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Research Article

Biomass carbon stock and water yield of teak catchments

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Abstract: Rehabilitation of degraded forests and lands using the vegetative method can be used to improve the environmental condition and sequestered carbon dioxide from the atmosphere. However, improper plant selection may create water shortage in dry season. Based on the background, the research was conducted in order to study the relationships of biomass carbon stock, evapotranspiration, and water yield of five catchments covered by various teak areas. The study was conducted in Blora Regency, Central Java, Indonesia. The percentage of mature teak plantation areas in the catchments were 82, 82, 73, 70, and 53%. The biomass carbon stock in each catchment was estimated using previously published data. The water yield of the catchments was calculated from the conversion of the stream water level at the outlet of each catchment. The evapotranspiration was calculated based on a simple water budget of a catchment. The results showed that the highest carbon stock was 64 t/ha and found in Modang Catchment (82% mature teak). The lowest carbon stock was 22 t/ha and measured in Gagakan Catchment (53% mature teak). In parallel with the amount of carbon stock, the highest evapotranspiration was measured in Modang Catchment, and the lowest was found in Gagakan Catchment. The observation of water yield during 2008-2019 showed that the higher the carbon stock in the catchments, the lower the water yield. Synergy in reducing CO_2 emission and sustaining water flows can be achieved by considering land suitability for plant growth and applying water conservation in forests and lands rehabilitation.

***Keywords**: carbon stock, evapotranspiration, teak plantation, water yield*

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Introduction

Deforestation and forest degradation have become major issues in the global community for several decades (Goetz et al., 2015; Houghton, 2012). The deforestation and forest degradation in tropical countries have caused millions of degraded lands, consequently increase greenhouse gas emission. Indeed, the increase in concentration of the greenhouse gas, especially CO_2, into the atmosphere has caused global warming and climate change (Basuki, 2012; Torres and Skutsch, 2012; Souza et al., 2013; Pearson et al., 2017).

Realizing the importance of climate change mitigation, the Government of Indonesia under the United Nations Framework Convention on Climate Change (UNFCCC) has committed to reduce greenhouse gas emission. With regards to the Paris Agreement, Conference of the Party (COP) 21, Indonesia through Nationally Determined Contribution (NDC) has committed to reduce greenhouse gas emission by 29% without international assistance (unconditional) and 41% with supported by international funding (conditional) (Kementerian Lingkungan Hidup dan Kehutanan, 2018). Those targets are based on all sectors that contribute to the greenhouse gas emission. In the forestry sector, the reduction of the greenhouse gas is targeted 17.2% and 23%, for independent budget and with international funding support, respectively (Kementerian Lingkungan Hidup dan Kehutanan, 2018). Those targets should be achieved during 2020-2030.

To implement the reduction of CO_2 above, the Government of Indonesia has established policies, one of which is by conducting forest and land rehabilitation programme. However, due to the high rate of deforestation and forest degradation in the past, therefore the degraded land remains large, which is 14006.450 ha in 2018 (Kementerian Lingkungan Hidup dan Kehutanan, 2018). To achieve the reduction emission target in 2030, the Government of Indonesia has continued to conduct reforestation and land rehabilitation especially through the vegetative method. Planting for the rehabilitation of the degraded lands can reduce CO_2 through photosynthesis process, reduce runoff and soil erosion (Wang et al., 2015; Basuki, 2017). During the photosynthesis process, CO_2 from the atmosphere and H_2O (water) from the soil solum are converted into carbohydrate by plant and stored as biomass. The amount of biomass varies among different plantations. For example, the amount of dry weight of biomass of *Agathis loranthifolia* (9 years) and *Pinus merkusii* (16 years) with stand densities 908 and 1200 trees/ha are 46.7 and 241 t/ha (Basuki et al., 2004).

