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Peak Discharge in Jemelak Subwatershed, Sintang District

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ABSTRACT

Jemelak Sub Watershed is close to the junction of two big rivers, i.e., Kapuas and Melawi. Therefore, this location faces environmental issues such as a flood. To avoid its possible damages, information on peak discharge becomes critical, particularly in calculating the drainage structure. This study was aimed to predict the peak discharge in this area using a rational method. The maximum daily rainfall data from 1998 to 2017 were divided into two periods of 10 years and analyzed. In the first period, maximum rainfall ranges from 98.6 to 176.3 mm, while the second period fluctuates from 67.6 to 190 mm. Analysis of land cover described that 43.97% of secondary swamp forests turned into shrubs and swamp shrubs in the first period. Furthermore, about 800.71 ha of secondary swamp forest tuned into 582.80 ha of bare land, 181.04 ha of a plantation, and 36.88 ha of swamp shrubs in the second period. About 95.15% of shrubs were also turned into agricultural land mixed with shrubs in the second period. The result showed that the changes in the maximum daily rainfall and land cover simultaneously affected the improvement of the peak discharge by about 2.53% in the first period and 28.30% in the second period. If the peak discharge exceeds the river capacity, then the local flooding will occur along the river border.

Keywords: *land cover, peak discharge, rainfall, Jemelak*

INTRODUCTION

The global climate is changing unarguably (Siswanto et al. 2016). Consequently, all natural biological systems have been affected by climate change (Stone et al. 2013). It has inevitably altering weather characteristics around the world (Weatherhead et al. 2010). Accordingly, this problem has contributed to the precipitation patterns locally and regionally (Chadwick et al. 2013; Rowell 2012).

Precipitation is the primary input in the watershed system, primarily as rainfall in a tropical area such as Indonesia. Some water flows quickly to produce streamflow, while the other flows through groundwater aquifers. Ordinarily, the streamflow is considered as an integrated response of the watershed properties by alteration of the precipitation (Edwards et al. 2015). This integrated response occurs due to its complex interactions between surface flow and saturated and unsaturated subsurface regimes (Camporese et al. 2010). Changes in rainfall contributed to the fluctuation of discharge in both annual and seasonal patterns (Wahyu et al. 2010).

Peak discharge information is crucial for infrastructure design (Camporese et al. 2010). The determination is strongly influenced by climate variations (Ward et al. 2010). Furthermore, it is also closely related to the flood since its ability to reflect the watershed degradation (Pramono et al. 2010). If the stream capacity is smaller than the peak discharge, the flood will occur. It will cause damage to the surrounding infrastructure.

Jemelak Subwatershed is part of Kapuas Watershed. This subwatershed is located near the junction of two big rivers, i.e., Kapuas and Melawi. Therefore, this location faces environmental issues in the form of the flood during the rainy season. In detail, this catchment area is mostly located in Sintang Sub District, the center of the Sintang District government. The floods that may appear caused not only victims and damages but also disrupted government activities (Pramulya et al. 2011).

As an area that will be developed following the spatial land use plans, it is necessary to know the peak discharge information of Jemelak Sub Watershed. Unfortunately, this area does not have any hydrologic station. However, remote sensing technology could provide data and information about natural resources as well as environmental monitoring (Basuki and Wahyuningrum 2014). This technology can be conducted using rational methods to get information about peak discharge easily (Pramono et al. 2010; Grimaldi and Petroselli 2014). This study was aimed to predict the peak discharge in Jemelak Sub Watershed using a rational method.

MATERIALS AND METHODS

This study was conducted in Jemelak Subwatershed, Sintang District, West Kalimantan province, Indonesia. Jemelak Subwatershed covers a territory of 5,241 ha, extending from 111°29’47” to 111°37’13” East longitude and 0°2’3” to 0°6’33” North latitude (Figure 1). Moreover, it is 118-231 m above sea level, slopes ranging from 0% to 39%.

