result, 2020).

| Area | Pre-Regulation | Post-Regulation |
|------|----------------|-----------------|
| KBU  | -5.8           | -6.6            |
| WUn  | -3.2           | 0               |
| WT   | -18.4          | -1.6            |
| WS   | -19            | +1.5            |

There is a problem to analyse the effect of spatial variation and urban growth on flood discharge in Figures 7 and 8. The problem is the same with urban growth analysis, that it has a different range of time. Because of the differences in the time range, the increases tend not to be seen. However, seeing the flood discharge response, because Perda KBU's will not take the same method as urban growth analysis that transforms the time range to the same temporal scale, it is necessary to calculate the period difference with the same time reference as in figure 9. In this case, 1989 will be a time reference. Also to calculate the increase in the post-regulation period, the difference between 2019 and 2009 increase ratios will be calculated.

Figure 10. Ratio increase of post-regional regulation period’s flood discharge. (Source: Analysis Result, 2020).

After calculating the difference with the same reference, we can see that figure 9 shows an increase in the ratio of flood discharge on the post-regulation period. Because Perda KBU affects the shift in urbanization to WUn and WT, it can be concluded in figure 9 that Perda KBU also has a big impact on WT and relatively no impact on WUn. WT is said to have a big impact. With an urban growth percentage that is approximately the same as KBU, WT has the biggest increase. While WUn is said to have relatively no impact because with the largest urban growth percentage, it has approximately the same increase on flood discharge as WS which should not have an increase.

3.4. Discussion
Sub-section 3.2 shows that Perda KBU has an impact on urbanization shifting to WUn and WT. This urbanization shifting also has an impact on increasing flood discharge in WT as shown in sub-section 3.3. Therefore, this study has proven that Perda KBU has an impact on increasing flood discharge in other areas.
This condition, probably, will worsen the impending flood event in Bandung Basin. Figures 10 – 12 show that WT supplies approximately the same volume of runoff as KBU’s, even with KBU’s extreme precipitation being the biggest (sub-section 3.1). Based on table 5, WT still has enough forest percentage to multiply the flood discharge up to 1.7 more, according to figure 7. Without any intervention, urbanization shifting to WT can multiply the flood discharge in WT and then increase the supply of runoff volumes from WT. So, in the end, the Perda KBU might prevent KBU from becoming the biggest contributor of the Bandung Basin flood, but the flood can get worse because other areas become bigger contributors to the Bandung Basin flood than before.

![Figure 11](image1.png)

**Figure 11.** Runoff volume of 2-year recurrence interval. (Source: Analysis Result, 2020).

![Figure 12](image2.png)

**Figure 12.** Runoff volume of 1.5-year recurrence interval. (Source: Analysis Result, 2020).
Figure 13. Runoff volume of 1-year recurrence interval. (Source: Analysis Result, 2020).

This study has not been able to prove the impact of Perda KBU in WS. However, this study shows some reasons to consider WS will probably be the most contributed area of the Bandung Basin flood in the future. First, figures 10 – 12 show that WS has the biggest runoff volume and table 5 shows that WS has the smallest urban area percentage and the biggest forest percentage. This means that if the impact of Perda KBU or the urban growth in the future reaches WS, WS flood discharge will be multiplied and its runoff volume will be much greater. Therefore, it is necessary to study the projected impact of flood discharges responses on urbanization in the Southern region, related to the Southern region’s development. Second, imagine that in the future Bandung Basin flood might occur frequently. It because WS, which is expected to be the biggest contributor to the Bandung Basin flood, has a frequent event of extreme precipitation. It is shown in figure 5 (sub-section 3.1). So, regarding the frequency of extreme precipitation in the Southern region, studies on the amplification potential of flood frequency in the future need to be prioritized.

Table 5. Percentage of urban and forest land use in 2019 from each area.
(Source: Analysis Result, 2020).

| Area | Urban (%) | Forest (%) |
|------|-----------|------------|
| WS   | 26.3      | 29.6       |
| WT   | 36.4      | 15.6       |
| KBU  | 33.6      | 15.6       |
| WUn  | 85.8      | 0          |

4. Conclusions
Based on the result of the study on flood discharge response on regional regulations about KBU from extreme precipitation and urban land use spatial variations point of view, it can be concluded:

1. Perda KBU affects urbanization shifting to the Northern region beside KBU and Eastern regions.
2. These urbanization shifts cause a big impact on increasing flood discharge in the Eastern region and relatively no impact in the Northern region besides KBU.
3. With its extreme precipitation frequency, runoff volume, and urban-forest land use percentage, the Southern region has the potential to be the greatest contributor in Bandung Basin flood.

5. References
[1] -- 2016 Peraturan Daerah Provinsi Jawa Barat Nomor 2 Tahun 2016 Tentang Pedoman Pengendalian Kawasan Bandung Utara Sebagai Kawasan Strategis Provinsi Jawa Barat (Bandung: Pemerintah Daerah Provinsi Jawa Barat)
[2] Tjiptoherijanto P 2016 Urbanisasi dan pengembangan kota di indonesia Pop. 10 57–72
[3] Sibuea P 2018 Estimasi Probable Maximum Precipitation (PMP) dan Probable Maximum Flood (PMF) dengan Menggunakan Model GSSHA (Studi Kasus Daerah Kajian DAS Citarum Hulu) (Bandung: Program Sarjana Institut Teknologi Bandung)
[4] Hollis G 1975 The effect of urbanization on floods of different recurrence interval Water Reso. Rsrch. 11 431–5
[5] Fares Y and Yudianto D 2004 Assessment of hydrological characteristic in the upper citarum catchment J. of Env. Hydro. 12 1–13
[6] Goncalves A, Godoi R, Filho A, Folhes M and Pistori H 2018 Urban phytophysiognomy characterization using ndvi from satellites images and free software Anuá. do Inst. de Geoci. 41 24–36
[7] Virtriana R, Deliar A and Taufik M 2013 model of land cover change prediction using combination of binary logistic regression (blr) and cellular automata-markov chain (ca-mc) based on accessibility (case study: west java) 34 th Asian Conference on Remote Sensing 2013, ARCS 2013 2 1820–27
[8] Fung T and Siu W 2000 Environmental quality and its changes, an analysis using ndvi Int. J. of Rem. Sens. 21 1011–24
[9] Nugraha P 2020 Karakteristik Hujan Penyebab Banjir Bandung Tahun 1986 Berdasarkan Simulasi Model HEC-HMS (Studi Kasus pada DAS Citarum Hulu) (Bandung: Program Sarjana Institut Teknologi Bandung)
[10] Fitriani R 2018 Regenerasi Awan Konvektif Penghasil Hujan Di Wilayah Bandung (Bandung: Program Magister Institut Teknologi Bandung)
[11] Farid M, Mano A and Udo K 2010 Flood runoff characteristics due to land cover change in upper ciliwung river basin indonesia using 2d distributed model coupled with ncf tank model Ann. J. of Hydr. Eng. 54 157–62
[12] Bathrust J, Birkinshaw S, Espinosa F and Iroume A 2017 Forest impact on flood peak discharge and sediment yield in streamflow (River System Analysis and Management) ed. N Sharma (Singapore: Springer Nature) pp 15–28

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