Flashiness Index of Several Rivers in the Citarum Basin, West Java

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Abstract. This paper discusses the flashiness index of four rivers in the Citarum watershed, namely the Cisokan River, CIkundul, Cimeta and Cibalagung. The trend of the flashiness index of a river can be an indication of the changes occurring within the watershed. The flashiness is calculated by the Richards–Baker flashiness index (FI), which is the ratio of absolute day-to-day fluctuations of streamflow relative to total flow in a year on in a season. We analyzed daily streamflow data for the period 1994-2016. The results show that the mean annual flashiness index in the four watershed varies between 0.29 and 0.39, which is relatively homogenous showing the characteristic of a mountainous region. The high flashiness index occurs in the dry and transition season. Morphometric characteristic of the Cikundul watershed, such as low drainage density and basin slope, generated low flashiness index. The negative correlation between the flashiness index with mean annual flow discharge, while a positive correlation with the mean daily rainfall. The strong correlation is found particularly in the transition season, in the Cikundul and Cimeta, and dry season in the Cibalagung. The effect of land use change, especially changes in forest area, in this study is rather difficult to determine because the observation time is relatively short.

1. Introduction
The natural flow of a river is generally determined by climate factors, especially rainfall and its distribution in time dimensions [1]. The natural flow of a river in Java affected by the monsoon system is indicated by the exchange between high and low flow periods. High flow periods occurs during December to February and low flow periods occurs during July to September.

The change of land use in a watershed, especially the decrease of forest area and the increase of built-up area, on the one hand, and variability of rainfall on the other, can cause a changes in water balance in the watershed [2]. Research’s that have been widely conducted around the world shows that land use/land cover change watershed can increase the peak flow discharge [3,4], the average annual discharge [5,6] and also base flow discharge [7,8].

In regards to the relationship between rainfall and streamflow in a watershed, it is clear that the changes in land use and the widening of impervious areas decrease the soil's ability in the processes of water cycle. The soil’s ability to absorb and store water reduces, resulting in a large or accelerated surface flow. The result is that the groundwater flow becomes smaller. The magnitude of the event depends on the intensity and duration of rainfall, the area of the watershed and its land cover [1]. The change of rapid river discharge in a short time in hydrology is known as flashiness [9]. Flashiness can also be
interpreted as a sharp fluctuation of river discharge. Flashiness is an indicator of the response rate of discharge to rainfall and may indicate the bad or good condition of a watershed [9].

The Citarum basin with all available water resources (surface water, groundwater, springs) has a very important role in the national scope because of their use for domestic, electric, agricultural, fishery or industrial purposes. A high increase in population and all activities lead to an increase in the area of settlements and the need for water resources which may continue to cause changes in water balance. The impacts of land use change on hydrological characteristics between different watersheds can vary, due to differences in geological and topographic conditions of the watershed [7,10,11,12]. In this paper, we discuss the characteristics of the flashiness index (FI) of four rivers in the Citarum basin and their relation to rainfall factors, land use change and morphometric characteristics of each watershed. The four rivers discussed in this study are important rivers because they supply water sources for Cirata Reservoir (43,777.6 ha), which can generate an average power of 1,428 GWh per year.

2. Research Methodology

2.1. Research area

The research area includes 4 sub-watersheds in the Citarum Basin, namely, the Cisokan watershed (896.20 km²), the Cikundul (256.08 km²), the Cimeta (155.97 km²) and the Cibalagung (118.09 km²) (see Figure 1) The Cisokan, Cikundul, Cimeta and Cibalagung river all eventually flow into the Cirata Reservoir.

Figure 1. Map of research area
2.2. Data
Daily river flow data from 4 river gauge and daily rainfall data, for the period 1994-2016, were obtained from PT. Indonesia Power PLTA Cirata. Land use data for 1996, 2006 and 2015 were collected from the Ministry of Agraria and Spatial Planning, Republic Indonesia. While the morphometric characteristics of watershed, including basin shape coefficients, drainage density and basin slope index were obtained from the results of digitized topographic map processing of 1: 25,000 scale published by the Geospatial Information Agency.

The flashiness index (FI) was calculated using the R-B index (RBI) equation [9]:

$$ R - B Index = \frac{\sum_{i=1}^{n}[q_i - q_{i-1}]}{\sum_{i=1}^{n}q_i} $$

(1)

Where qi and qi-1 are the average daily discharge (m³ s⁻¹) on day i and day i - 1, respectively. The index is dimensionless meaning that similar result are obtained when replacing the discharge by total daily discharge volume (m³). The R-B index was calculated for each season, namely rainy season (December, January and February), dry season (includes June, July and August) and transition season (inc. March, April and October, November).

The mathematics equation for the calculating of morphometric parameters is shown in Table 1.