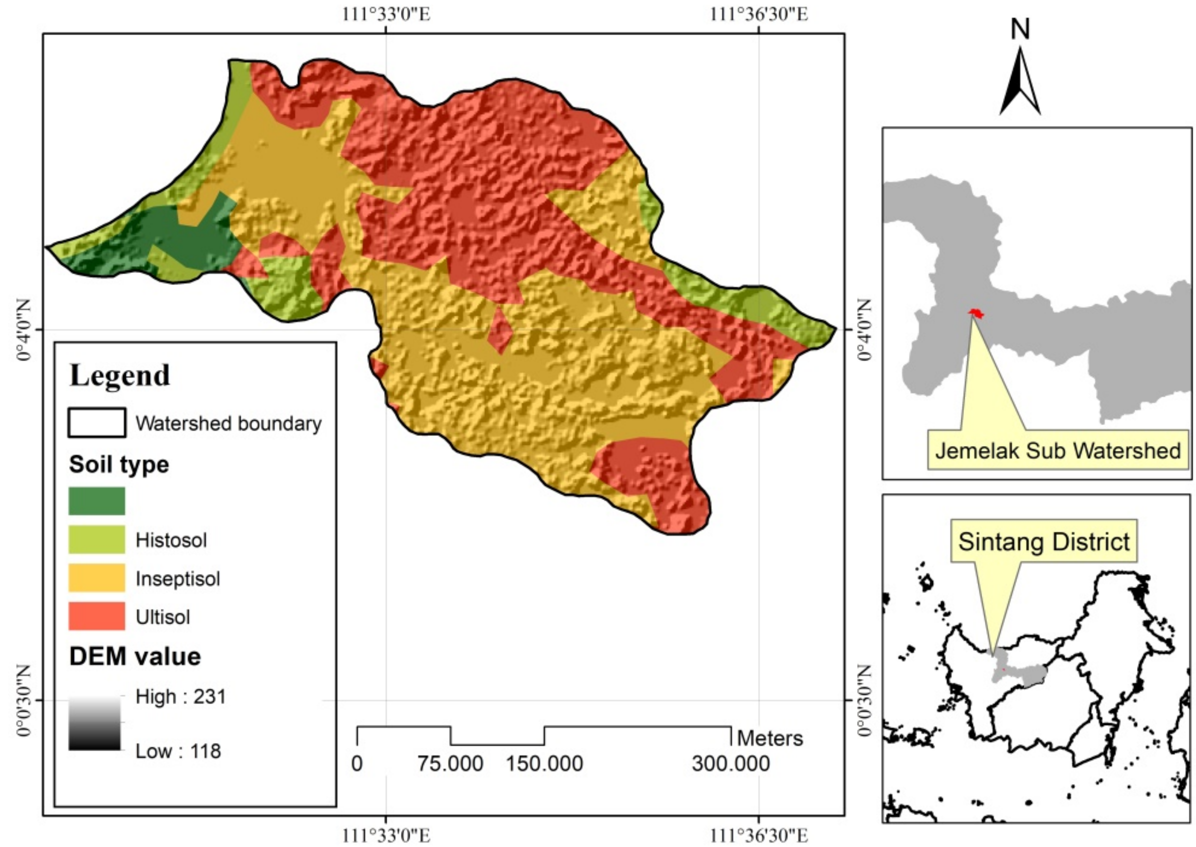

Figure 1. Location of Jemelak Subwatershed.

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This research methodology divided into three phases. The first phase was to analyze the precipitation pattern, and the second phase was to analyze the trend of land cover change, while the third phase was to calculate peak discharge in Jemelak Sub Watershed.

Analysis of Precipitation Pattern

Analysis of precipitation pattern was conducted using daily rainfall data of 20 years from 1998-2017 from rain gauge station managed by Susilo Airport. This daily rainfall data were rearranged into monthly data. In order to classify the rainfall trend, the monthly data was separated into 2-decade groups data, i.e., 1998-2007 and 2008-2017, and one data set covering the whole data 1998-2017 (inter-annual data). Furthermore, the rainfall pattern was analyzed descriptively.

Analysis of Land Cover Change

This research used the land cover map in 1990, 2006, and 2015 which were obtained from The Ministry of Environment and Forestry, The Republic of Indonesia. This land cover map was resulted from the manual interpretation of satellite imagery (on-screen digitation). Furthermore, land cover change was analyzed spatially using ArcMap 10.2.2. Since the study will be focused only on Jemelak Subwatershed, those three land cover are overlaid and intersect with the boundaries to get just the land cover map of this research area.

Peak Discharge Determination

Peak discharge was determined using remote sensing technology which was conducted by the rational method. The rational formula is a preferred approach in practical hydrology because of its capability to find the middle ground between theory and data availability (Grimaldi and Petroselli 2014). The equation of a rational formula is mentioned in the following equation (Pramono et al. 2010):

$$Q_p = 0,278 \times C \times I \times A$$

where Q_p is peak discharge (m^3/s), C is the rational runoff coefficient, I is the rainfall intensity (mm/hour), A is the drainage area (km^2), and 0.278 is a unit conversion in the metric unit.

