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Research Article

Temporal distribution of sediment yield from catchments covered by different pine plantation areas

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Abstract: Soil erosion and sedimentation are environmental problems faced by tropical countries. Many researches on soil erosion-sedimentation have been conducted with various results. Quantifying soil erosion-sedimentation and its temporal distribution are important for watershed management. Therefore, a study with the objective to quantify the amount of suspended sediment from catchments under various pine plantation areas was conducted. The research was undertaken during 2010 to 2017 in seven catchments with various percentage of pine coverage in Kebumen Regency, Central Java Province. The rainfall data were collected from two rainfall stations. A tide gauge was installed at the outlet of each catchment to monitor stream water level. The water samples for every stream water level increment were analyzed to obtain sediment concentration. The results showed that monthly suspended sediment of the catchments was high in January to April and October to December, and low in May to September. The annual suspended sediment fluctuated during the study period. Non-linear correlations were observed between suspended sediment and rainfall as well as suspended sediment and percentage pine areas. The line trend between suspended sediment and percentage of pine areas showed that the increase in pine areas decreased suspended sediment, with the slope of the graph is sharp at the percentage of pine areas from 8% to 40%, then is gentle for pine plantation areas more than 40%.

Keywords: *area coverage, pine plantation, sediment, soil erosion*

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Introduction

Soil erosion by water has been one of environmental problems faced by tropical countries. Onsite impact of soil erosion causes loss of A horizon including nutrients content (Shi et al., 2013). This condition leads to decrease of land productivity. The offsite effect at the middle and lower of a watershed, the soil resulting from erosion process increases suspended sediment in the rivers (Fu et al., 2011; Wang et al., 2009).

The suspended sediment can be from various soil erosions which are sheet, riil, as well as gully erosions (Diodato et al., 2015). In addition to those types of erosion, streambank erosion can be source of suspended sediment as observed by Basuki (2017) and Rijsdijk et al. (2007). Regarding to the streambank erosion, Rijsdijk et al. (2007) have examined that the contribution of streambank erosion on sediment yield reached 8% at the upper Konto watershed in East Java.

Sediment in the river bodies will cause siltation, flooding in rainy seasons, as well as decrease quality of aquatic ecosystem (Bussi et al., 2014; Zhao et al., 2013). The increase of sediment content in the river flows leads to water eutriphication (Wang et al., 2009). Vilmin et al. (2015) have observed that the suspended sediment in river bodies will decrease aquatic ecosystem because the sediment flows will carry nutrients content including organic matter, pathogen, and metal compounds from the upper to the lower of river basin.

Soil erosion as well as sediment yield are not only affected by human induced, but also some biophysical properties of the catchment such as topography, characteristics of rainfall and soil (Phomcha et al., 2011). Quantifying the amount of sediment is useful for designing of soil and water conservation, estimating life span of a reservoir, and other processes related to watershed management planning (Mukundan et al., 2013; Ranzi et al., 2012).

Soil erosion as a source of sediment, is generally low in watersheds covered by forest with litter coverage on the forest floor (Sagha et al., 2014). Ngo et al. (2015) have studied that land cover conversion from forest into agricultural area and urban has caused increase in sediment from 101.3 t/ha to 148.1 t/ha in 1995 to 2005 in Da watershed in Northwest of Vietnam. At the same site, due to reforestation and soil conservation practices in 2005 to 2010, then the sediment yield decreased from 148.1 to 74.0 t/ha (Ngo et al., 2015). Although the impact of forest cover on sediment yield has been studied for long time, the results varied. Basuki (2017) has studied that forest cover is not a single factor affecting sediment yield, but other land cover together with forest area will affect the sediment of a catchment. Based on a research conducted by Basuki (2017), suspended sediment in outlet of a catchment with 53% of old teak coverage was lower than a catchment with 70% old teak coverage due to differences in other land covers such as paddy field.

Research on the relationship between forest area and sediment yield is still limited, especially pine plantation in a tropical region. Therefore, this research has been conducted to study distribution of suspended sediment at catchments with various of pine forest areas.

Materials and Methods

Description of the study site

The research was undertaken in seven catchments with various percentage of pine coverage. The seven catchments were Kalipoh, Watujali, Lowereng, Kedungbulus, Kedungpane, Pasuruan, and Tapak Gajah. The pine plantations of the study areas are managed by Forest Management Unit (KPH), Perum Perhutani Unit I, Central Java. The studied catchments are situated at 336000 m East – 345000 m East and 9162500 m South – 9170000 m South. The study areas are, administratively, under management of Kebumen Regency, Central Java Province.