Vegetative method for land rehabilitation provides some benefits for improvement of the degraded environmental; however, improper plant selection will create another problem such as decreasing water yield of a catchment (Jackson et al., 2005; González-Sanchis et al., 2019). Reduction in water yield due to the expansion of forest plantation has been observed. In tropical to subtropical region of Xishuangbanna in China, Liu et al. (2017) have examined data from 1976 to 2012 and have found that conversion of native forest and expansion around 20 times of plantation in the study area resulted in decreasing carbon stock by 45% and water yield by 32%. In addition, the decrease in water yield due to the increase plantation areas were also observed by Pramono et al. (2017) in pine catchments and Basuki and Pramono (2020) in teak plantation catchments in the tropical region, Indonesia. The decrease in water yield at large plantation areas is caused by evapotranspiration (Price, 2011); however, Bruijnzeel (2004) has observed that the decrease in water yield is more triggered by soil compaction which reduces infiltration and dry season flow. According to Ellison et al. (2017), water vapour of the evapotranspiration has an essential role in the increase in atmospheric moisture which stimulates rainfall. The degraded forest and land should be rehabilitated still large. Therefore, in planning and planting for land rehabilitation programme should be carefully conducted; the plant water requirement for growth must be adjusted to the available water. Based on the background explained above, research to study the relationship among biomass carbon stock, evapotranspiration, and water yield was conducted at catchments covered by various teak plantation areas.

Materials and Methods

Description of the study site

Five catchments, i.e. Modang, Cemoro, Kejalen, Sambong, and Gagakan were chosen as the study sites. The first four catchments are inside the biggest catchment, ie. Gagakan Catchment. The administrative area of the catchments is in Blora Regency, Central Java. The teak plantations are managed by Perum Perhutani Unit I, Central Java. The geographical of the catchment stretched from 555600 - 566100 East Longitude and 9211500 – 9222000 South Latitude. The areas of Modang, Cemoro, Kejalen, Sambong, and Gagakan catchments are 3.4, 13.8, 20.1, 27.8, and 64.8 km^2 respectively and the percentage areas of the mature teak plantation are 82, 82, 74, 70, 53% respectively (Basuki et al., 2019). The river flows and landcover maps are presented in Figures 1 and 2.

Data collection

Monitoring of stream water levels was conducted at the outlet of the catchments. Rainfall gauge was installed at the representative location inside the catchments. Data collection were conducted from 2008 until 2019, except for Kejalen catchment which was conducted during 2008-2018. Spatial distribution of teak plantation density including age classes of the teak plantations was based on the map produced by Perum Perhutani Unit I, Central Java, c.q. Perencanaan & Pengembangan Bisnis Divre Jateng. Method to collect data of biomass carbon stock was based on Basuki et al. (2008).

Data analysis

Hydrological data analysis

Using rating curves formulas 1-11, the stream water level data were converted into discharge data. The data were converted on a daily basis and summing up for every month. The rating curve formulas are provided in Table 1.

Carbon stock analysis

The amount of carbon stock for each class age of the teak plantation was estimated based on (Basuki et al., 2008). The area of a sample plot was 1-5% of the stand area. Within the sample plots, height and diameter at breast height (dbh), and stand density were measured. Destructive sampling was applied to obtain the amount of fresh weight of the teak biomass. Conversion of fresh to dry weight of biomass was conducted after the moisture content of each partitioning stand was measured in the laboratory (Basuki et al., 2008). Detail explanation of the method was explained in (Basuki et al., 2008).

