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Base flow from various area of pine forest at Kedungbulus sub watershed, Kebumen District, Central Java, Indonesia

I.B. Pramono [1]*, M.Th.S. Budiastuti [2], T. Gunawan [3], Wiryanto [4]

[1] *Environmental Science, Sebelas Maret University (UNS) and Watershed Management Technology Center, Jl.A.Yani Pabelan, P.O.Box 295 Surakarta, Indonesia*
[2] *Faculty of Agriculture, Sebelas Maret University (UNS), Jalan Ir. Sutami No. 36A, Jebres, Surakarta ,Indonesia*
[3] *Faculty of Geography, Gadjah Mada University (UGM), Sekip Utara, Bulaksumur, Sinduadi, Sleman, Yogyakarta, Indonesia*
[4] *Faculty of Mathematic and Natural Science, Sebelas Maret University (UNS), Jalan Ir. Sutami No. 36A, Jebres, Surakarta, 57126, Indonesia*

Abstract

Many factors affect the existence of base flow such as geological type, slope, soil type, climate, and land cover. Among these factors, land cover is the only factor that can be managed. Therefore, a research has been counducted in order to find the effect of pine forest area on base flow, base flow index, and low flow. Five sub watersheds with different pine forest cover areas are used for analyzing the base flow and low flow. Base flow was separated from total flow using *Hydro Office package software* BFI+30, while low flows were measured directly during dry season. The results showed that the relationship between the area of pine forests and base flow has three patterns andit depends on daily rainfall. When daily rainfall is high (>70 mm), there was a positive correlation, which means the larger the forest the bigger the base flow. On the other hand, when the daily rainfallwas medium (40-70 mm), there is no correlation between the area and base flow, while at the low daily rainfall is which is less than 40 mm, the correlation is negative. In addition, there wasa positive correlation between pine forest area and base flow index (BFI). The higher the BFI value, the better the water storage. The average values of BFI were 0.55 and 0.75 for 43% and 75% pine forest coverage, respectively. The pine forest was still able to hold water in the rainy season and released it in the dry season. Positive correlations between pine forest area and low flow was observed during 2012 to 2015. In order to increase base flow and low flow in pine forest, water conservation measures should be implemented in forested area such as terraces and water trap.

Keywords: Base Flow, Low Flow, Pine Forest, Watershed, Indonesia

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* Corresponding author. *E-mail address:* ibpramono@yahoo.com

1. Introduction

Kebumen district, Central Java, Indonesia often has problems in water management that are flooding in rainy season and drought in dry season. Raharjo (2010) in his research in Kebumenhas examined that some sub-districts like Karanggayam, Karangsambung, Sadang, Alian, Puring, Klirong, BulusPesantren, Ambal, and Mirit have drought problem. In this case, pine forest is suspected to create drought problem in those districts.The pine forests ranksthe second largest forest in Java after teak.The teak forests occupy an area of 1,000,534 ha or 67.4%, while the pine forests occupy an area of 483 272 ha or 32.6% of the forest area in Java (Perhutani, 2014). The pine forests are planted in upstream of a watershed. Therefore the forests have influence for water system. Bruijnzeel (2004) in reviewing the role of forests in a water system has expalined that despite reducing a severe flooding, the implementation of reforestation and soil conservation in the uplands will increase low flow. However, that evident has not yet documented, and therefore low flows problem needs further researches since it is identified as the most important factor in watershed management to fulfill continuous raw water availability.

Effects of forests on low flow have not well been known. The low flow is important for water needs, both for households and industrials. This continuation of low flow is needed along with increase water demand. During the dry season, the water stored in the watershed decrease because the process of evapotranspiration and drying via groundwater. Knowledge of low flow is very important for understanding of water balance and watershed responses (Tallaksen, 1995). Yue and Hashino (2005) have stated that the effects of forests on the total flow, the flood peak and low flows should be examined closely. Over assessment of the function of forests will lead to wrong decisions in the management of water resources that could potentially cause dryness. FAO & CIFOR (2005) have emphasized that storage water in forests is not simple as giant “sponges soaking up water during heavy rainfall and releasing fresh water slowly during dry month, but the reality is far more complex.

Besides land cover, others factor influencing the base flow are geology, slope, soil type, climate, and land cover. The geological factor is the main factor that controls the base flow (Price, 2011; Smaktin, 2001; Bloomfield et al., 2009). Johnson (1998) has observed that geology, soil and slope are important in determining the magnitude of the base flow. Sănchez_Murillo et al. (2014) mentioned that mean basin slope and the aridity index were found to be the best estimators of base flow coefficients. It is in agreement with Djuwarsah (2006) that has found the geological aspect generally has a strong influence on the hydrological function of an area while the other factor is land cover. Ala-Aho et al. (2015) has concluded that unsaturated thickness and vegetation cover are important to estimate recharge in sandy unconfined aquifer, while Ahiablame et al. (2013) have stated that base flow is influenced by watershed area and precipitation.

Quantifying the effects of land use change on water availability is essential, particularly when communities dependent on limited water sources. Thist is usually more vulnerable to inter annual fluctuations in precipitation and also to climate change. Based on the results of the above studies there is still a gap of research on base flow ofpine forest areas, especially in the tropics. For the presence of pine forests in regulating the water system, it needs a study in the ability of pine forest in delivering water during dry season.

2. Method

2.1. Description of the study area

Kedungbulus watershed was chosen as the study area, because this watershed can be devide into several sub watershed which are covered by various percentage of pine forests. These forestsare managed by PT Perhutani I which is a State Forest Corporation. The watershed is located between 336000 m East – 345000 m East and 9162500 m South – 9170000 m South. The study area is belongs to Kebumen Regency, Central Java Province, Indonesia. Figure 1 presents the situation map of the study area.