The main river and its branches is shown in Figure 1. Location of the outlet for each catchment can be seen in Figure 1. Six of the catchments are inside the big catchment, which is Kedungbulus catchment. The lowest outlet is Kedungbulus catchment as presented in Figure 1. The percentage areas of land covers for each catchment are provided in Table 1.

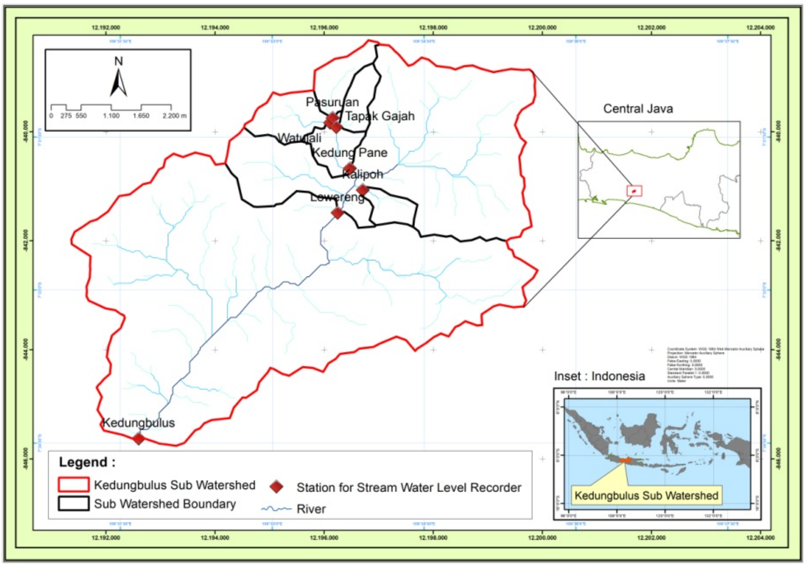


Figure 1. Situation map of the study area
Source: Modified from Pramono et al (2017)

Table 1. The percentage of land covers of the observed catchments

Land cover	Kalipoh	Watujali	Kedungbulus	Lowereng	Kedungpane	Pasuruan	Tapak Gajah
Pine plantation	95	75	47	43	39	29	8
Mix garden	0	0	30	32	50	52	76
Bareland	0	1	1	0	1	0	0
Grassland	4	5	1	1	0	5	1
Settlement	0	0	2	2	2	5	4
Paddy field	0	0	9	15	0	0	2
Shrub	0	19	7	6	8	8	9
Water body	0	0	1	0	0	0	0
Cloud	0	0	2	0	0	0	0
Total	100	100	100	100	100	100	100

Source: Modified from Pramono et al. (2017).

Data collection

The data were collected from 2010 to 2017. The rainfall data were collected from two rainfall stations inside Kedungbulus catchment. The rainfall stations are located at Silengkong and at Kedungbulus. In 2012 only rainfall data from Kedungbulus station were used in the research. At the outlet of each catchment, a tide gauge was installed to monitor stream water level. For every increment of stream water level, then a water sample was taken from outlet of each catchment. The water samples were analyzed in laboratory to obtain the amount of suspended sediment. The suspended sediment concentration of the water samples were used to built sediment discharge rating curve for every catchment. The formulas were used to convert stream water discharge into suspended sediment.

Data analysis

Paired T-test was performed to know whether the rainfall data from Silengkong and Kedungbulus stations were not statistically different. Afterwards, the data were averaged and used for further analysis.The Paired T-test was also applied to know the differences of mean monthly suspended sediment during the study period between two catcments. Daily suspended sediment data were obtained by conversion of stream water discharge using sediment discharge rating curve. The formulas of sediment discharge rating curves of the studied catchments are presented below. The sediment discharge data were converted into t/ha by considering the area of each catchment.

Kalipoh : $Qs = 8,417*Q^{\wedge 2,199}$............(1)*
Silengkong : $Qs = 2,762*Q^{\wedge 2,356}$...........(2)*
Watujali : $Qs = 1,044*Q^{\wedge 1,697}$...........(3)
Kedungbulus : $Qs = 1,701*Q^{\wedge 0,762}$..........(4)*
Lowereng : $Qs = 1,144*Q^{\wedge 2,241}$..........(6)
Kedungpane : $Qs = 1,311*Q^{\wedge 1,045}$..........(7)
Pasuruan : $Qs = 3,517*Q^{\wedge 0,782}$..........(8)
Tapak Gajah : $Qs = 2,647*Q^{\wedge 0,733}$..........(9)

Note:
Qs = Sediment discharge (kg/second)
Q = Discharge (m^3/second)
Source: Primary data analysis
*)Watershed Management Technology Center (unpublished data)

Results and Discussion

Temporal distribution of rainfall

Annual rainfall data of the study areas are illustrated in Figure 2. The graph shows that the highest rainfall occurred in 2010 and the driest happened in 2012.