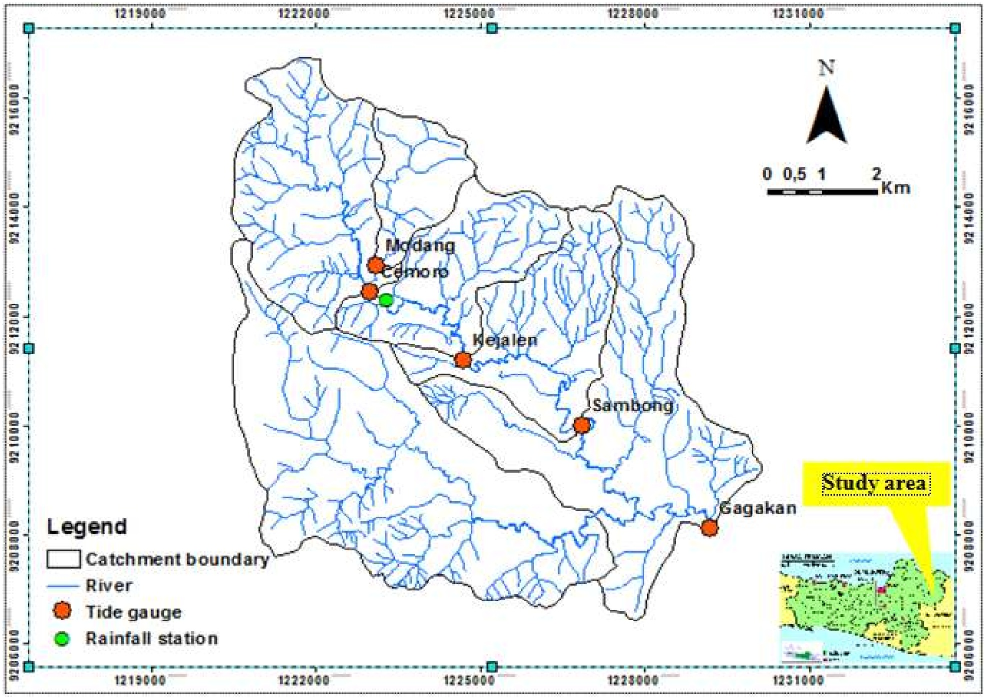

Figure 1. Stream channels of the study area.
Source: Basuki (2017).

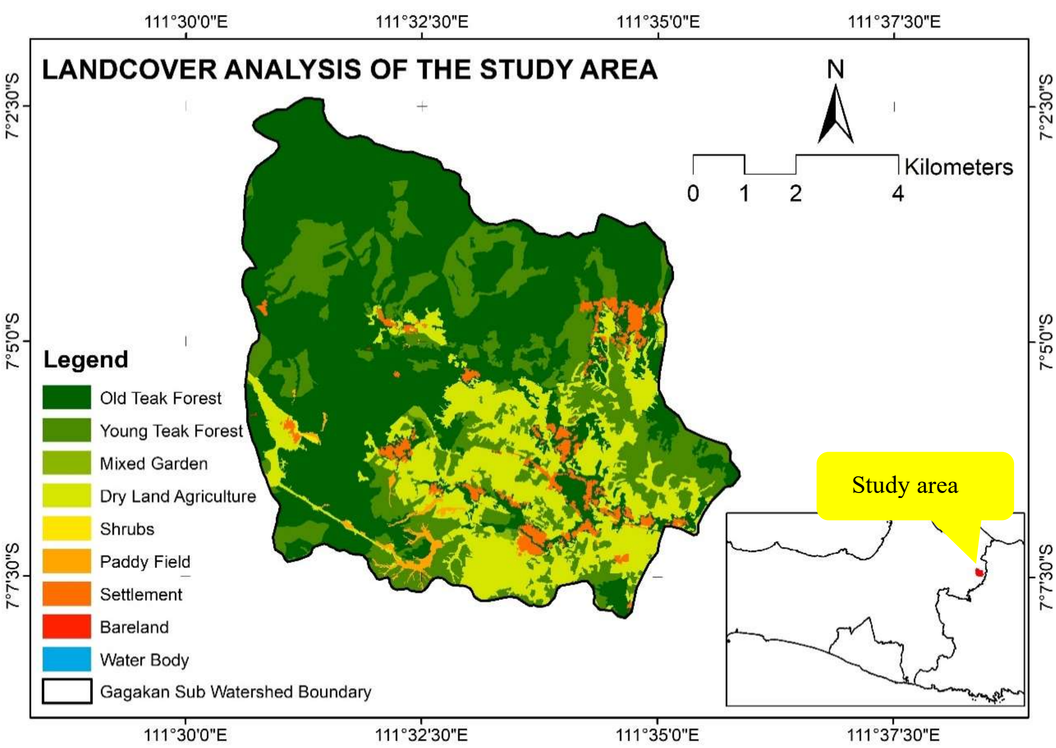

Figure 2. Land cover map of the study area.
Source: Basuki (2017).