The I value and Tc value were calculated as follows:

$$I = \frac{R}{24} \times \left(\frac{24}{Tc}\right)^{0.67}$$

$$T_c = \frac{L^{1.15}}{7700 \times H^{0.385}}$$

where R is daily rainfall (mm/hour), T_c is the time of concentration (hour), L is the length of the main stream (km), and H is the altitude difference in the watershed area (m).

In previous research, the T_c is widely used to estimate the peak discharge of a watershed (de Almeida et al. 2014). The Digital Elevation Model (DEM) - The Shuttle Radar Topography Mission (SRTM) 30 m x 30 m resolution can be analyzed spatially into topographic characteristics, which is significantly affect the Tc value such as stream order and slope. Based on this extraction, the Tc value is 0.12 hours. In other words, the raindrop that falls on the furthest area of Jemelak Subwatershed takes 7 minutes and 2 seconds to flow up to the outlet.

The biophysical characteristics which considered to produce a flow are described in Table 1. The C value is determined using the biophysical characteristics of the catchment, also known as Cook Method (Gafuri et al. 2016):

$$C = Slope + Infiltration + Land\ cover + Drainage\ density$$

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Table 1. The biophysical characteristics considered to determine the C value.

No.	Watershed characteristics	Characteristic produces a flow			
		100% (Extreme)	75% (High)	50% (Normal)	25% (Low)
1	Slope	>30% (40)	10-30% (30)	5-10% (20)	<5% (10)
2	Infiltration (according to the soil texture)	Clay loam, silty clay loam, sandy clay, silty clay, or clay (20)	Sandy clay loam (15)	Silt loam, or loam (10)	Sand, Loamy sand, or sandy loam (5)
3	Land cover	No effective land cover (20)	Less than 10% of watershed covered by trees (15)	Approximately 50% of watershed covered by both trees and grasses (10)	Approximately 90% of watershed covered by trees and grasses (5)
4	Drainage density	>8 km/km^2 (20)	3,2-8 km/km^2 (15)	1,6-3,2 km/km^2 (10)	<1,6 km/km^2 (5)

RESULTS AND DISCUSSION

Precipitation Pattern

Precipitation is one of the climate parameters, so it can be used to illustrate climate change (Willems and Vrac 2011). According to daily rainfall data at the Susilo rainfall station, it is known that the annual rainfall during 1998-2017 is 2,625.1 mm. Rainfall analysis during the past 20 years shows a decreasing trend at the largest decline rate that occurred in the first ten years (the first period). The mean annual rainfall in the first period was 2,718.5 mm fell to 2,531.7 mm in the second period. The annual rainfall fluctuation is showed in Figure 2.