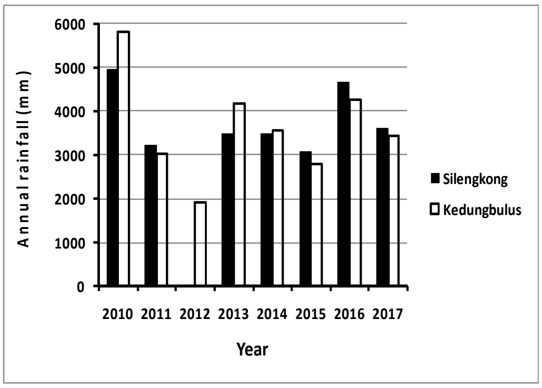


Figure 2. Annual rainfall at two stations of the study area
Source: Primary data analysis

Based on Paired T-test, it was found that on the monthly bases the data were not significantly different for 95% confidence interval. The results of the Paired T-test are in Table 2. Only in 2010 monthly rainfall between Silengkong station and Kedungbulus station is significantly different at 95% confidance interval. Temporal monthly rainfall distribution is graphed and illustrated in Figure 3. It can be seen that starting in April the amount of rainfall decreased and in September the rainfall increased. In general, the driest month occurred in August or July. An exception occurred in 2015, the dry period occurred from July to October. The wet seasons usually occurred in January to April and October to December.

Table 2. Paired T-test at 95% confidence interval, two tailed between monthly rainfall of Silengkong and Kedungbulus stations

No	**Year**	**p-value at 95% confidence interval**
1	2010	0,001
2	2011	0,601
3	2012	*)
4	2013	0,157
5	2014	0,842
6	2015	0,279
7	2016	0,238
8	2017	0,635

Source: Primary data analysis
Note : *) data only from Kedungbulus station

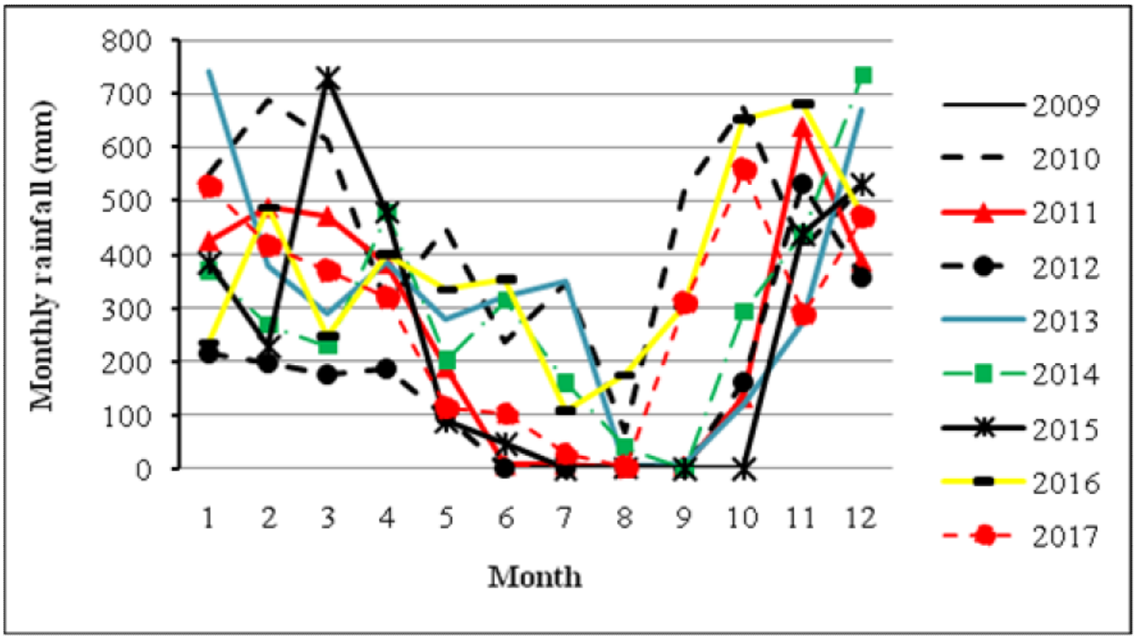


Figure 3. The mean annual rainfall of the study area
Source: Primary data analysis