Table 1. Discharge rating curves to convert stream water level to discharge.

No	Catchment	Discharge rating curve	Equation
1	Modang	$Q = 0.52H^{1,22}$, H<0.3 m	…..1
		$Q = 6.89H^{3,07}$, H = 0.3 – 0.9 m	…..2
		$Q = 7.79H^{2,78}$, H>0.9 m	…..3
2	Cemoro	$Q = 2.94H^{1,63}$, H<0.3 m	…..4
		$Q = 22.16H^{3,80}$, H=0.3 – 0.6 m	…..5
		$Q= 12.15H^{1,89}$, H>0.6 m	…..6
3	Kejalen	$Q = 1.41H^{2,62}$, H<1.2 m	…..7
		$Q = 1.10H^{2,19}$, H>1.2 m	…..8
4	Sambong	$Q = 3.40H^{2,68}$, H>1.95 m	…..9
		$Q = 5.56H^{1,54}$, H<1.95 m	….10
5	Gagakan	$Q = 9.28H^{2,00}$	11

Note: Q = discharge (m^3/second), H = stream water level (m). Source: Analyzed by Team of Watershed Management Technology Center, unpublished as cited by Basuki and Pramono (2017).

Evapotranspiration of each catchment was calculated based on a simple water balance of a catchment (Dunne and Leopold, 1978; Brantley et al., 2017), as the equation 12:

$$Q = P - ET \pm \Delta s \quad \ldots\ldots 12$$

Note:

Q	=	discharge (mm)
P	=	precipitation (mm)
ET	=	evapotranspiration (mm)
Δ	=	soil moisture change

For the whole year, Δs was assumed as 0

In the current paper, 50% of dry weight of the biomass is assumed as organic carbon (Basuki et al., 2009; Basuki, 2012). Dry weight of biomass for each class age of teak plantation was determined based on the research findings of Basuki et al. (2008) as presented in Table 2.

The area of each class age within each catchment was calculated, then the amount of dry weight biomass was estimated according to Basuki et al. (2008). Biomass carbon stock of each catchment was estimated by weighted average. The formula to calculate the biomass carbon stock for each catchment is:

$$\text{Dry biomass} = \sum \frac{a1x1+a2x2+a3x3+aixi}{A} \quad \ldots\ldots 13$$

Note:

a1, a2, a3,….ai	=	area of each class age of teak plantation within a catchment (ha)
$x_1, x_2, x_3, \ldots x_i$	=	class age
A	=	area of a catchment (ha)

Table 2. Biomass carbon stock from each teak class age.

Age (Year)	Age class	Dry weight of biomass (t/ha)	Carbon stock (t/ha)
≤10	1	8.65	4.33
>10-20	2	72.62	36.31
>20-30	3	11.89	5.95
>30-40	4	140.74	70.37
>40-50	5	164.63	82.32
>50-60	6	186.51	93.26
>60-70	7	207.90	103.95
>70-80	8	226.42	113.21
>80-90	9	251.11	125.56

Source: Basuki et al. (2008). Note: At the third class age, the amount of carbon stock is low due to thinning.