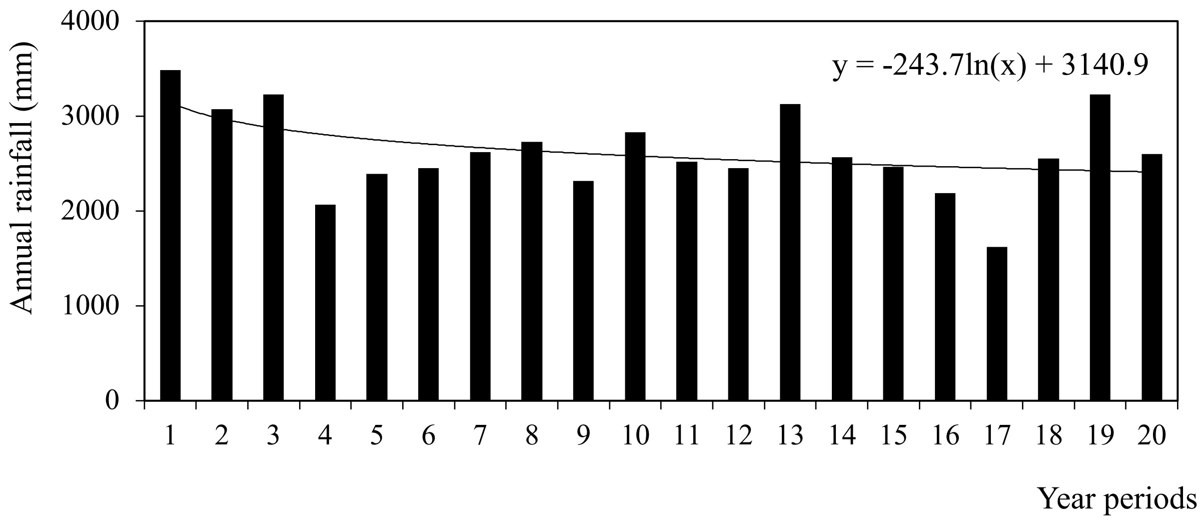

Figure 2. The annual rainfall oscillation in Susilo rainfall station.

According to the number of wet months in Figure 3, it shows the occurrence of seasonal shifts. The number of wet months that originally occurred throughout the first year even reached only three months in 2014. In addition, the declining number of wet months means dry months (known as the dry season) being longer than in the first year. Ordinarily, an increase in the dry month will raise the risk of drought.

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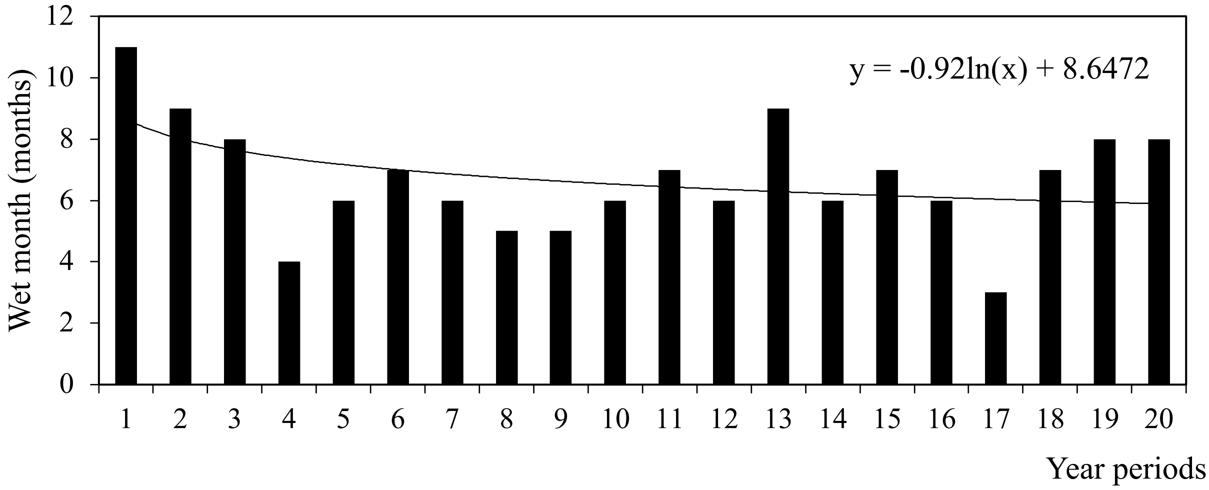

Figure 3. The fluctuation of total wet months in Susilo rainfall station.

The Jemelak Subwatershed that located near the equator line was causing rain events happening throughout the year, even at the peak of the dry season. Although the amount of annual rainfall and wet months explained above experienced a decline during the years of observation, however, the maximum daily rainfall increases in the inter-annual ranges (Figure 4). In more detail, the maximum daily rainfall increased in the first decade and decreased in the second decade. In several studies, it was mentioned that climate change caused more intense precipitation events as well as peak precipitation intensities (Supari et al. 2017). The intense rainfall can lead to the occurrence of hydro-meteorology disasters such as erosion, sedimentation, landslide, flood, and flash flood. The physical condition of each watershed will significantly influence the risk of such disasters.