**Table 1. Methods for calculating the morphometric parameters [13]**

| Morphometric parameter | Equation | Explanation |
|------------------------|----------|-------------|
| 1 Basin shape coefficient | F = A.L² | where F is the basin shape coefficient, A is the length of basin, and A is basin area. |
| 2 Drainage density | D = L/A | where D is drainage density, L is the total length of stream thalwegs in an area of size A |
| 3 basin slope | S= hL/A¹ | where S is the basin slope, h is the contour lines difference, L is the total length of average elevation lines and A is the total area of watershed/basin. |

3. Results and Discussion

3.1. Morphometric characteristics and land use of watersheds
The morphometric characteristics of the four watersheds are presented in Table 2. Related to basin slope index, Cibalagung watershed have the largest value with 0,27, followed by Cimeta (0,19), Cisokan (0,08), and Cikundul watershed (0,06). It means that the Cibalagung and Cimeta watersheds are relatively steeper than other watersheds. A more elongated and narrow shape watershed with high river network densities of 2.90 is shown for the Cimeta watershed which can be able to produce faster peak discharge [13].

**Table 2. Morphometric parameters of watersheds in the study area**

| Watershed | Area (km²) | Length of main river (km) | Form Factor | Drainage Density (km/km²) | Basin Slope |
|-----------|------------|--------------------------|-------------|--------------------------|-------------|
| Cisokan   | 896,20     | 87.72                    | 12.10       | 1,19                     | 0,08        |
| Cikundul  | 256,08     | 35.37                    | 7.24        | 0,83                     | 0,06        |
| Cimeta    | 155,87     | 43.90                    | 3.55        | 2,90                     | 0,19        |
| Cibalagung| 118,09     | 31.17                    | 3.79        | 0.86                     | 0,27        |

Land use in each watershed is dominated by agricultural land, including plantations, mixed garden, non-irrigated fields (“tegalan” in bahasa) and rice fields. Its areas encompass more than 60% of the total area each watershed. The proportion of the forest for each watershed in 2015 varies between 13 and 22 percent (see Table 3), if we compare the existing forest area with the conditions of 1996, the forest area
for all watersheds decreased by a range of between 3 and 6 percent of the watershed, but it is followed by an increase in the area of settlements.

Table 3. Forest and settlement areas (in percent) in 1996, 2006, and 2015 in each watershed.

| Land use | Cisokan | Cikundul | Cimeta | Cibalagung |
|----------|---------|----------|--------|------------|
| Forest   | 17.4    | 16.2     | 15.1   | 15.4       |
| Settlement| 3.2     | 5.7      | 6.5    | 4.1        |

3.2. Spatial and temporal variability of flashiness

Table 4 shows the FI (R-B Index) of the annual, rainy, dry and transition seasons for the Cisokan, Cikundul, Cimeta and Cibalagung rivers respectively. The mean annual flashiness index in the four watersheds varies between 0.29 and 0.39. 0.43 (Fig. 3). This means that the average day-to-day fluctuations of streamflow vary from 29% to 43%, depending on the watershed. The flashiness index for the Cikundul, both annual and seasonal, is the lowest compared to the other three rivers. It can give an indication of the morphometric factor of watershed on flashiness index. The Cikundul watershed has the lowest drainage density and basin slope compared to the other three watersheds with a value of 0.83 km/km2 and 0.06 respectively, so that allowing it to generate a low FI [14]. In contrast, the Cimeta watershed characterized by the high values of drainage density and basin slope show a high flashiness index.

Table 4. The flashiness index (R-B index) of the annual, rainy (RS), dry (DS) and transition seasons (TS) for the Cisokan, Cikundul, Cimeta and Cibalagung rivers respectively.

| Year | Cisokan | Cikundul | Cimeta | Cibalagung |
|------|---------|----------|--------|------------|
| 1994 | 0.28    | 0.35     | 0.47   | 0.23       |
| 1995 | 0.32    | 0.31     | 0.29   | 0.31       |
| 1996 | 0.30    | 0.30     | 0.56   | 0.38       |
| 1997 | 0.38    | 0.36     | 0.58   | 0.44       |
| 1998 | 0.29    | 0.30     | 0.28   | 0.34       |
| 1999 | 0.32    | 0.24     | 0.46   | 0.38       |
| 2000 | 0.36    | 0.29     | 0.51   | 0.35       |
| 2001 | 0.34    | 0.45     | 0.49   | 0.36       |
| 2002 | 0.45    | 0.44     | 0.50   | 0.63       |
| 2003 | 0.47    | 0.29     | 0.41   | 0.48       |
| 2004 | 0.36    | 0.34     | 0.44   | 0.48       |
| 2005 | 0.37    | 0.31     | 0.42   | 0.38       |
| 2006 | 0.40    | 0.34     | 0.47   | 0.38       |
| 2007 | 0.40    | 0.29     | 0.51   | 0.46       |
| 2008 | 0.44    | 0.31     | 0.47   | 0.57       |
| 2009 | 0.31    | 0.28     | 0.35   | 0.23       |
| 2010 | 0.31    | 0.41     | 0.43   | 0.22       |
| 2011 | 0.45    | 0.41     | 0.45   | 0.19       |
| 2012 | 0.45    | 0.38     | 0.48   | 0.23       |
| 2013 | 0.38    | 0.34     | 0.49   | 0.15       |
| 2014 | 0.36    | 0.31     | 0.45   | 0.15       |
| 2015 | 0.33    | 0.23     | 0.50   | 0.13       |
| 2016 | 0.33    | 0.32     | 0.42   | 0.20       |