Relationship between rainfall and suspended sediment

The relationships between mean monthly rainfall and mean monthly suspended sediment of the observed catchments are provided in Figure 4. Non linear correlations are shown between these parameters for all of the catchments. The coefficient of determinations are high, the lowest is found in Watujali catchment (0.73) and the highest in Tapak Gajah (0.95). Wei et al. (2009) have observed that rainfall is the most determining factor of soil erosion which is the source of sediment in the river body. In this regards, the relation between rainfall and sediment yield is driven by the erosivity of rainfall or the erosive force of rainfall from the kinetic energy created by rainfall drop (Meusburger et al., 2012). This is in line with our research finding, the increase of monthly rainfall was followed by the increase in suspended sediment as illustrated in Figure 5. Martínez-murillo (2013) have found that rainfall intensity, runoff coefficient, and slope steepness as well as rainfall depth (Nu-Fang et al., 2011) have strong impact on sediment yield. Mean monthly rainfall together with monthly suspended sediment of the catchments from 2010 to 2017 are presented in

Figure 5. In general, the increase of rainfall causes the increase of suspended sediment. High suspended sediment tended to occur in Januari to April and in October to December. However, in the dry year such as in 2012 low suspended sediment was observed, even in Januari to April. On the contrary, at the wet years such as in 2010, 2016, 2017, suspended sediment was produced for all of the months eventhough in June to August which are ussually dry periods. These conditions are especially in the catchments with low percentage of pine coverage such as in Kedungpane, Pasuruan, and Tapak Gajah. The existence of suspended sediment during June to August in the studied catchments because at that time there were still rainfall. The information when the suspended sediment is high can be used for improving application soil conservation practice before rainfall season happen in order to prevent or reduce severe erosion-sedimentation.