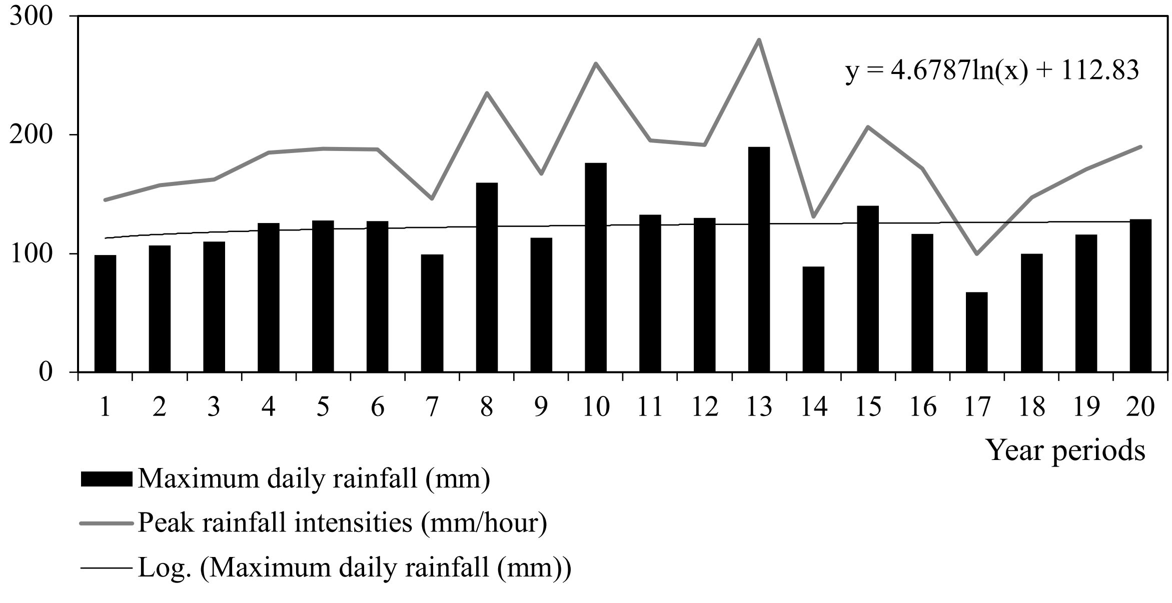

Figure 4. The maximum daily rainfall and rainfall intensity distribution.

Instead of the value of maximum daily rainfall intensity value, the maximum rainfall intensity is more critical in the peak discharge estimation. Accordingly, the maximum rainfall changes will be followed by changes in the maximum rainfall intensity. The trend of maximum rainfall intensities is increased in the first decade, while in the second decade is decreased (Figure 4). This maximum rainfall intensity was eventually used to calculate the peak discharge.

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Land Cover Change

Land coverage as a dynamic parameter is strongly influenced by anthropogenic activity. Population growth is pressuring the forest indirectly. The land cover in 1990 was divided into 30.6% secondary swamp forest, 20.3% plantations, 43.2% shrubs, 3.5% dryland agriculture mixed shrubs, 2% settlement, 0.1% mining land, and 0.3% swamp shrubs. There were very significant changes in land cover on the secondary swamp forest and dryland agriculture mixed shrubs, as shown in Figure 5 and Table 2.

Secondary swamp forest shrunk drastically in 2006 of about 705.9 ha (43.97%), followed by the growth of shrubs and swamp shrubs. This was caused by forest fires. Some forests in the Jemelak watershed are part of the Baning Nature Park, which is managed by the Natural Resources Conservation Center (BKSDA) in West Kalimantan. This area is indeed prone to forest and land fires. Burnt land experienced a succession that led to the emergence of shrubs and swamp shrubs.

