The influence of teak plantation areas on water yield and peak discharge from five catchments in Blora Regency

T M Basuki and I B Pramono
Watershed Management Technology Center, Jl. Jend. A. Yani, Pabelan - Kartasura, PO BOX 295

E-mail: tmbasuki@yahoo.com

Abstract. Teak plantation occupies 67% of plantation areas in Java-Indonesia; however, its impact on hydrological responses has not been studied in detail. Therefore, a study to assess the impact of teak areas on water yield and peak discharge was conducted in Blora, Central Java. Five catchments with different percentages of the mature teak plantation from 53% to 82% were chosen. Five stream water level recorders were installed at the outlet of the catchments to measure stream water level (SWL). The SWL data were converted into a discharge. Based on 2008–2018 data, the results showed that the lowest monthly (8–41 mm mo$^{-1}$) and annual (140–445 mm yr$^{-1}$) water yield were found in Modang catchment with teak areas (82%), and the highest monthly (41–107 mm mo$^{-1}$) and annual (526–1,500 mm yr$^{-1}$) water yield occurred in Kejalen catchment with teak areas (74%). Generally, all the catchments had the highest water yield in 2010 and the lowest in 2012. It was found that the broader the teak areas, the lower the peak discharge. Although the catchments with the highest (82%) teak areas produced less monthly and annual water yield compared to the catchments with less teak coverage, however, the catchments with high teak coverage can control peak discharge.

1. Introduction
Forests have essential roles in the water cycle and thus influence the water yield of watersheds or catchments. Each species with its characteristics may have a different impact on the water yield [1]. Through evapotranspiration, interception, infiltration, as well as runoff, the forest ecosystem will influence and regulate water yield [2-4]. In this case, the rate of evapotranspiration and interception will be limited by water availability from the rainfall [2,5,6]. In addition, forest management such as thinning, may impact on water regulation in catchments [7, 8] and peak flow [9].

Although some research findings have shown that tree species characteristics influence the water yield, the study by [10] has observed that the relationship between forest and water yield is not only affected by species and forest areas but also influenced by planting position and scale. Therefore, the relationship between forest cover and water yield is complicated and vary among watersheds due to differences in climate, geology, topography, and forest types [11,12].

Due to differences in biophysical properties and management of the catchments as mentioned above, therefore, some of the researchers found that increasing forest cover will reduce water yield [13...
However, the other researchers have observed that reforestation has a positive impact on stream water continuity even in the dry season [17].

The role of forests in regulating water yield of watersheds is not only limited in the term of quantity of the water yield within a specified period but also its influence on peak discharge for certain rainfall events. In this paper, we present the research findings from five catchments covered by various areas of teak plantations. The teak plantation is the dominant species in Java Island, and it covers around 67% of Java’s area. However, information on the hydrological properties of teak catchments is lacking. Therefore, this research has been conducted to study the influence of teak plantations on water yield and peak discharge.

2. Location and method
2.1. Time and location
The teak catchments are administratively located in Blora Regency, Central Java Province, Indonesia. The teak plantations in the catchments area are managed by Forest Management Unit (Kesatuan Pemangkuan Hutan or KPH) Cepu, Unit I Central Java. Figure 1 shows the position of the catchments area, and Table 1 presents the catchments and teak areas.

![Figure1](image-url)

**Figure1.** River network and hydrological stations for stream water level recorder at the studied catchments.

Source: [18]

| No | Catchment | Catchment area (km²) | % of the mature teak area to the catchment area |
|----|-----------|----------------------|-----------------------------------------------|
| 1  | Modang    | 3.4                  | 82                                             |
| 2  | Cemoro    | 13.8                 | 82                                             |
| 3  | Kejalen   | 20.1                 | 74                                             |
| 4  | Sambong   | 27.8                 | 70                                             |
| 5  | Gagakan   | 64.8                 | 53                                             |
2.2. Method
IKONOS image 2015 from Google Earth was digitized to derive land cover map [18]. The percentage of the mature teak area was obtained by dividing the area of mature teak plantation by each catchment area. Table 1 presents the catchments and the percentage of mature teak areas. In this research, the soil type, rainfall, geology were considered similar for the whole catchments, and therefore only the teak plantation area was assumed to be the factor influencing the water yield and the peak discharge of each catchment.