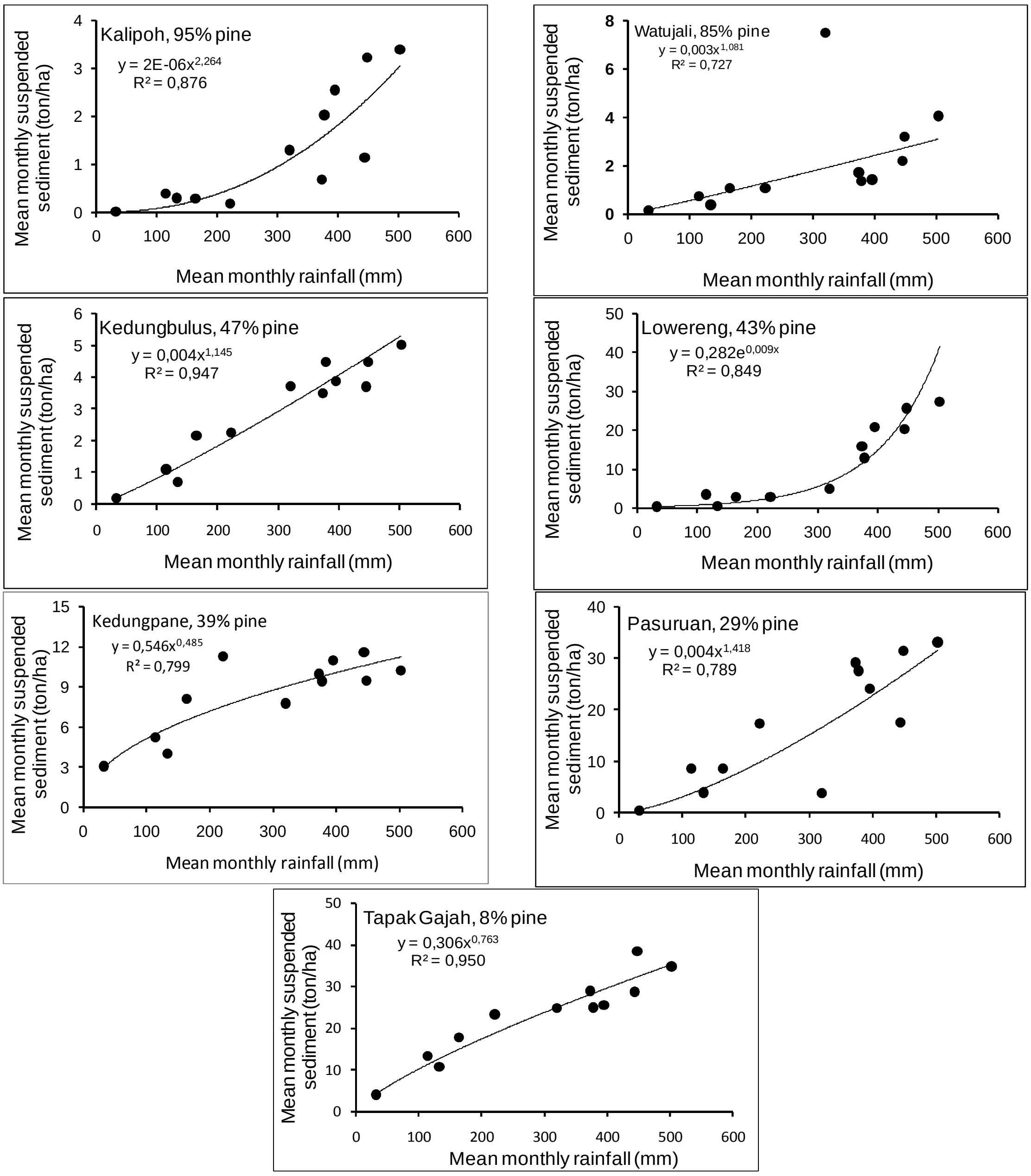
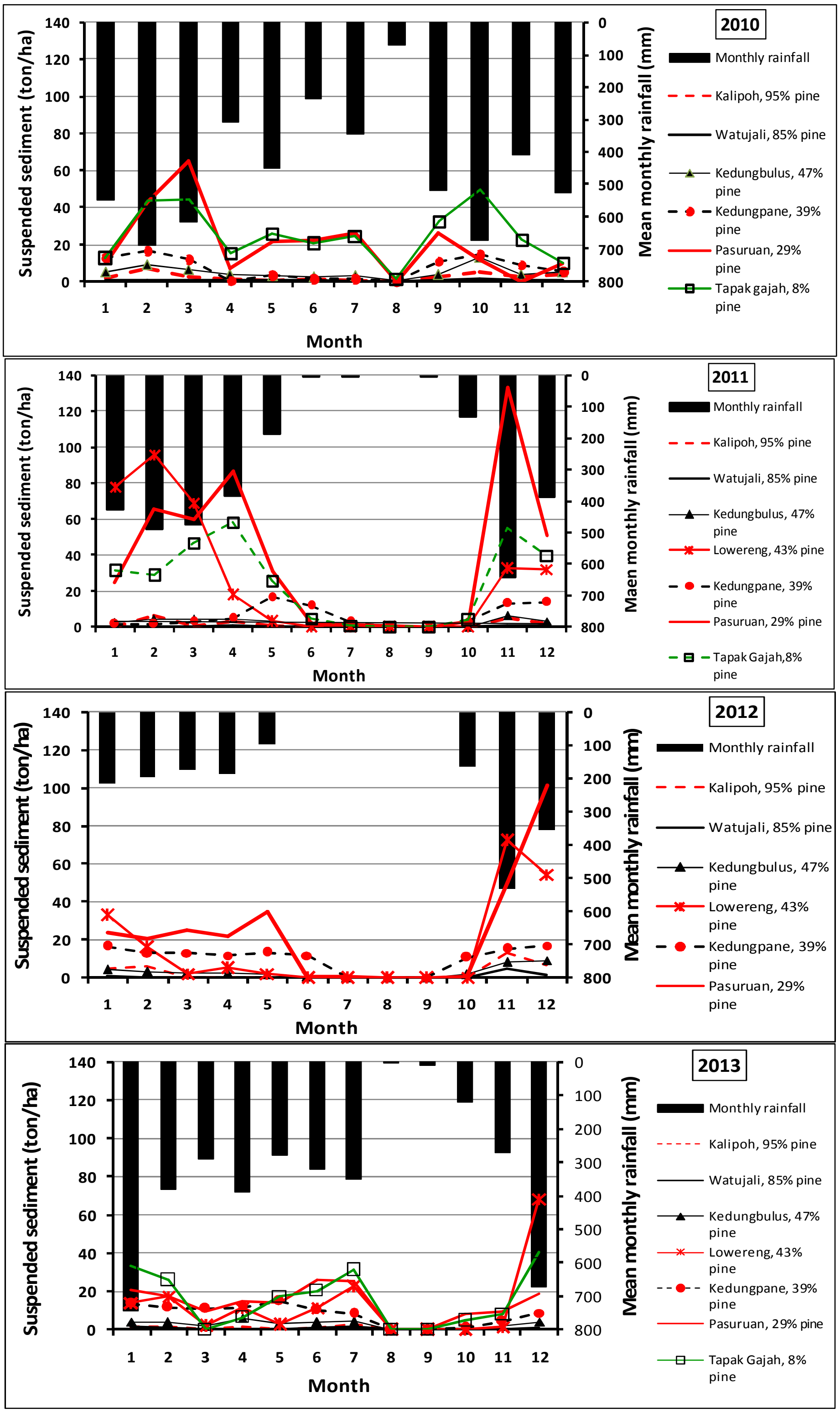