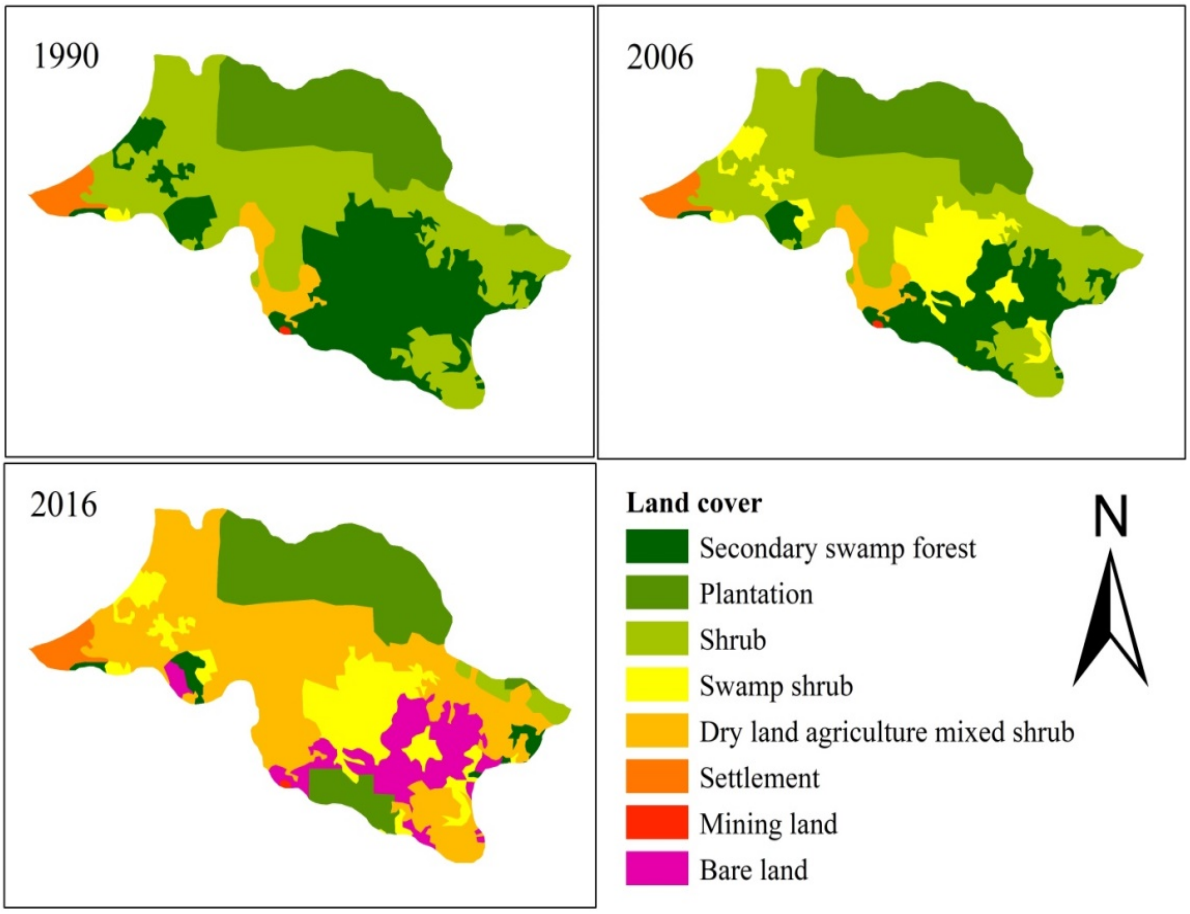

Figure 5. Land cover changes of Jemelak Subwatershed.

The second shift in the function of secondary swamp forests occurred in 2016. About 800.71 ha of secondary swamp forest tuned into 582.80 ha of bare land, 181.04 ha of a plantation, and 36.88 ha of swamp shrubs. The amount of bare land in 2016 is intended as a settlement area. Furthermore, the conversion of 95.15% of shrubs into agricultural land mixed with shrubs was also seen. The dry season which was occurring longer than in the first year causing the community to expand their farmland. They did the shrubs clearing to be dryland agriculture.

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Table 2. Land cover change in Jemelak Subwatershed.

No	Land cover	Coverage area (Ha)		
		1990	2006	2016
1	Secondary swamp forest	1,605.34	899.43	98.71
2	Plantations	1,067.21	1,067.21	1,248.85
3	Shrubs	2,271.54	2,275.13	95.15
4	Swamp shrubs	16.35	718.67	754.94
5	Dryland agriculture mixed shrubs	182.23	182.23	2,362.21
6	Settlement	107.17	107.17	107.17
7	Mining land	4.45	4.45	4.45
8	Bare land	0	0	582.80
	Total area	5,254.28	5,254.28	5,254.28

In general, there has been a 93.85% decrease in a secondary swamp forest area during 1990-2016. Due to its capability to store a large amount of carbon, peat swamp forest conversion into other land use is causing a decrease in carbon stock (Rochmayanto et al. 2010). Moreover, the most significant contributor to climate change is carbon emissions that are released into the atmosphere. Accordingly, reducing the rate of deforestation will contribute to holding climate change (Lawrence and Vandecar 2015).

Impact of Land Cover and Precipitation on Peak Discharge Prediction

Knowledge of basic watershed characteristics could provides valuable information for managing and protecting water resources. Based on the DEM/SRTM spatial extraction, the length of the main river in the Jemelak Subwatershed is 7.88 km, while the drainage density is 0.86 km/km^2. Peak discharge associated with the runoff coefficient. This research used the Cook method in runoff coefficient determination which regards to slope, infiltration, land cover, and drainage density. Of those parameters, the land cover was the only parameter that changes during the observation. Furthermore, changes to the land cover affected the increment of the runoff coefficient value from 0.49 in 1990 became 0.50 in 2006 and continued into 0.64 in 2016. The increase of peak discharge would follow the changes in the runoff coefficient value.