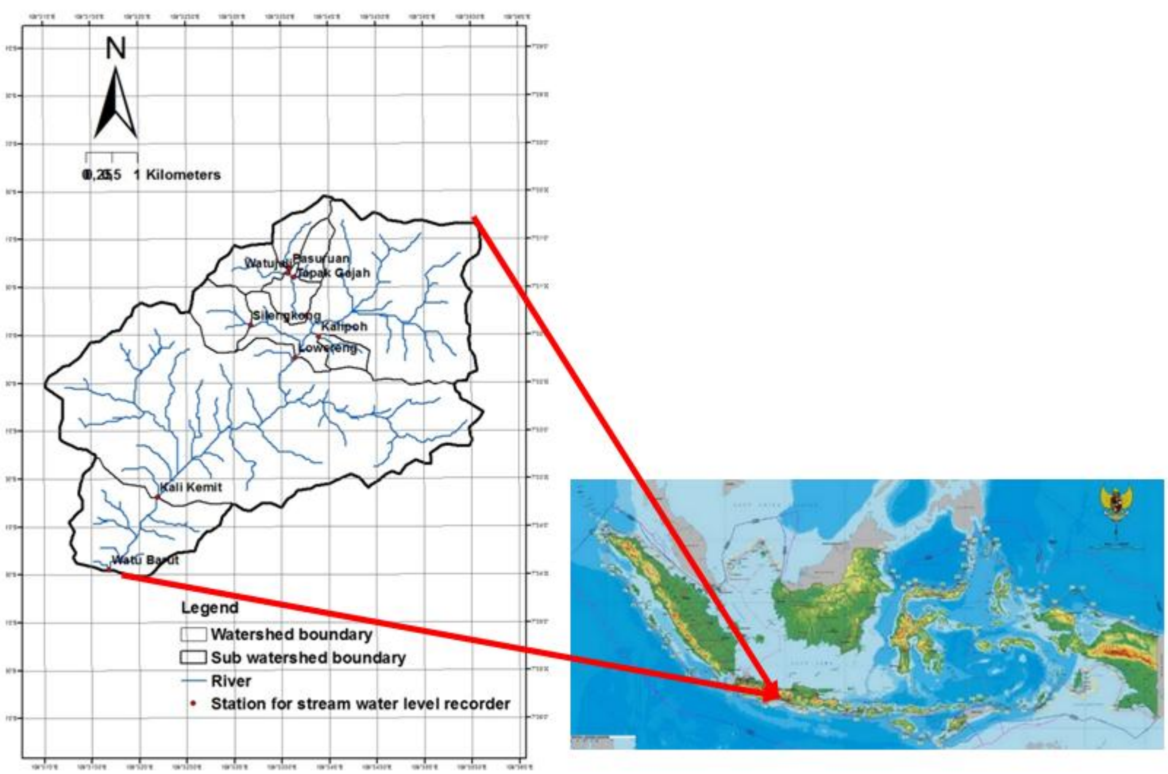


Figure 1. Situation map of the study area

2.2. Methodological approach and steps

Watershed units are used to observed baseflow. Each outlet of the sub watershed was installed water level monitor by logger. The methodology used to develop the relationship between pine forest area and base flow entails the following steps:

1- Land covers classification. This step requires satellite imagery (*World View* images and IKONOS image from Google Earth) and field observation (measuring pine forest characteristics).

2- Watershed characterization. This characteristics are derived from DEM (Digital Elevation Model) image of SRTM (Shuttle Radar Thermal Mission).

3- Base flow separation and determination of base flow index using a recursive digital filter technique for base flow separation. The base flow was separated using software package “Hydro Office ”BFI + 3.0 (Gregor, 2010). The software was also used to calculate base flow index.

4- Development of regression equations to obtain relationship between pine forest area and specific base flow (during rainy season), specific low flow (during dry season), and base flow index.

2.2.1. Land cover classification

To obtained spatial distribution of land cover, Worldview image 2012 and IKONOS image from google Earth were used. The spatial resolution of the images are 1 by 1 m. Land cover classification was carried out by on screen digitizing. Ground check of the classification results was conducted in 2015. Figure 2 presents the result of land cover classification. Along with field check of land cover, characteristics of the pine forests were measured.

In addition, secondary data were collected at that time. Observations and measurements characteristics of pine forests were conducted in 20 by 20 m rectangle sample plots. These measurements included stand diameter at breath height (DBH) or at 130 cm above ground, stand density, and stand height.