Figure 4. The relationship of mean monthly rainfall (mm) and mean monthly suspended sediment (t/ha)
Source: Primary data analysis


2010
Suspended sediment (ton/ha)
Mean monthly rainfall (mm)
Month
Monthly rainfall
Kalipoh, 95% pine
Watujali, 85% pine
Kedungbulus, 47% pine
Kedungpane, 39% pine
Pasuruan, 29% pine
Tapak gajah, 8% pine
2011
Suspended sediment (ton/ha)
Maen monthly rainfall (mm)
Month
Monthly rainfall
Kalipoh, 95% pine
Watujali, 85% pine
Kedungbulus, 47% pine
Lowereng, 43% pine
Kedungpane, 39% pine
Pasuruan, 29% pine
Tapak Gajah,8% pine
2012
Suspended sediment (ton/ha)
Mean monthly rainfall (mm)
Month
Monthly rainfall
Kalipoh, 95% pine
Watujali, 85% pine
Kedungbulus, 47% pine
Lowereng, 43% pine
Kedungpane, 39% pine
Pasuruan, 29% pine
2013
Suspended sediment (ton/ha)
Mean monthly rainfall (mm)
Month
Monthly rainfall
Kalipoh, 95% pine
Watujali, 85% pine
Kedungbulus, 47% pine
Lowereng, 43% pine
Kedungpane, 39% pine
Pasuruan, 29% pine
Tapak Gajah, 8% pine