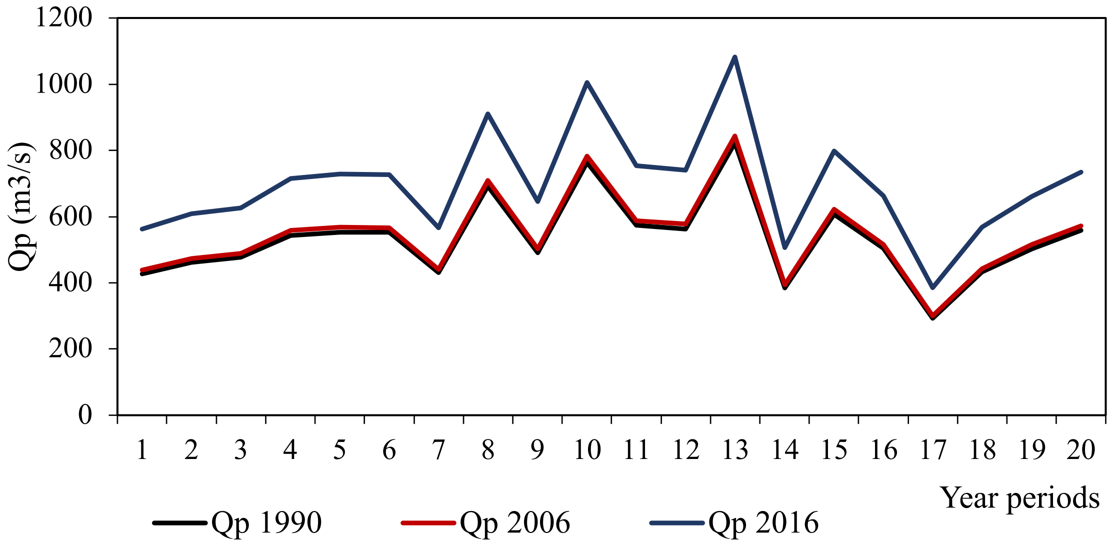

Figure 6. Peak discharge (Qp) fluctuations in Jemelak Subwatershed.

Not only rainfall as the primary input, but peak discharge also depends on the watershed properties. Even without precipitation and evapotranspiration, streamflow (also called discharge) is continuously changing due to the changes in land use and land cover. Accordingly, changes in the rainfall and land cover at once would be more oscillate the peak discharge. In detail, the peak discharge of Jemelak Subwatershed is presented in Figure 6. Moreover, the changes in the maximum daily rainfall and land cover increased the peak discharge by about 2.53% in the first period and 28.30% in the second period. This occurred due to the secondary swamp forest degradation. In forest land cover, most raindrops pass through vegetation before reaching the ground is called interception. Some intercepted raindrops never reach the ground because it is evaporated back to the atmosphere. In addition, intense rainfall events have a larger raindrop that drives through the canopy more easily (Edwards et al. 2015). Reversely, In the agricultural land cover, raindrops may be transferred to become streamflow quickly. If the streamflow exceeds its capacity, then the local flooding will occur along the river border.

CONCLUSIONS

The maximum daily rainfall data from 1998 to 2017 were divided into two periods of 10 years and analyzed. The result showed that maximum rainfall in the first period ranges from 98.6 to 176.3 mm, while the second period fluctuates over 67.6 to 190 mm. Analysis of land cover described that 43.97% of secondary swamp forests turned into shrubs and swamp shrubs in the first period. Furthermore, about 800.71 ha of secondary swamp forest tuned into 582.80 ha of bare land, 181.04 ha of a plantation, and 36.88 ha of swamp shrubs in the second period. About 95.15% of shrubs were also turned into agricultural land mixed with shrubs in the second period. Maximum daily rainfall and land cover changes turn into agricultural area simultaneously affected the improvement of the peak discharge. Peak discharge in Jemelak Subwatershed was increased, especially in the last ten years. The increment of peak discharge was about 2.53% in the first period and 28.30% in the second period. If the peak discharge exceeds the river capacity, then the local flooding will occur along the river border.

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