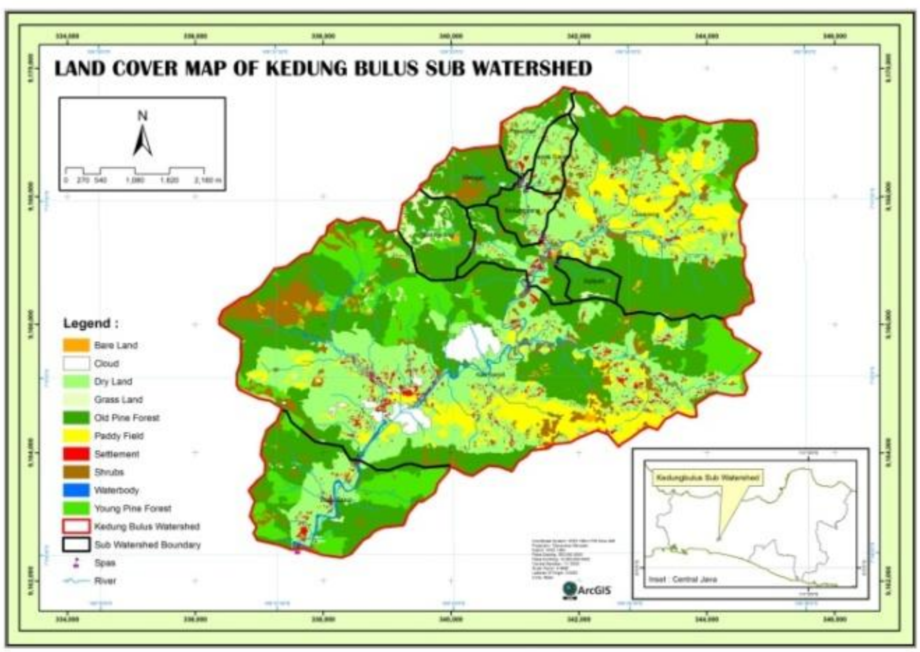


Figure 2. Spatial distribution of land cover f the study area

2.2.2. Derivation of watershed, sub watersheds and their characteristics

Digital Elevation Model (DEM) image of SRTM with spatial resolution of 30 x 30 m was used to derive watershed/sub watersheds boundaries. This image is free downloaded from http://earthexplorer.usgs.gov.

Characteristics of the watershed including area, elevation, the longest of the main river, river slope, and drainage density were measured in each watershed/sub watersheds. These parameters was also derived from DEM SRTM. The results can be seen in Table 1. Rainfall characteristics which are consisted of depth, intensity and antecedent soil moisture content were obtained by installing automatic rain gauge in the watershed.

Table 1. Characteristics of the sub watersheds

Watershed characteristics	Sub-watershed				
	Kedungpane	Lowereng	Kedungbulus	Watujali	Kalipoh
Pine forest area (%)	38	43	47	75	95
Tree density (tree/ha)	44	585	507	410	388
Tree height (m)	21.98	20.2	21.95	23.64	2
Diameter (cm)	29	27	31	35	35
Slope (%)	20-30	20-40	10-30	25-45	25-35
Elevation (m msl)	104-458	91-526	37-526	142-384	122-302
River Slope (%)	7,9	5,3	1,36	5,5	8,2
Longest stream (km)	2,4	3,9	10,1	1,3	1,0

2.2.3. Base flow separation

Stream flow of a river can be divided into direct flow and base flow. Direct flow occurs because of the direct input of rainwater, while the base flow is the flow that comes from groundwater. In this research, the base flow was separated using software package "Hydro Office" BFI+3.0. (Gregor, 2010). There are eight recursive digital filters in the software, namely One parameter algorithm, Broughton two-parameter algorithm, IHACRES, BFLOW, Chapman algorithm, Furey& Gupta filter, Eckhardt filter, and EWMA filter. The recursive digital filters are routine tools in signal analysis and processing, and these are used to remove the high-frequency quick flow signal in order to derive the low-frequency base flow signal. Based on comparison of the manual base flow separation and the software, it was found that IHACRES filter is the most suitable for the Kedungbulus watershed with value of k=0.97, c=0.014, and ά=0.93.

2.2.4. Development of regression equations

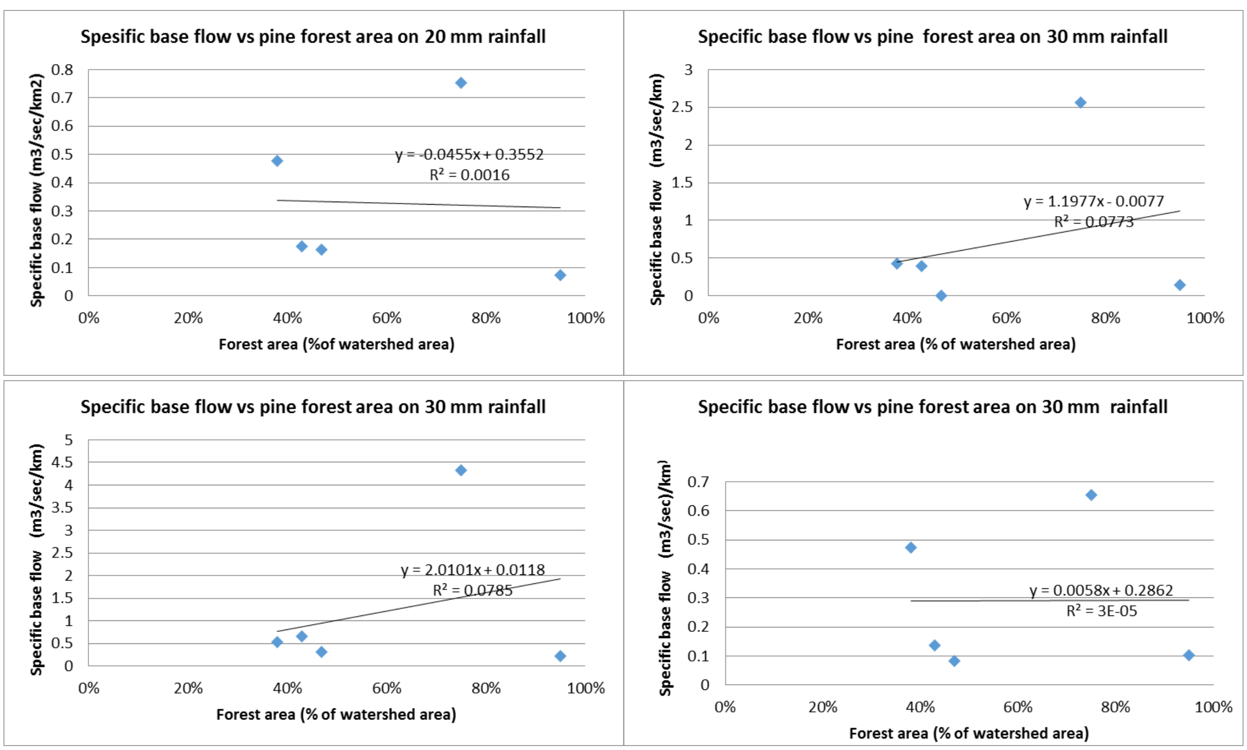
The regression has been developed to get relationship between pine forest area and specific base flow; pine forest area and specific low flow; and pine forest area and base flow index using Microsoft Office Excel 2007.