The research was undertaken in the catchment bases. Conventional stream water gauges and automatic water level recorders using loggers were installed at the outlet of each catchment, which has different teak plantation area, to measure stream water level manually and automatically. The measurements of stream water levels using conventional stream water gauges were conducted three times a day, which were at 7:00 a.m., 12:00 a.m., and 5:00 p.m. The loggers were set up to record the stream water level for five minutes interval. All the stream water level data were converted into a discharge using the discharge rating curve, as presented in Table 2.

| No | Sub DAS | Discharge Rating curve |
|----|---------|------------------------|
| 1  | Modang  | $Q = 0.52H^{1.22}, H < 0.3 \text{ m}$<br>$Q = 6.89H^{3.07}, H = 0.3 - 0.9 \text{ m}$<br>$Q = 7.79H^{2.78}, H > 0.9 \text{ m}$ |
| 2  | Cemoro  | $Q = 2.94H^{1.63}, H < 0.3 \text{ m}$<br>$Q = 22.16H^{3.80}, H = 0.3 - 0.6 \text{ m}$<br>$Q = 12.15H^{1.89}, H > 0.6 \text{ m}$ |
| 3  | Kejalen | $Q = 1.41H^{2.62}, H < 1.2 \text{ m}$<br>$Q = 1.10H^{2.19}, H > 1.2 \text{ m}$ |
| 4  | Sambong | $Q = 3.40H^{2.68}, H > 1.95 \text{ m}$<br>$Q = 5.56H^{1.54}, H < 1.95 \text{ m}$ |
| 5  | Gagakan | $Q = 9.28H^{2.00}$ |

Note: $Q =$ discharge ($\text{m}^3 \text{ sec}^{-1} \text{ km}^{-2}$), $H =$ stream water level (m)
Source: Analyzed by the Team of Watershed Management Technology Center, unpublished as cited by [19]

The peak discharge data were obtained based on the five minutes observation. Both conventional and automatic rainfall gauges were set up to obtain rainfall data. The automatic rainfall gauge was set up for every five minutes.

3. Results and discussion
3.1. Temporal distribution of water yield
The mean monthly water yield based on data from 2008 to 2018 for each catchment is provided in figure 2. The trend lines indicating the relationship between the mean monthly water yield and the percentage area of mature teak show that for the wet season, the higher the percentage of the teak area, the lower the mean monthly water yield. However, in the dry season, the trend lines are relatively
horizontal, and there are no differences between catchments with different teak areas. It means the increase in rainfall does not significantly increase the discharge. In the dry month of August, the trend line shows a bit higher in the catchment with the more extensive mature teak areas than in the catchments with the smaller teak areas. It indicates that on the broader teak area, more rainfall can be preserved in the soil and released in the dry season. In the broader teak area, there are more soil organic matter and litterfall, and therefore, soil aggregation much better, and more rainwater can be infiltrated into the soil.

The findings in our research are in agreement with some research findings of the previously published papers, although the species are different. At a micro-scale, a reduction of forest area will increase water yield due to decreasing evapotranspiration [20]. However, in a large watershed, which is more than 10,000 km$^2$, [21] have concluded that the hydrological responses of reforested watersheds were also affected by the properties of the watersheds. Besides [21], a review by [22] have found research findings on the impact of forest changes on hydrological responses from small (< 1,000 km$^2$) to large (> 1,000 km$^2$) watersheds and have found that the increase of water yield due to the decrease in forest cover is statistically significant for all of the watershed sizes. On the other hand, the effect of the increase in forest cover on water yield is not consistent among the watershed sizes [22].

The annual water yield of the studied catchments is presented in figure 3. On the annual bases, the trend lines indicate that the increase in the mature teak areas causes a decrease in annual water yield. This research finding is in line with the research conducted by [23] and [24]. A research conducted by [25] in Willow Watershed in Central British Columbia has found that the annual water yield at the large watershed was also significantly increased with the increase in forest harvesting. The increase in water yield in the less forest cover within the watersheds is because of the decrease in evapotranspiration and interception [25].

