JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
ISSN: 2339-076X (p); 2502-2458 (e), Volume 5, Number 1 (October 2017): 965-973
DOI:10.15243/jdmlm.2017.051.965

Research Article

Sediment yield and alternatives soil conservation practices of teak catchments

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Received 04 September 2017, Accepted 18 September 2017

Abstract : Quantifying sediment is essential to determine its sources and reduce its negative impacts. A study was conducted to quantify suspended sediments of catchments covering by teak plantation and to provide alternatives soil conservation practices. Five catchments with old teak coverages of 82, 82, 74, 70, and 53 % were chosen. At the outlet of each catchment was installed tide gauge to monitor stream water level (SWL). Water samples for sediment analyses were taken for every increament of SWL. Sediment yield was calculated based on rating curves of sediment discharge. The results showed that the sources of sediment in the streams were dryland agricultural and streambank erosion. The mean annual sediment yield during the study were 9.3, 10, 15, 53.3, and 22.5 t/ha for catchments covered by old teak plantation of 82, 82, 74, 70, and 53 %, respectively. To reduce sediment yield some soil conservation practices must be applied. Conservation of soil organic matter is important in order to stabilize soil aggregate and prevent clay dispersion which causes erosion and sedimentation. Green firebreaks or making channels are needed to prevent fire during dry season and organic matter loss. Stabilization of streambank is neccesary, either using vegetative method or civil technics.

***Keywords**: erosion, sediment, soil conservation, streambank erosion, teak plantation*

To cite this article: Basuki, T.M. 2017. Sediment yield and alternatives soil conservation practices of teak catctments. J. Degrade. Min. Land Manage. 5(1): 965-973, DOI: 10.15243/jdmlm.2017.051.965.

Introduction

Teak (*Tectona grandis*) is one of high quality hardwoods and has economic value. This species has been widely planted in 36 countries around the world (Behari, 2007). In Indonesia, it is mainly planted in Java Island and managed by Perum Perhutani. The area of teak plantations is 1,000,534 ha or it is around 67% of forest in Java island (Perhutani, 2014). To ensure enviromental sustainability, a 50 year of logging cycle has to apply (Siswamartana, 2007). This is to turn back the plantation environment including soil and its components, understory, micro climate, and the stand themself into a normal condition.

In Indonesia, canopies of the teak plantations are generally dense in rainy season, however in dry period the leaves fall to reduce transpiration. In the dry periods, lands under the teak plantations are clean and there are limited or even no understories and litters. At the condition the teak stand do not have leaves, the soil under the stands are no covers and when the rainy season start, then the energy from rain drops will destroy soil agregate. On sloping lands the resulted soil from erosion along with soil nutrients will flow down carried out by surface runoff (Baker and Miller, 2013; Shi et al., 2012). The material from soil erosion and surface runoff will fill in lower areas and finally will go into streams or rivers. Soil erosion is considered as on-site effect of land degradation, and the material of soil erosion carried in stream water known as sediment which is considered as off-site effect (Duvert et al., 2012). In this regards, the term of sediment yield refers to the amount of sediment outflow from a watershed or catchment per unit time (Aksoy and Kavvas, 2005).

Suspended sediment has impacts on aquatic ecosystem because of its roles in transportation of nutrients content, organic carbon, pathogen or methal compund from one place to other places (Vilmin et al., 2015). Sedimentation leads to flooding, siltation of water body and reservoir (Bussi et al., 2015) as well as disturb fish ecosystem (Paryono et al., 2017). The siltation of reservoirs will decrease life expectacy and creates economic burders (Brosisnsky et al., 2015). Quantifying sediment yield is essential for many purposes (Yeshaneh et al., 2014), for example it can be used to understanding and predicting future sediment transport for watershed management planning (Mukundan et al., 2013). In addition, it can be used to design erosion control structures (Senti et al., 2001) and also to predict life expectancy of a reservoir (Ranzi et al., 2012).

Sediment yields in a catchment basis have been studied for various land uses. However, based on studied literatures, it is difficult to find a scientific paper presenting and discussing sediment yields from catchments covering by teak plantation. Therefore, a study has been undertaken in order to quantify suspended sediments from catchments covering by various teak plantation areas and provide alternatives conservation practices to prevent and reduce soil erosion as the source of suspended sediments in the stream.