Results and Discussion

Annual rainfall, evapotranspiration, and water yield of the catchments are provided in Figure 3. In the wet years in 2010 with rainfall of 2434 mm, 2016 with rainfall of 2182 mm, 2016 with rainfall of 2112 mm, the evapotranspiration increases (Figure 3). This is because the amount of water for evapotranspiration depends on water availability (Dye and Versfeld, 2007; Cristiano et al., 2015; Bosquilia et al., 2019) during the wet year this water is available. The highest evapotranspiration is found in the catchment with the highest percentage area of the teak plantation, which is in Modang catchment. In the Modang catchment the evapotranspiration ranged from 938 mm/year in 2019, and the highest is 1989 mm/year in 2010. In the catchment with the lowest percentage of teak area, which is Gagakan (53%), the annual evapotranspiration varies from 373 mm/year to 1285 mm/year. The trendline in Figure 4 shows that the smaller the areas of teak plantation, the lower the amount of water for evapotranspiration. A possible reason for this condition is because the amount of water for evapotranspiration is higher at the catchment with wider forest areas as explained by (Feng et al., 2012). In this case, (Wang et al., 2011) have emphasized that the water yield of catchments may not only be affected by forest covers, but also climatic aspects. In addition to area percentage of teak plantation, the age stands is also affects water yield of catchments. The older stands have higher evapotranspiration than the younger ones (Liu et al., 2017). In the study area of Modang and Cemoro catchments, the mature teak plantation is 82% and the young teak is around 18%. On the other catchments, the mature teak less than 82%, however, the young teak plantation is 22 to 29% of the catchment areas, as explained by Basuki (2017). As a comparison to our research findings, research conducted from 2005 to 2012 by Igarashi et al. (2015) have shown that around 73% of rainfall (1335 ± 256 mm/year) is used for evapotranspiration by teak plantation in Thailand. Attarod et al. (2009) also have measured evapotranspiration of teak plantation in Thailand. During the day at the rainy season, the amount of water for evapotranspiration ranges from 2 to 6 mm with an average of 4 mm/day.

Besides water loss by evapotranspiration process, high interception rate is also considered as a factor reducing water yield of catchments (Munoz-Villers and McDonnell, 2013). Large areas of plantation forests will consume water for biomass accumulation during the growing stage (Beck et al., 2013). In this regards, the amount of biomass reflects the amount of CO_2 atmosphere sequestrated by vegetations. Therefore from the perspective of CO_2 mitigation, the increase in accumulation of stand biomass means the higher reduction of the CO_2 from the atmosphere.

Carbon stock in the biomass of each catchment is presented in Figure 5. In this figure, Kejalen Catchment is not included because since 2019 this catchment was not observed. Figure 5 indicates that the higher the biomass carbon stock, the lower the water yield. The implication of the research finding for forest management is that in conducting rehabilitation of degraded lands should be considered multi proposed of ecosystem services. Synergy to achieve the goals in ecosystem services should be implemented simultaneously (Cademus et al., 2014). In this case, ecosystem services for reducing the emission of CO_2 should avoid reduction of water yield.