Based on the previous researches, the increase in water yield due to the decrease in forest covers varies among the studies. Observation on water yield for two years in the old-growth of tropical Montane Cloud Forest (TMCF) in eastern Mexico, 20 yr-old TMCF naturally regenerating, and a heavily grazed pasture was conducted by [26]. It was observed that the yearly and seasonal patterns of water yield in the mature and secondary forest were similar. However, in the pasture catchment, the annual water yield was 10% higher than the forested catchments due to low interception [26]. In the Upper Zaguano River Watershed, China [27] have measured that in this large study area (> 10,000 km$^2$), the mean annual water yield increment due to forest harvesting was 38 mm yr$^{-1}$ and -38.3 mm yr$^{-1}$ which was caused by climatic variability.

Based on figure 3, it can be seen that the annual water yield of the Gagakan Catchment with the lowest mature teak area (53%) fluctuates more than the catchment with higher teak coverage. The ranges of annual water yield between dry and wet years are broader compared to other years. For example, the annual water yield of the catchment with 53% mature teak area in the dry year 2008 was around 405 mm, however, at the wet year 2010, it increased into 1,522 mm. On the other hand, Cemoro catchment with 82% mature teak area had an annual water yield of 436 mm in 2008, and it became 849 mm in a wet year in 2010. A possible reason for this condition is less water can be stored during the dry year in the catchment with a 53% teak coverage area.
Figure 2. Mean monthly water yield at different mature teak areas at the observed catchments.
Figure 3. Annual water yield of the studied catchments.
3.2. Peak discharge at various rainfall event

At the same rainfall event, the hydrological responses of the catchments are varied. For instance, at the rainfall 44 mm per event, on 22\textsuperscript{nd} February at Gagakan catchment covered by 53\% of old teak, the peak discharge was 0.21 m\textsuperscript{3}sec\textsuperscript{-1}km\textsuperscript{-2}. However, on 25 February at the same catchment with the same rainfall (44 mm per event), the peak discharge was 1.22 m\textsuperscript{3}sec\textsuperscript{-1}km\textsuperscript{-2}. A possible reason for this condition is the difference in soil moisture content [28]. The peak discharge of the catchments at various rainfall events are presented in figure 4. Results from the data analysis also show that the relationships between the percentage of the teak plantation area in the catchments and the peak discharge are generally strong, but the relationships are not linear (figure 4).

Although the increase in teak coverage decreases the mean monthly and annual water yield, however, the teak plantations can reduce peak discharge, as presented in figure 4. The possible reason is that more rainwater that can be retained in the forest floor and also more evapotranspiration and interception at the broader teak plantation area compared to the smaller teak plantation area, and therefore the less peak discharge. In this case, the higher rainfall depth is not always causing higher peak discharge. This means that the factors affecting peak discharge are not only rainfall and forest cover (in this research teak plantation), but other factors such as soil moisture may influence the peak discharge. Antecedent soil moisture at the forest area has a strong (92\%) correlation with the direct runoff [29].

As a comparison to our findings, [30] reported their findings based on the research in the seasonal tropics of Central Panama. It has observed that peak discharge of the mosaic catchment (subsistence agriculture, mixed-age forest, and pasture) and graze pasture catchment were 1.4 and 1.7 higher than that of the forested catchment, respectively. Meanwhile, [31] have examined that planned forest harvesting 50\% of the catchment has increased from 9\% to 25\% compared to the peak discharge of the control catchment.
Figure 4. The relationship between the teak plantation area and peak discharge.
4. Conclusion
Based on the study in the five teak catchments with various teak areas, it can be concluded that the increase in the mature teak area will cause a decrease in annual water yield. The mean monthly water yield in the wet season is higher in the catchment with the smaller teak area, and however, in the dry season, the water yield is similar among the catchments with various teak areas. The increase in the teak areas causes a decrease in water yield; however, the wider the teak areas within the catchments reduce the peak discharge. The implication of the latest finding is forests in general or teak plantation, in this case, can be used to mitigate peak flood until a particular rainfall event. The research findings are based on relatively small catchments, and the impact of teak plantation on water yield and peak discharge may be different at a large watershed. Therefore, in the future, research on the impact of teak plantation on water yield at large watersheds is a challenge.

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