Materials and Methods

Biophysical condition of the study area

The study was conducted at five catchments covered by various teak plantation area. These teak plantations were managed by Forest Management Unit (KPH) Cepu, Perum Perhutani Unit I. Geographically, these catchments are located at 55600 - 566100 East Longitude and 9211500-9222000 South Latitude. Adminstratively, the catchments are located in Blora Regency, Central Java Province.

The observed catchments are Modang, Cemoro, Kejalen, Sambong, and Gagakan. The first four catchments are located within Gagakan catchment. Modang catchment is inside Cemoro catchment. The Modang and Cemoro catchments are inside Kejalen catchment. The Kejalen catchment is part of Sambong catchment. Those four catchments are situated inside of Gagakan catchment. Finally the outlet of the Gagakan situated in the lowest one. The stream channels are illustrated in Figure 1.

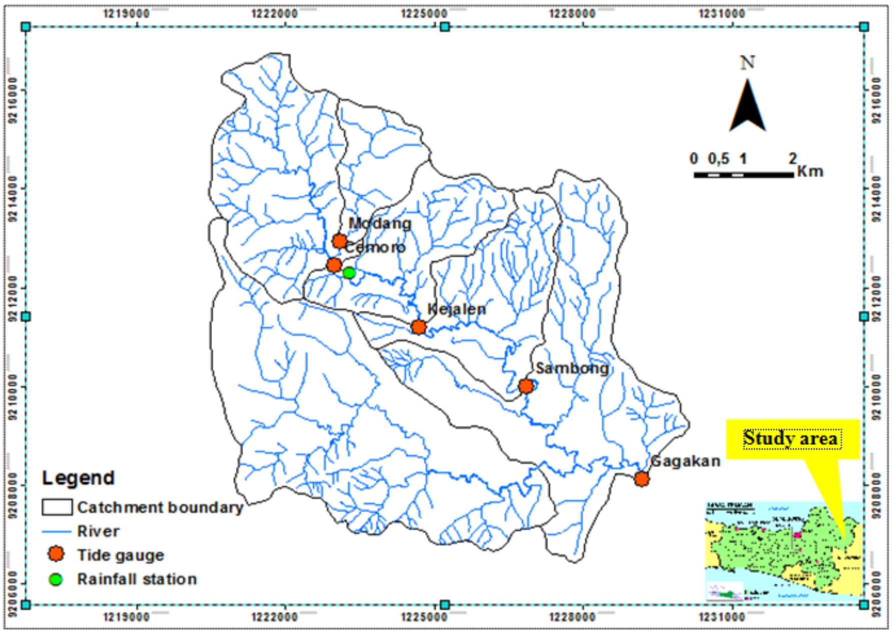

Figure 1. Stream channels of the study area

Data collection

Land cover map was obtained by digitizing IKONOS image from Google Earth (Basuki et al., 2017b). Based on the previous analysis, the land cover of the study site can be differentiated into old and young teak plantations, paddy field (*sawah*), dryland agriculture, shrub, water body, mixed garden, and settlement (Basuki et al., 2017b). The land cover map of the study site is presented in Figure 2. The catchment size and the percentage of the old teak plantation to the corresponding catchment area for each catchment are presented in Table 1.