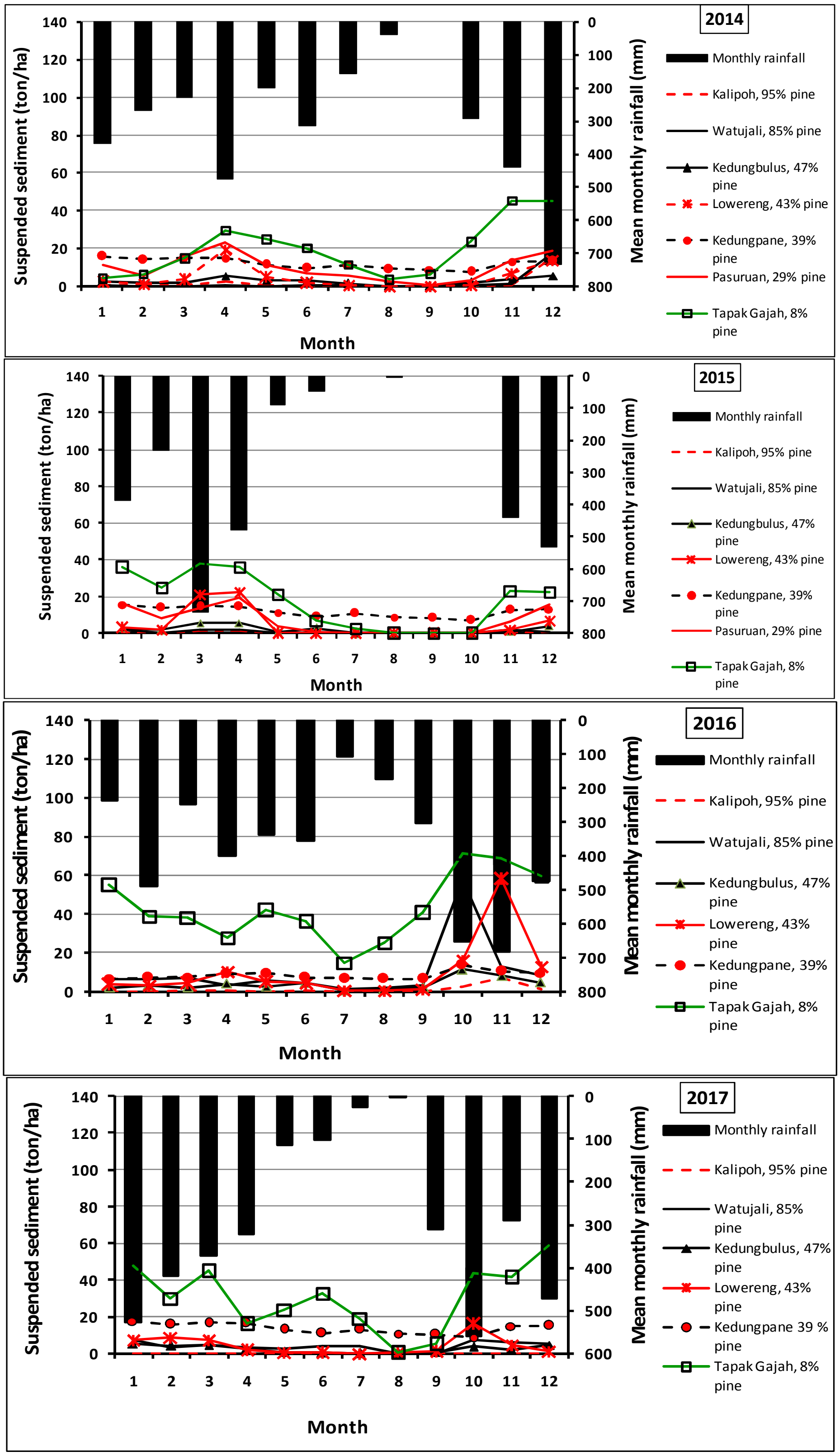


Figure 5. Temporal distribution of monthly rainfall and suspended sediment of the catchments
Source: Primary data analysis

Suspended sediment from catchments with various pine areas

Based on Figure 5, it can be examined that monthly suspended sediment for every year between Kalipoh catchment (95% pine coverage) and Watujali catchment (85% pine coverage) is similar. Based on Paired T-test at 95% confidence interval, the mean monthly suspended sediment of Kalipoh and Watujali is not different significantly (Table 3). However, suspended sediment between Kalipoh or Watujali catchment with the other observed catcments are significantly different. The results of statitical analysis of the catchments can be seen in Table 3. A little bit higher of suspended sediment compared to Kalipoh and Watujali catchments was found in Kedungbulus catchment with pine coverage of 47%. High suspended sediment was produced by four catchments which are Lowereng, Kedungpane, Pasuruan, and Tapak Gajah. Although sometimes catchment with higher pine plantation has higher suspended sediment content than the catchment with a lower pine plantation, generally, the highest suspended sediment among the last four catchments was found in Tapak Gajah catchment, which only has 8% of pine plantation areas.

Table 3. Paired T-test at 95% confidence interval of mean monthly suspended sediment of the observed catchment

No	Catchment	p-value
1	Kalipoh-Watujali	0.156
2	Kalipoh-Kedungbulus	0.000
3	Kalipoh-Lowereng	0.003
4	Kalipoh-Kedungpane	0.000
5	Kalipoh-Pasuruan	0.000
6	Kalipoh-Tapak Gajah	0.000
7	Watujali-Kedungbulus	0.002
8	Watujali-Lowereng	0.004
9	Watujali-Kedungpane	0.000
10	Watujali-Pasuruan	0.001
11	Watujali-Tapak Gajah	0.000
12	Kedungbulus-lowerng	0.007
13	Kedungbulus-Kedungpane	0.000
14	Kedungbulus-Pasuruan	0.001
15	Kedungbulus-Tapak Gajah	0.000
16	Lowereng-Kedungpane	0.497
17	Lowereng-Pasuruan	0.002
18	Lowereng-Tapak Gajah	0.000
19	Kedungpane-Pasuruan	0.013
20	Kedungpane-Tapak Gajah	0.000
21	Pasuruan-Tapak Gajah	0.057

A possible reason a catchment with a higher forest or plantation cover has a higher sediment yield than a catchment with lower forest or plantation cover is the occurance of stream bank erosion. One of sources of suspended sediment in river bodies is stream bank erosion as found by Basuki (2017) in some catchments with teak plantations. For the studied catchments, therefore, soil conservation practices should not only be foccused on cultivation areas, but also on the river banks.

The effect of landuse or land cover on sediment yield has been studied previously. Yan et al. (2013) have studied at the upper Du Watershed at China and have found that the dominant factors influenting fluctuation of sediment yield is the existence of farmland followed by forest area. They have measured a strong coefficient of determination between streamflow and sediment yield with the proportional of farmland (R^2 values of 0.99 and 0.98) and a negative relationship between the forest areas and streamflow and sediment yield (R^2 is 0.83 and 0.88).