3. Results

3.1. The relationship between pine forest areas and base flow during rainy season

The relationship between forest covers and base flows show various patterns. Based on the base flow measurement in 2015and 2016, the first pattern shows positive relationship between forest area and base flow. The second pattern indicates that there is no relationship between forest area and base flow. The third pattern produces negative relationship between forest area and base flow. Further analysis reveals thatif the rainfall is low (<40 mm), the area of pine forest does not effect on the magnitude of the base flow. The other observation shows that when the amount of rainfall is low and also the rainfall intensity is low (<50 mm / hour) then the increase in pine forest areas will decrease the base flow as shown in Figure 3. However, if the rainfall event is >60 mm, the intensity of rainfall is > 100 mm/hour, and antecedent soil moisture content is > 100 mm/5 days which are classified as high, then it shows the increase in pine forest areas will increase base flow as shown in Figure 4.

The data mentioned above show that the base flow is not just influenced by the area of pine forest, but it also affected by many factors such as the amount of rainfall, rainfall intensity and the previous soil moisture content. Based on the Figure 3 and 4, it appears that the relationship between the area of pine forests and the base flow has a low coefficient of determination (R^2) which varies from 0.000 up to 0.215.



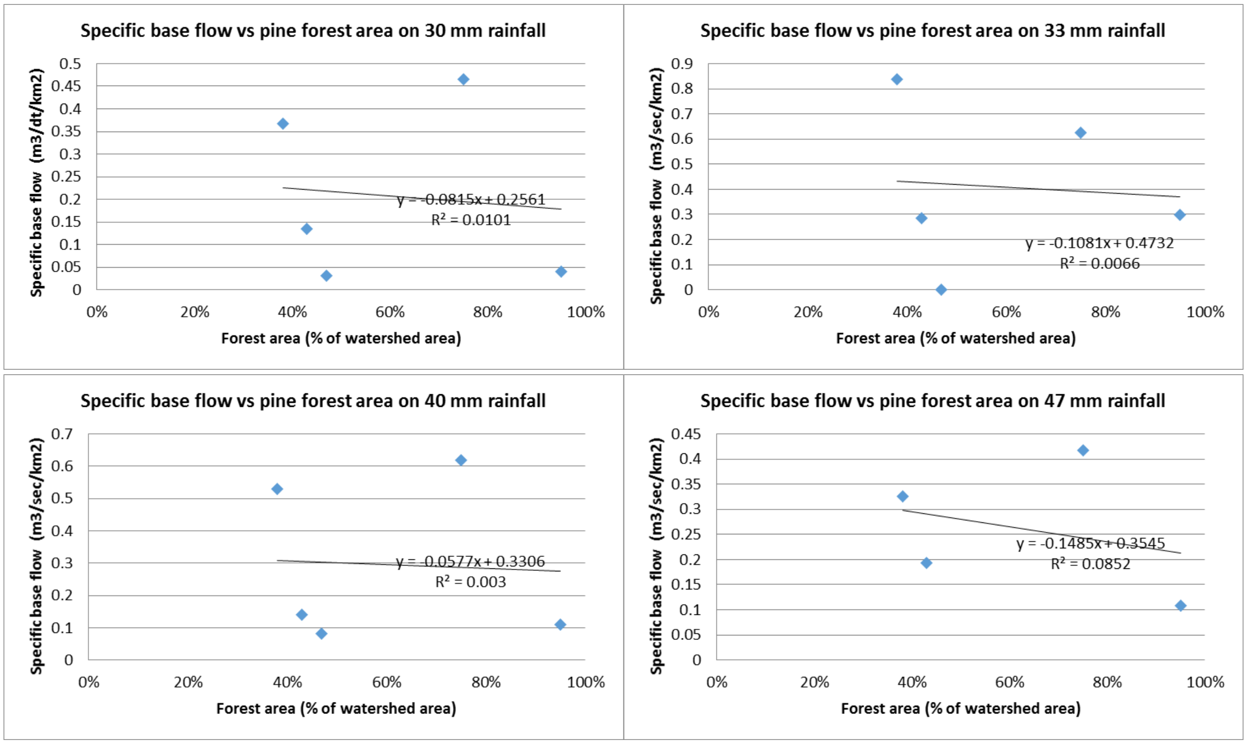
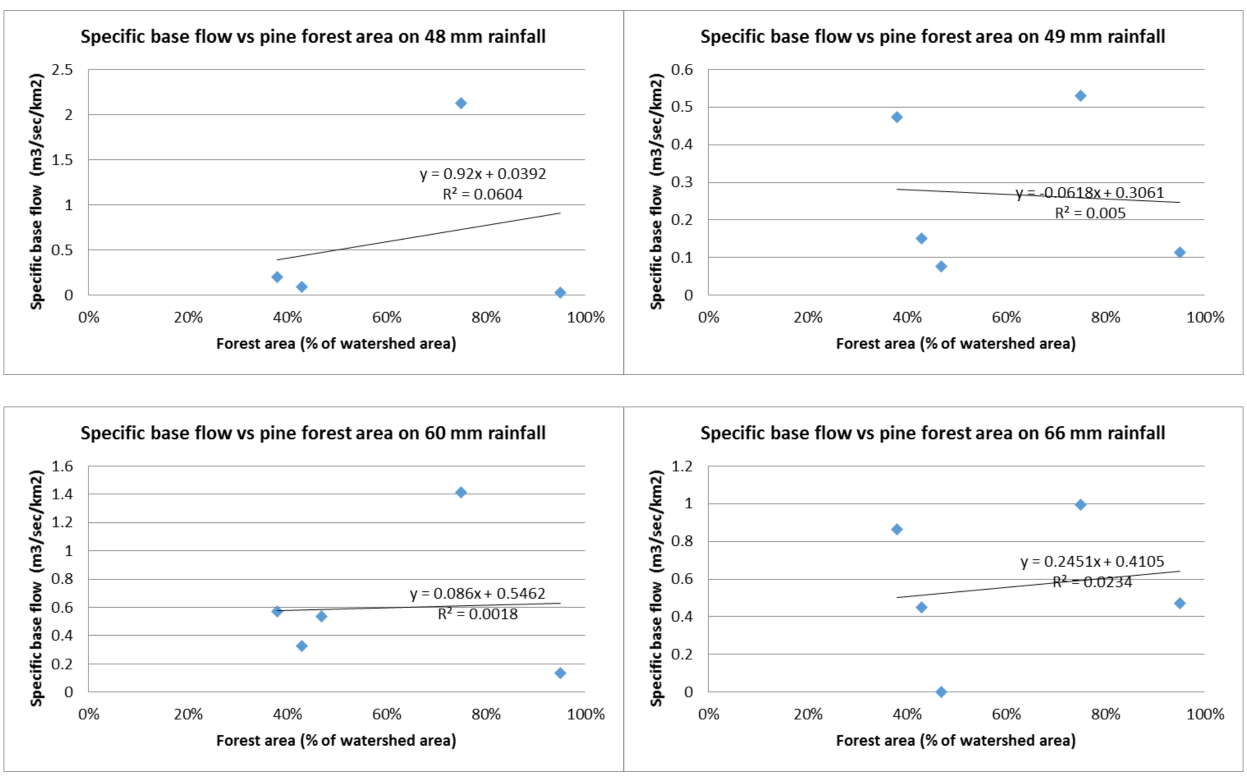
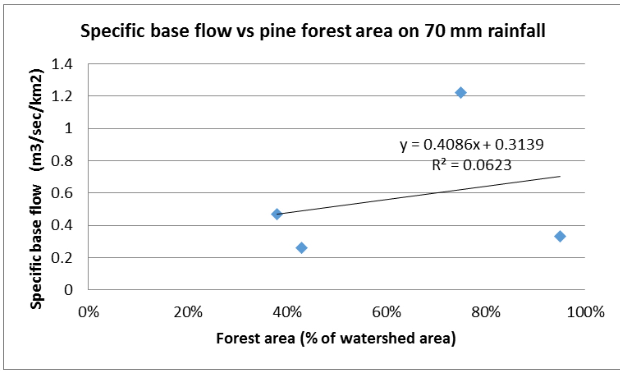
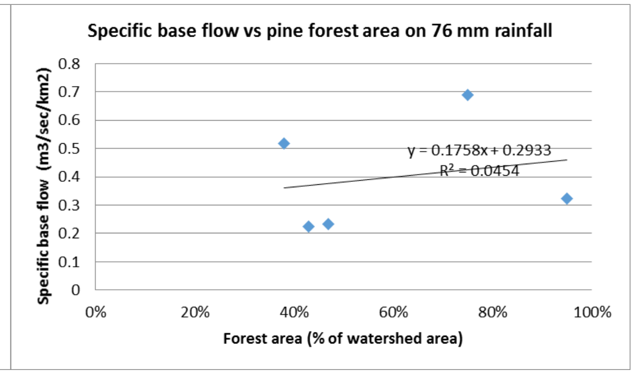