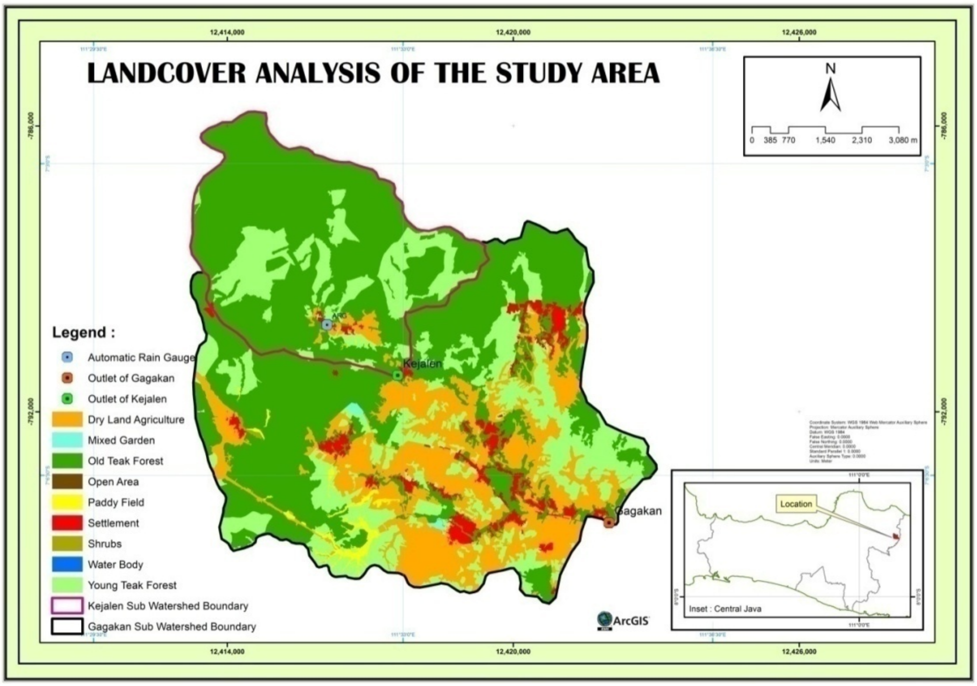

Figure 2. Land cover map of the study area
Source: Basuki et al. (2017)

Table 1. The area and the percentage of teak plantation of the study area

No	Catchment	Area (km^2)	% teak plantation area to the corresponding 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

The spatial distribution of the teak plantation was accessed using remote sensing data, and to provide information of the teak stands field measurements were undertaken in November 2015. During the field campaign, sample plots with 20 by 20 m size were made and the teak stands inside the plots were measured. In this research, young and old teak plantations were differentiated. The result of the field measurements were provided in Table 2, those data were based on Basuki et al. (2017b). Figures 3 and 4 illustrate the young and old teak plantations in the field.

Table 2. The characteristics of the teak plantation

Plot number	Class age of teak plantation	Diameter at breast height (cm)	Average free branch height (m)	Average total height (m)	Average of projected canopy width (m)
1	Young teak	10.5	2.6	7.8	3.5
2	Young teak	16.6	5.6	13.5	4.1
3	Young teak	16.4	4.7	12.6	7.8
4	Young teak	8.0	8.2	8.2	2.3
5	Young teak	13.2	3.1	11.3	4.3
6	Young teak	11.9	5.8	10.7	2.6
7	Old teak	32.4	6,9	18.5	6.8
8	Old teak	49.2	16.3	23.5	10.2
9	Old teak	28.8	10.8	19.9	5.9

Source: Basuki et al. (2017)

Figure 3. The young teak plantation in the study area

Figure 4. The old teak plantation in the study area

To obtain rainfall data, a rainfall gauge was installed inside the catchment areas. The rainfall data were collected every day at 7.00 a.m. Tide gauges were installed at every outlet of the catchments to monitor Stream Water Level (SWL). The SWL was recorded everyday at 7.00 a.m., 12.00.a.m, and 17.00 p.m. To obtain suspended sediment from each catchment, water samples were taken when the SWL increases, at each outlet of the catchment. The water samples, then analysed in laboratory to obtain sediment concentration. In this paper, sediment yield is retristicted to suspended sediment. The rainfall and stream water level data were collected from 2008 to 2015.

Data analysis

The values of stream water level were averaged and converted into stream water discharge (Basuki et al., 2017a,b). The Sediment yield was obtained by conversion of sedimen concentration from the water samples by considering stream water discharge. Five formulas of sediment discharge rating curves from every catchment are provided below. Using the formulas, the discharge was converted into sediment yield.

Modang : $Qs = 4{,}66Q\wedge^{0,99}$..................(1)

Cemoro : $Qs = 1{,}18Q\wedge^{1,33}$..................(2)

Kejalen : $Qs = 0{,}93Q\wedge^{1,37}$..................(3)

Sambong : $Qs = 4{,}92Q\wedge^{0,84}$..................(4)

Gagakan : $Qs = 0{,}86\wedge^{0,97}$.....................(5)

Note:
Qs = Sediment discharge (kg/second)
Q = Discharge (m^3/second)

After calculating the sediment discharge, then regression analysis was conducted between the rainfall and sediment data.

Results and Discussion

Temporal variation of rainfall

In average, dry season in the study area was within three month from June to September, and the rest are classified as wet months. Figure 5 shows observation of monthly rainfall from 2008 to 2015. Based on the rainfall data during the study period, annual rainfall more than 2000 mm were only happened in 2010 which was 2434 mm and 2013 which was 2182 mm. The lowest rainfall occured in 2012 with rainfall depth of 1309 mm.