In addition, Quiñonero-rubio et al. (2014) have examined the effectiveness of forest restoration and check dams on sediment yield at the upper Taibilla catchment, South East Spain. They have found that land use changes alone reduced sediment yielded up to 14%, and the sediment decreased when restoration was combined with check-dams, the reduction in sediment yield reached 44 ± 6%. The mean annual suspended sediment is provided in Figure 6. During the study period, from 2010 to 2013, the highest suspended sediment was found in Pasuruan catcment, however starting 2014 until 2017, the highest suspended sediment was observed in Tapak Gajah catchment with pine plantation coverage of 8%. Due to equipments damage and lack of observation, then data for certain years cannot be presented.

Relationship between percentage of pine plantation area of the observed catcments and mean annual suspended sediment is shown in Figure 7. Based on this figure, it can be seen non linear correlation between the two parameters. The line trend shows the increase in pine areas cause decrease suspended sediment. The slope of the graph is sharp at percentage of pine areas from 8% to 40%, then gentle after 40% pine coverage. The graph shows that the change in pine plantation coverage from 8% to 40% will change strongly the suspended sediment, and after more than 40% the change of pine coverage will not drastically change in suspended sediment. The sediment data are the average values from 2010 to 2017.

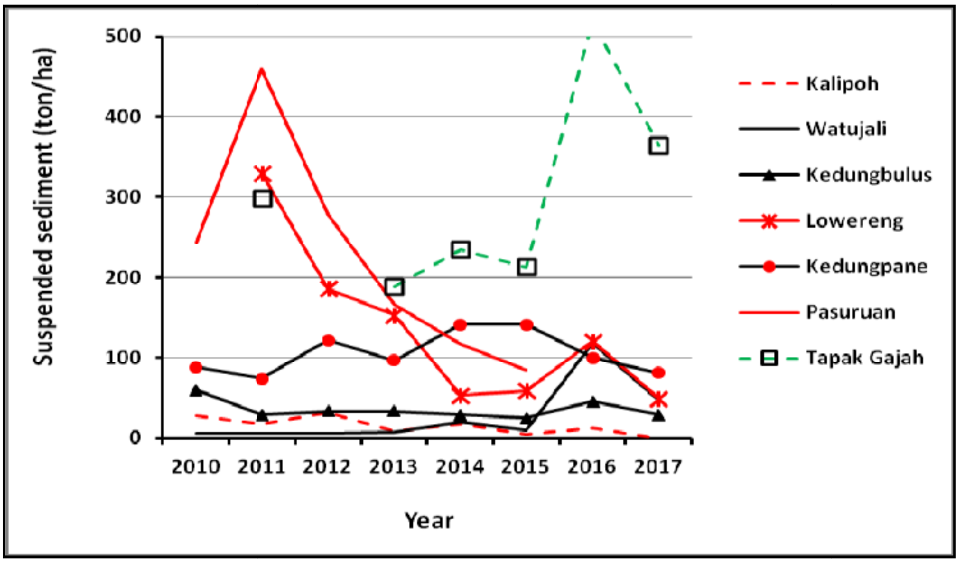


Figure 6. Annual suspended sediment of the observed catchments
Source : Primary data analysis
Note : No data in 2010 at Lowereng, 2010 and 2012 at Tapak Gajah, and after 2016 at Pasuruan catchments

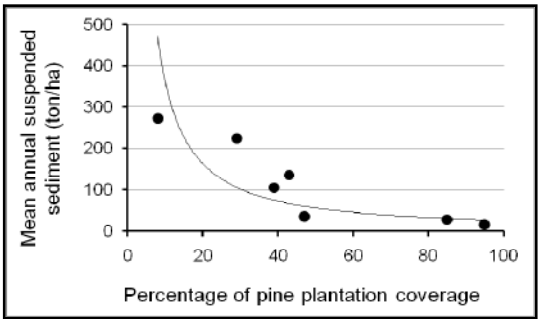


Figure 7. The scatter plot of plantation area vs mean annual suspended sediment

Source: Primary data analysis

Conclusions

Commonly, the suspended sediments of the observed catchments tended to be high in Januari to April and in October to December. Low suspended sediment commonly was found in May to September. During the study period, the highest annual suspended sediment occurred in Tapak Gajah catcment with pine plantation coverage 8% which occurred in 2016. The lowest suspended sediment was found in Kalipoh catchment with pine plantation coverage of 95% in 2017. Non-linear correlation was found between mean monthly rainfall and mean monthly suspended sediment with high coefficient of determination. For annual bases, the change in pine plantation coverage areas from 8% to 40% will change drastically the suspended sediment, and after more than 40%, the change of pine coverage areas will not drastically alter the suspended sediment.

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