Figure 2 shows the annual flashiness index and the annual flow discharge for the Cisokan, Cikundul, Cimeta and Cibalagung rivers. The pattern of the figure shows no relationship between the annual flow discharge and the annual FI. The high flow discharge for all rivers in 2010 generated a low FI for all rivers, but that did not occur in 2016. The result of the statistical analysis shows a weak negative correlation with the correlation coefficient of -0.4; -0.3; -0.2 and 0.0 for the Cikundul, Cisokan, Cimeta and Cibalagung respectively.

Temporal variability in the FI can be evaluated by standard deviation (see Table 4). The standard deviation of annual FI between years varies between 0.06 and 0.12. The Cisokan and Cimeta rivers have low standard deviation, while the Cikundul and Cibalagung rivers have high standard deviation.
Figure 2. Annual flashiness index for the Cisokan, Cikundul, Cimeta and Cibalagung rivers (A); and annual flow discharge for the Cisokan and Cikundul (B) and Cimeta and Cibalagung rivers (C) in the periods 1994-2016.

Based on the seasonal FI (see Table 3), it appears that river flows during the transition period (March-April and October-November) are flashier than in the rainy and dry seasons. Referring to the mean monthly flow discharge (see Figure 3), the high flashiness index can be related to the high flow discharge in the transition season, especially in March and April. Temporal variability in the seasonal FI show that the FI during the dry season have high standard deviation compared to the other season.
3.3. Discussion

The FI obtained in this research ranged from 0.08 to 0.60 which are not very different from what is obtained from Holko’s research in 2011 (0.06 to 0.43) at the mountainous region of Slovakia and Austria [15]. The study area is located in a mountainous area where most of the area (more than 40%) exist in an area with a slope of 25-40%. The results obtained in this research is different than the earlier research done by Nugrahaeni [16] in the watershed in the lowland area of Jakarta where the FI ranged between 0.09 and 0.28.

As noted by previous studies [9, 3,14] the physical characteristics of watersheds, especially morphometric factors influence the differences in the FI between watersheds. In this study, the statement is shown in case of the Cikundul River. The FI, both annual and seasonal, for the Cikundul is lower than other rivers.

The high FI in the transition and dry season may be explained by the characteristics of streamflow discharge which tend very fluctuate. The caused factor is the rainfall in that season which to be marked with high intensity (convective rainfall) [1]. High-intensity rainfall in a watershed coupled with the conditions of its land use causes increased surface runoff and it opposite reduces the groundwater flow.

Table 4 shows the correlation coefficient between the average daily rainfall and flashiness index variables for the period of 1994-2016. The results are grouped for yearly, and seasonally. For annual data, the results show that there is not a correlation between the mean daily rainfall and the annual flashiness index and applies to all watersheds. For seasonal data, the results show the differences between watersheds. In general, the correlation is relatively weak. The strong correlation is found particularly in the transition season, in the Cikundul and Cimeta, and dry season in the Cibalagung. These results confirm the results of research conducted by Baker et al. in Midwestern USA. Baker et al. [9] reported a positive correlation between flashiness index with increasing frequency and magnitude of storm events. In further studies, more detailed analyses are needed to examine the effect of the variability of climate variables, especially rainfall intensity, on the seasonal change in daily streamflow fluctuations.

Table 5. Coefficient of correlation between the mean daily rainfall and the flashiness index for annual and seasonal data.

| Watershed | Annual | Rainy season | Dry season | Transition season |
|-----------|--------|--------------|------------|------------------|
| 1 Cisokan | 0.03   | 0.15         | 0.26       | 0.03             |
| 2 Cikundul | 0.11  | 0.31         | 0.30       | 0.40             |
| 3 Cimeta | 0.012  | 0.02         | 0.31       | 0.53             |
| 4 Cibalagung | 0.11  | 0.41         | 0.28       | 0.14             |

The effect of land use change, especially changes in forest area, in this study is rather difficult to establish because the observation time is relatively short. Although the positive trend of the flashiness index for the Cisokan, Cimeta and Cibalagung rivers clear can be marked, it is too early to establish these trends due to changes in forest area.

4. Conclusions

- The variation of flashiness index in the four rivers in the research area is relatively homogenous that shows the characteristic of a mountainous region. The high flashiness index occurs in the dry and transition season.
- Morphometric characteristic of the Cikundul watershed, such as low drainage density and basin slope, generated low flashiness index.
- The negative correlation between the flashiness index with mean annual flow discharge, while a positive correlation with the mean daily rainfall. The strong correlation is found particularly in the transition season, in the Cikundul and Cimeta, and dry season in the Cibalagung.
In further studies, more detailed analyses are needed to examine the effect of the variability of climate variables, especially rainfall intensity, on the seasonal change in daily streamflow fluctuations.

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