Figure 3. Specific base flow versus forest area on medium rainfall







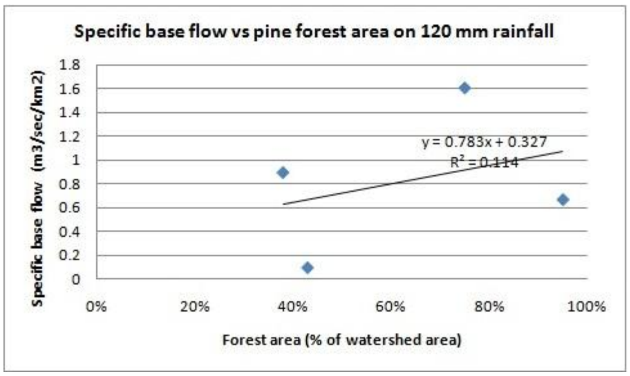


Figure 4. Specific base flow versus forest area on high rainfall

3.2. Base flow index on various pine forest areas

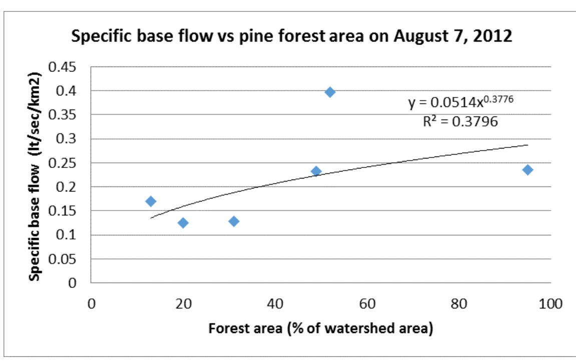
Base flow index (BFI) is the ratio between the base flow and total flow (Tallaksen and Lanen, 2004). BFI is analyzed to see the hydrological function. If a watershed can regulate water fluctuations or flooding after rain then the hydrological function of the watershed is considered as good. The low-flow parameters can be used as an indicator of availability of water resources andas an indicator of damage to a watershed (Djuwansah, 2006). The relationship between the area of pine forests and base flow index are not significant, but there is a tendency the increase in pine forest area will increase base flow index. Based on the base flow index analysis at each flood event from 2015 to 2016, it is obtained an average base flow index of 0.63; 0.63; 0.55; 0.77; 0.64 for the pine forests area of 38%, 43%, 47%, 75% and 95%, respectively. The detail results are provided in Table 2.

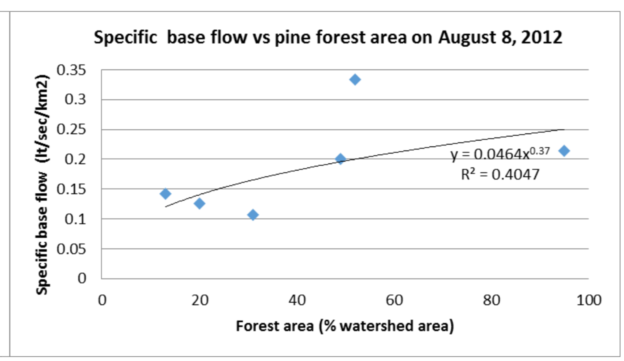
3.3. The relationship between pine forest area and base flow (low flow) during dry season

The base flow in the dry season is often called low flow. It is the minimum flow in the river during the dry season period (Smakthin, 2001).The relationship between the area of pine forests and base flow (low flow) shows more pronounced during the dry season. In the dry season of 2012, the relationship between pine forest area and specific base flow has a coefficient of determination of 0.38 to 0.40 as shown in Figure 5, but in the dry season of 2013 this relationship only has determination coefficient 0.27 until 0.36. In 2014 and 2015, the coefficient of determination ranged from 0.20 until 0.35 and from 0.41 to 0.47. Based on Figure 5 there is a tendency that the increase in pine forest areas will increase low flow.The coefficient of determinations varies from 0.2 to 0.47.The relationship between the area of pine forests and the base flow in the dry season and the base flow in the rainy season has similar pattern that the increase in pine forest area will increase base flow.

Tabel 2. Base Flow Index of various pine forest areas

Date	Base Flow Index from various pine forest areas				
	Kedungpane	Lowereng	Kedungbulu s	Watujali	Kalipoh
	(38% forest)	(43% forest)	(47% forest)	(75% forest)	(95% forest)
14/3/2015	0.735	0.706	0.671	0.814	0.784
28/3/2015	0.599	0.724	0.591	0.68	0.634
28/4/2015	0.526	0.562	0.551	0.791	0.642
30/4/2016	0.605	0.538	0.548	0.768	0.691
9/5/2016	0.612	0.665	0.602	0.847	0.858
9/6/2016	0.779	0.66	0.661	0.966	0.671
19/9/2016	0.921	0.85	_	0.933	0.394
20/9/2016	0.76	0.79	_	0.99	0.81
7/10/2016	0.592	0.66	_	0.665	0.519
8/10/2016	0.561	0.389	_	0.623	0.499
16/10/2016	0.56	0.607	0.552	0.541	0.597
24/10/2016	0.543	0.554	0.45	0.674	0.587
26/10/2016	0.535	0.525	0.557	0.737	0.759
27/10/2016	0.689	0.691	0.548	0.854	0.796
31/10/2016	0.542	0.553	0.409	0.782	0.575
2/11/2016	0.563	0.549	0.478	0.707	0.477
Average	0.632	0.627	0.552	0.773	0.643