Sources of sediment in the study areas

Based on the field observations, the sources of suspended sediment in the observed catchments are from soil erosion of dryland agricultural activities which take places among the teak plantations and also from dryland agricultural outside the plantation areas. A sample of a cultivated cassava at the areas among the young or old teak plantation as shown in Figure 6.The cause of soil erosion in the catchment areas is not only derived from agricultural activities, but it is also exacerbated by the nature of the soil and the character of the teak stands. The dominant soil in the study areas is Vertisol which consists of montmorillonite mineral (Djordjevic et al., 2012). This mineral has unique characters which is swelling when the soil wet, srinking and cracking when the soil is dry (Kovda et al., 2010). Swelling on rainy days causes diperse clay particles of soil aggregate (Shabtai et al., 2014). The dispersion causes the soil to erode and transport to a lower place even to the stream as suspended sediment.

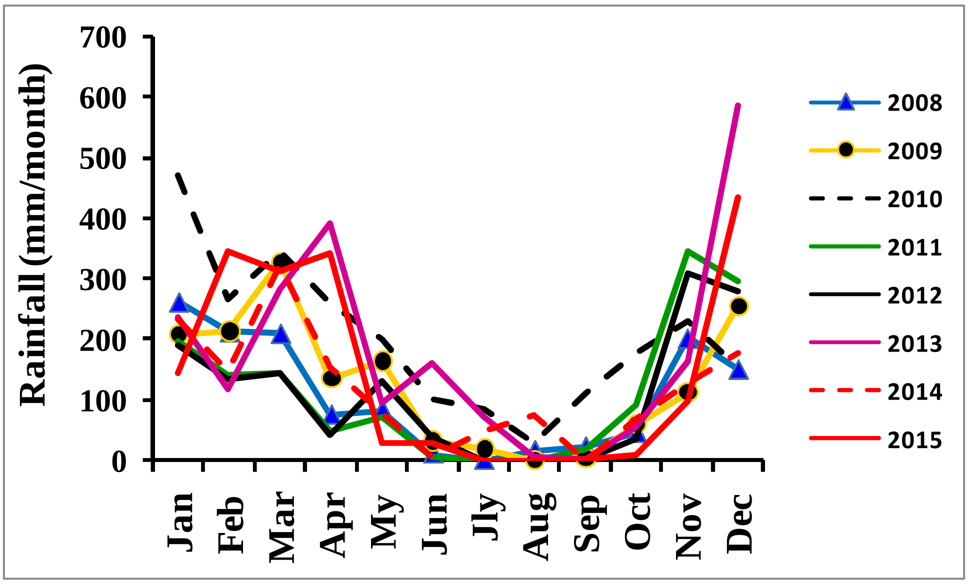

Figure 5. Monthly rainfall of the study area

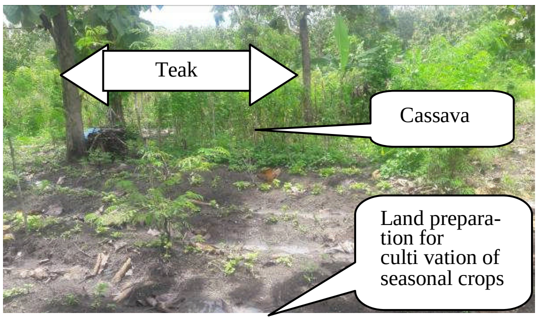

Figure 6. Cultivated areas among teak plantations

Cracking at a dry season can reach 50 cm depth, at least 1 cm wide and washing materials on surface soil in the cracks (Aydinalp, 2010). A deeper chrack (100 cm depth and 1-2 cm wide) in Trigay, Northen Ethiopia has been found by Araya et al. (2011).

A unique characteristic of the teak plantations in the study area is that the teak stands release their leaves in dry season. The impact of this characteristic on soil erosion has being debate among researchers. Fernandéz-Moya et al. (2014) have measured that erosion under teak plantations at slope lands from 30 to 60% in Guanacaste, Costa Rica during 14 months are 6.7 t/ha at mature teak and 7.2 t/ha at young clones. Therefore, Fernandéz-Moya et al. (2014) have argued that falling leaves of the teak stands during the dry season and approaching the rainy season does not lead to soil erosion.