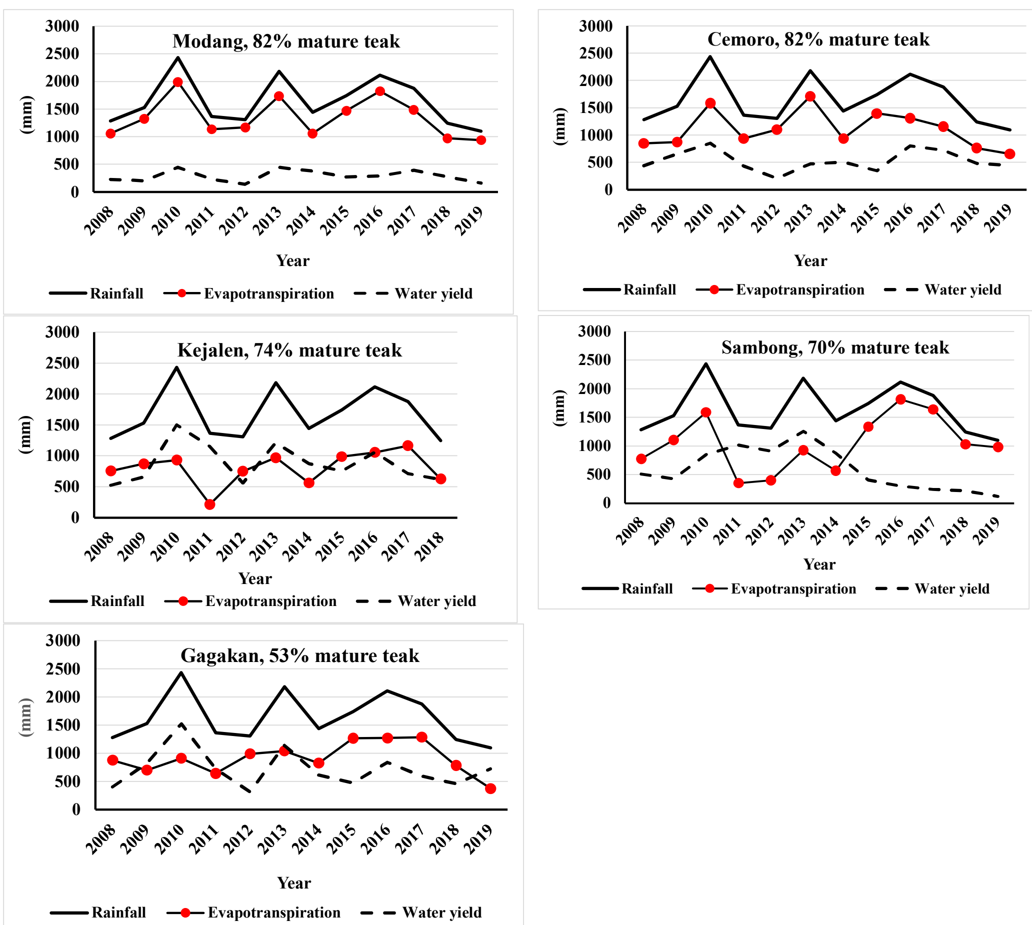

Figure 3. Annual rainfall, evapotranspiration, and water yield of the studied catchments.