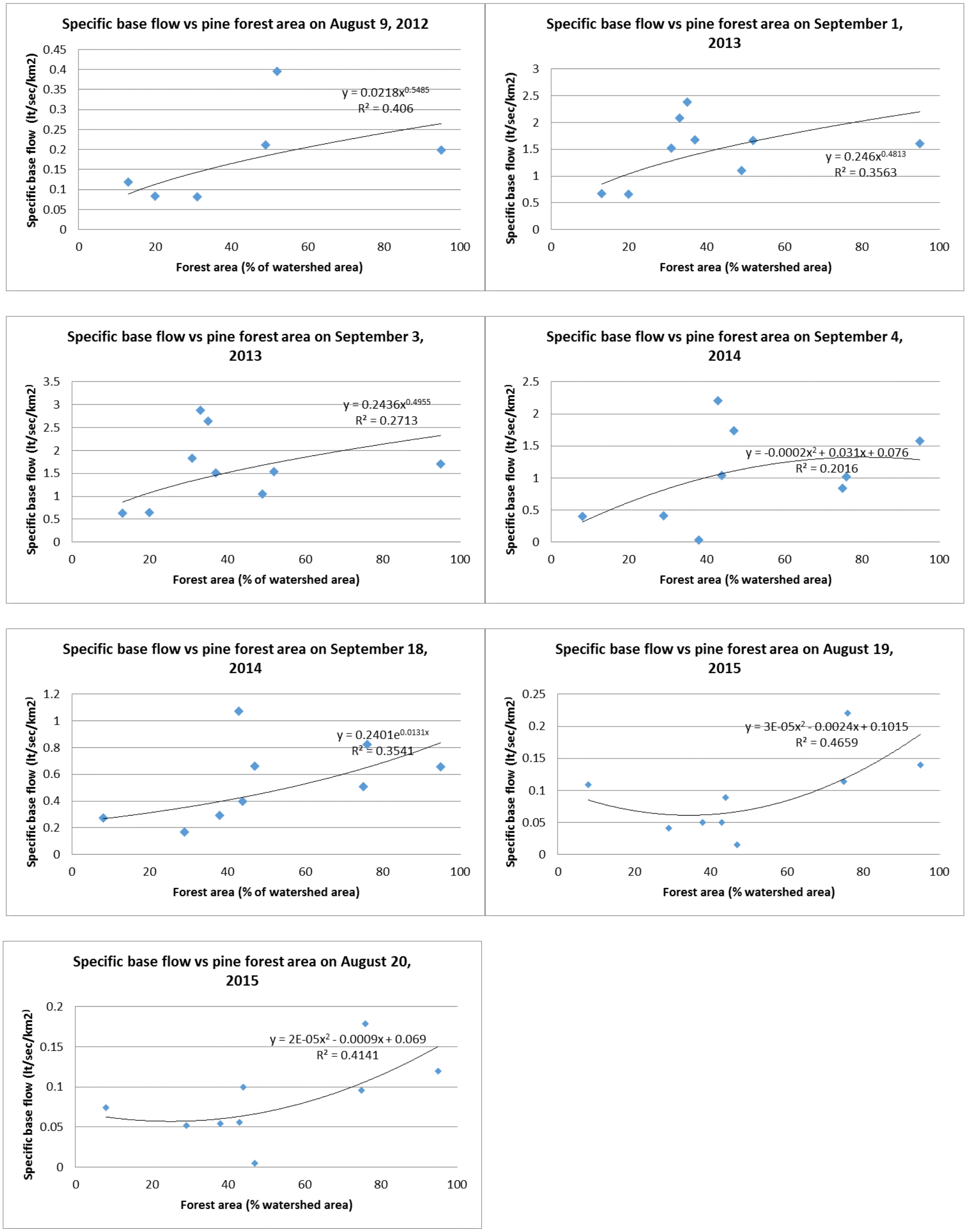


Figure 5. Specific base flow in dry season (low flow) versus pine forest area during 2012 to 2015

4. Discussion

4.1. Pine forest area and base flow

Base flow under the pine forest was influenced by factors such as the amount of rainfall, rainfall intensity and antecedent soil moisture content. If the single event rainfall is high (> 60 mm) then the relationship between the base flow and pine forests area becomes positive. This is because the pine forest can retard the flow rate of the surface runoff, and therefore rain water infiltrate into the ground and runas s sub-surface and base flows. However, if rainfall is low (<40 mm), the relationship between the area of pine forests and base flow becomes negative.This is becausein the sub watershed with high pine cover almost all the rain water is intercepted into the atmospher, while in the sub watershed covered by lower pine forests area some of the rain water will be infiltrated into the soil because part of the watersheds are covered by other land cover types. While in a moderate rainfall (40-60 mm), the relationship between pine forest area and base flow shows a horizontal line that indicates there are no differences between base flows from sub watersheds with higher and lower forest areas. It is happendue to the level of infiltration and interception in a pine forest is parallel with those in other land covers within the corresponding sub watershed. In the pine forest the infiltration is lower and the interception is higher, conversely in the other land cover the infiltration is higher and the interception is lower. These results are almost the same with the research undertaken by Price and Jackson (2007) who have examined 10 pairs of watersheds. The first 10 of the watersheds are covered by forests and the other 10 watersheds are not covered by forests but other type of land covers. Price and Jackson (2007) have found that 5 of the 10 watersheds in pairs show high base flow in forested watershed and the other three of the 10 watersheds in pairs do not indicate differences in base flow in forested and non forested areas.It was only 2 of the 10 watersheds in pairs showed low base flow occurred from watershed non-forested areas. Furthermore, Price et al. (2011) have found that the forest cover in the watershed showed a positive correlation with low flow, it means the higher the forest area the higher the low flow. Although the forest has a higher evapotranspiration rate compared to other land uses, but because the infiltartion is higher than the evapotranspiration rate in the forest area, therefore low flow from forest is higher than in the non-forested areas. Price (2011) has concluded that there is a positive relationships between forest cover and base flow and it supports the hypothesis that forest cover is associated with high infiltration and sub surface recharge, and finally increases base flow.Another research shows that pasture produces 10% higher mean annual stream flow than forest cover, it reflects a lower rainfall interception. However, at the end of dry season, low flow was the lower in the pasture, a possible explaination is due to a lower infiltration capacity and thus it reduces recharge of sub surface water storage (Munoz-Villers et al., 2013).

4.2. Base Flow Index on various pine forest areas

Various pine forest areas have almost no effect on base flow index. In a watershed with 37% covered by pine the BFI is 0.6 while at the watershed with 95% covered by pine forest the BFI is 0.65 as seen in Figure 6.