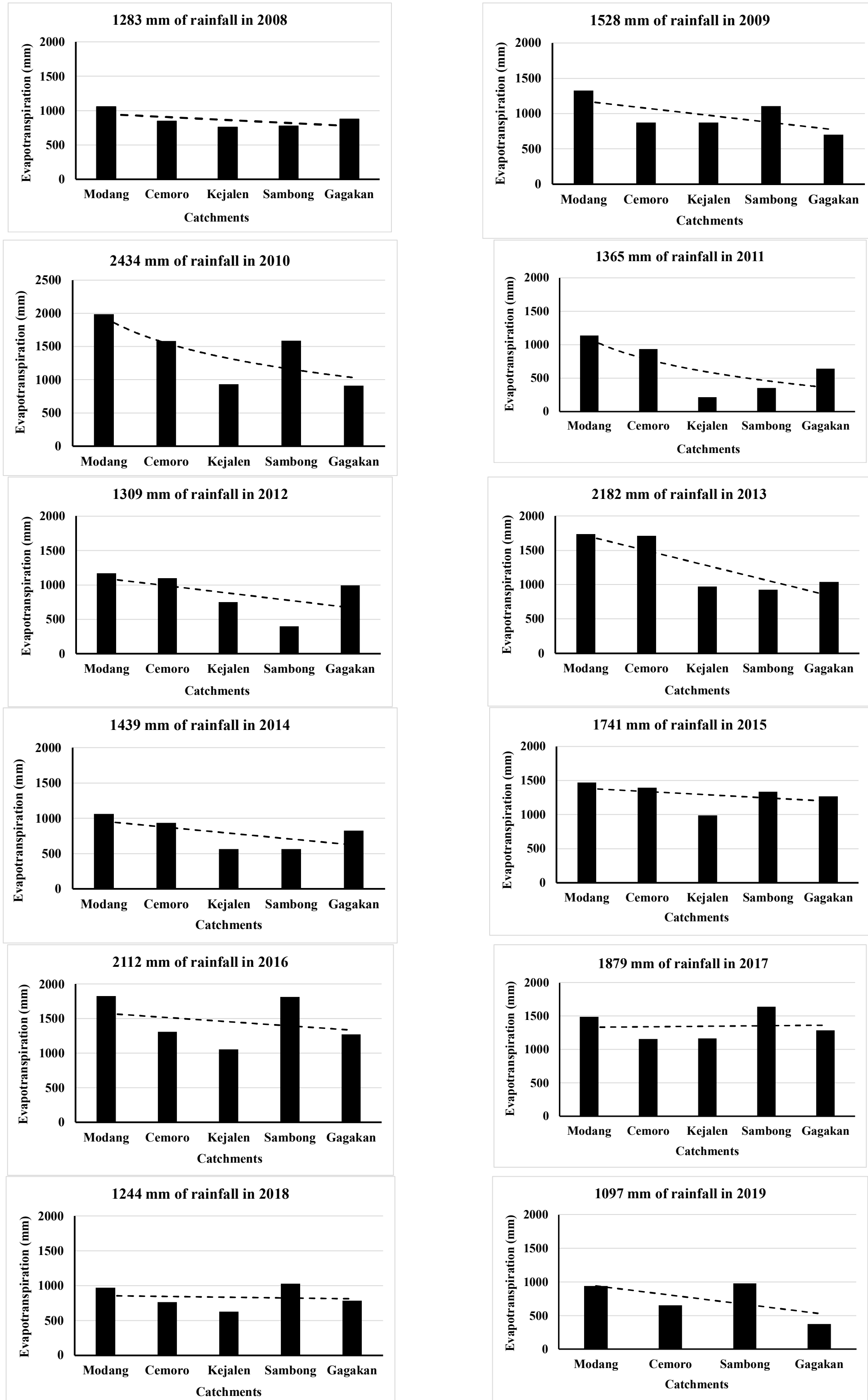

Figure 4. Annual evapotranspiration of teak forests in various rainfall.
Notes: The teak area of Modang (82%), Cemoro (82%), Kejalen (74%), Sambong (70%), and Gagakan (53%).

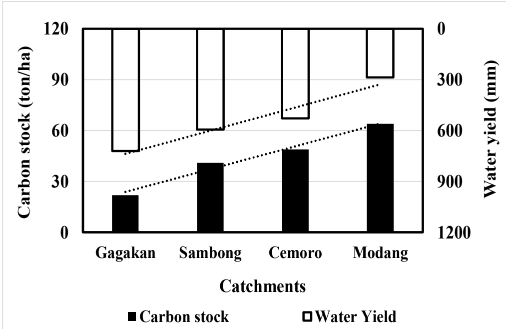

Figure 5. Carbon stock of biomass and water yield

To achieve the CO_2 reduction target while maintaining the continuity of water yield can be applied using some approaches. de Barros Ferraz et al. (2013) suggest to apply forest management based on scale areas, especially for eucalyptus plantation; however, we believe that the suggestions can be applied for plantation forests in general. At a broad level based on natural climatic constraints, classification of the water availability for stand growth is essential since the amount of water for evapotranspiration in the tropics is limited by the available water (de Barros Ferraz et al., 2013). At a meso or landscape scale, a mozaic management between areas for natural and plantation forests should be applied in order to maintain quantity and continuity of water yield from plantation areas (de Barros Ferraz et al., 2013). Application of water conservation practices is important at the operational or micro scale to fulfil available water for stand growth and regulate water flow (de Barros Ferraz et al., 2013).

Conclusion

The research findings show that the increase in biomass carbon stock per ha in the catchments causes the increase evapotranspiration and decrease water yield of the corresponding catchments. Synergy to achieve multiple ecosystem services, i.e. the reduction CO_2 emission and regulate water flows can be implemented by promoting land suitability classification with the emphasize in water availability, management mosaic of natural and plantation forests, and conducting water conservation measures.

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