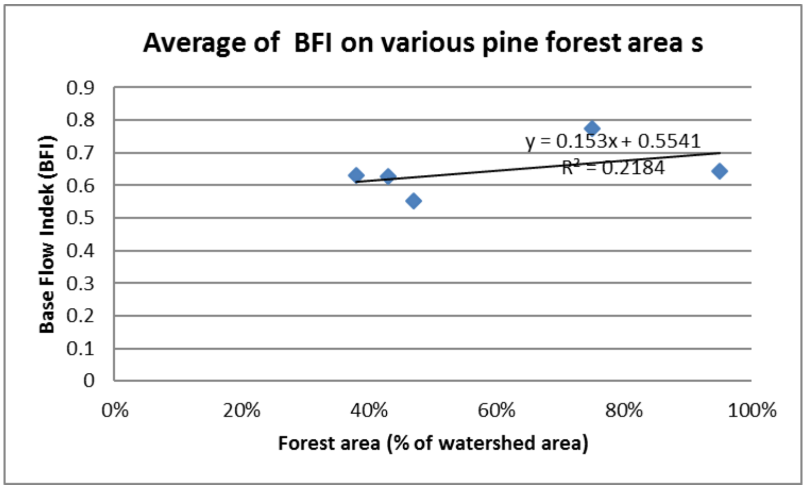


Figure 6. Average BFI on various pine forest area

Based on Figure 6, it can be seen that the forest cover does not effect on the magnitude of BFI. The contribution of the forest area in determining the BFI is only 0.2, while other factors such as geology and soil are very influential (Djuwansah, 2006). Tallaksen and Lanen (2004) have categorized that the BFI = 0.9 is for a watershed with a high degree of permeability and for a watershed with low permeability, the BFI value ranges between 0, 15 up to 0.5. Based on base flow analysis of 65 river in North West China, the base flow index was 0.27 – 0.79 with a mean of 0.57 (Gan et al., 2015). Another research done by Ahiablame et al. (2013) with 22 watershed in Indiana, the BFI various between 0.4 to 0.88 with the average of 0.6. Beck et al. (2013) have observed that the BFI depends on climate, topography, land cover, geology, and soil texture. The climatic factors include rainfall and evapotranspiration, the topography consists of altitude and slope, the land cover includes a percentage of water body, the percentage of forest area, the variables of geology are permeability, and the texture of soil covering the percentage of gravel, sand, silt, and clay (Beck et al., 2013). This is in accordance with this research that shows the effect of forest area on the BFI only showsa low coefficient of determination (R^2= 0.218). Gan et al. (2015) indicated that factors explained 65% of the variability of BFI. BFI was significantly correlated with catchment climatic factors such as precipitation and air temperature, aquifer properties represented by the recession (Gan et al., 2015).

4.3. Pine forest area and low flow

Pine forest area and low flow has positive relationship with coefficient of determination from 0.20 to 0.47,it indicates that 53% to 80% ofother factors affect low flow. According to Smakhtin (2001), factors influencing low flow areinfiltration rate, existance of aquifer, amount of recharge, evapotranspiration rate, topography, and climate.

In contrast with research findings mentioned above, some researchers have concluded that forest area and low flow has a negative relationship. Base flow increase significantly after forest harvesting from 10% to 16% of rainfall (Waterloo et al., 2007). Deforestation generally increase water yield and base flow (Bosch and Hewlet,1982; Andréassian, 2004; Robinson et al., 2003; Scott et al., 1998; Scott et al., 2004). Some researchers have observed that forest conversions reduce base flows, specifically low flows, because the intensive soil compaction and increase in impervious surface (Chaves et al., 2008; Germer et al., 2009; Price, 2011). Adane et al. (2014) have concluded that conversion of grass land to forest plantation has reduced 77 and 88% ofrecharge for ponderosa pine and eastern red cedar respectively. Scherer (2001) has found that based on researches in Canada and US, the response of peak flow, annual water yield, and low flows due to changes in forest cover are highly variable. Forest cover negatively impactswater supply when studying in annual basic but positively when studying in low flow (Brogna et al., 2017). Ala-Ahoet al. (2015) have observed that different forest management scenarioshave showed differences in annual recharge of up to 100 mm. Based on our research in Kedungbulus sub watershed, there are a consistent positive relationship between pine forest area and low flow, although the determination coefficient only 0.2 to 0.47. A possible expalination for this condition is the higher infiltration rate than evapotranspiration rate from pine forest.

The difference of determination coefficient between pine forest area and low flow might be caused by the number of dry month during the research. The dry month in 2012, 2013, 2014, and 2015 are 4, 2, 2, and 6 months, respectively. The average determination coefficient is 0.39; 0.31; 0.28; 0.44 for the dry month 4, 2, 2, and 6 respectively. The longerthe dry month period, the higher the coefficient of determination. It means that pine forest area during longer periode of dry months has a high influence in determining base flow (low flow).

Water conservation measurement should be installed in forest area for increasing base flow. Terrace or water trap may be suitable for water conservation in pine plantation. The cost for terrace (ridge) construction is about 36 US $/hectare (Mulyasari et al., 2006), while water trap costs about 914 US $/hectare (Aldrian and Purwanto, 2016). Due to high cost for installing water trap, therefore terrace is a suitable choice of the study areas. However, in order to get higher infiltration water, the water trap should be applied in the area with deeper soil and lower slope. When the water trap is applied in the area with higher slope and shallow soil depth, it will create land slide.

5. Conclusions

The relationship between pine forest area and baseflow depends on the rainfall events, it can be positive, negative or flat. However, the pine forest was still able to hold the water in the rainy season and running it in the dry season. It was showed in positive correlations between pine forest area and low flow during 2012 to 2015, although the coefficient of determination are only 0.2 to 0.47. The longer the dry month's period, the higher the coefficient of determination. It means that pine forest area has higher contribution for generating base flow. In order to increase base flow and low flow in pine forest, water conservation measurement should be implemented in forested area such as terrace and water trap. Water trap maybe the most effective method toincrease base flow due to high capacity to infiltrate rainfall, however a caution should be paid when this method will be applied on a steep slope area and shallow soil depth. In addition installation of water trap is also high cost. Therefore, terrace (ridge) application in pine plantation forest is the most reasonable method due to low cost and without environmental impact.

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