On the contrary, a previous study conducted by Acre and Avarado as cited by Fernandéz-Moya et al. (2014) at the same place, have examined that the soil erosion at teak plantation at intermediate age are from 162 to 190 t/ha/year. According to Fernandéz-Moya et al. (2014) these differences are caused by differences in plantation management. At the time when Acre and Averado conducted their research, the forest floor are clean without understory and litter, and therefore on rainy days this condition subject to soil erosion. The energy of direct rainfall from the atmosfer or rain drops from teak branches will disperse the aggregate soils. Soil erosion in the current study area based on plot measurements is 5.55 t/ha/year at age class I (≤10 years old) and for age classes V (≤50 years old) is 1.76 t/ha/year (Supangat et al., 2014). The amount of soil erosion can increase drastically when the teak stands are dried (*in Indonesia*: *diteres*) in order to reduce water content in the stem before harvesting (Supangat et al., 2014). When the teak stems being dried, there are no leaves at branches and if the soils under these condition are planted seasonal crops then the erosion become worse and it can reaches 236.7 t/ha/year (Supangat et al., 2014). Teak plantations without leaves due to drying process of the stems are presented in Figure 7 and because of dry season is provided in Figure 8.

Besides from agricultural areas, the source of sediment in the river is streambank erosion. As noted by Diodato et al. (2015) the sources of sediment in rivers could be from all of erosion types which are surface, riil, inter riil, gully and streambank erosion. Contribution of streambank erosion on sediment yield is also observed by Rijsdijk et al. (2007) in their study in the upper

Konto catchment, East Java. They have measured that at a short term extreme wet season a contribution of non surface erosion can reach 8% sediment yield of a catchment.

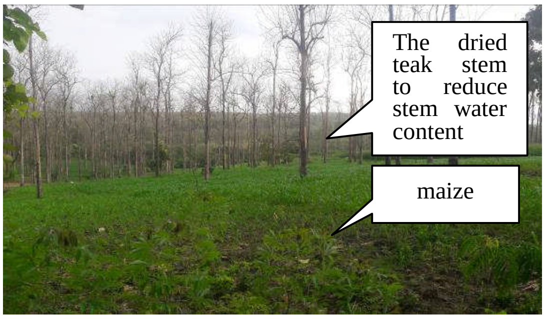

Figure 7. Drying teak plantation in the study area

Figure 8. Teak plantation in dry season at the study area

At an annual basis, the non surface erosion contributes 8 to 119% of annual sediment yield (Rijsdijk et al., 2007). If soil conservation practices are not applied to reduce or prevent strembank erosion, then the sediment concentration in stream water increases. This condition will cause water pollution in the river and disrupt the life of aquatic biota (Russell, 2001; Velentin et al., 2008). Figure 9 shows streambank erosion in the study area.

Temporal variation of sediment yields

Almost all of the areas at Modang and Cemoro catchments are covered by old teak plantation (82%), however it does not guarantee that both catchments are free from erosion and sedimentation because some areas under the teak plantaions are used for cultivation. Besides that, as mentioned previously the source of sediment in the river body is come from streambank erosion. Mean monthly distribution of sediment yield of the observed catchments are provided in Figure 10. The graph in Figure 10 is based on data analysis from 2008 until 2015. It shows that the highest sediment yield in dry and rainy seasons occure in Sambong catchment.

Figure 9. Streambank erosion in the study area

Although the percentage area of the old teak plantation in Gagakan catchment (53%) is lower than in Sambong catchment (70%), however the sediment yields from Gagakan catchment are lower than sediment yields poduced by Sambong catchment. Some possible reasons for this condition is the length of the catchment, the existing landcover, and the micro topography. Since Gagakan catchment is longer than Sambong catchment, then the materials of soil erosion will have more opportunities to deposit in lower areas before reaching the stream and therefore sediment yields from Gagakan catchment lower than that from Sambong catchment. These deposit materials maybe re-suspended and transported later into water bodies (Gao and Puckett, 2012). The second reason is that the Gagakan catchment has wider (579576.7 ha) paddy field area than Sambong catchment (7950 ha), paddy field generally have concave areas to retain water and re-locate materials of soil erosion, thus reduce suspended sediment in the stream. In addition, the percentage of sloping areas in Gagakan catchment is less than in Sambong catchment. Annual variation of sediment yield of the catchments is presented in Figure 11. The highest annual sediment yield occured in 2013 at Sambong catchment (76.5 t/ha) followed by 2010 which is also at Sambong (59.4 t/ha). Although rainfall in 2010 was higher than in 2013, however, the total sediment yield in 2013 was higher than sediment yield in 2010. A possible reason for this situation is the difference in rainfall intensity and rainfall depth. According to Diodato et al. (2012) if high rainfall intensity occur at the beginning of growing season or after harvesting time and the soil only protected by minimum coverage, than it will be more eroded soil and consequently the sediment yield increases.

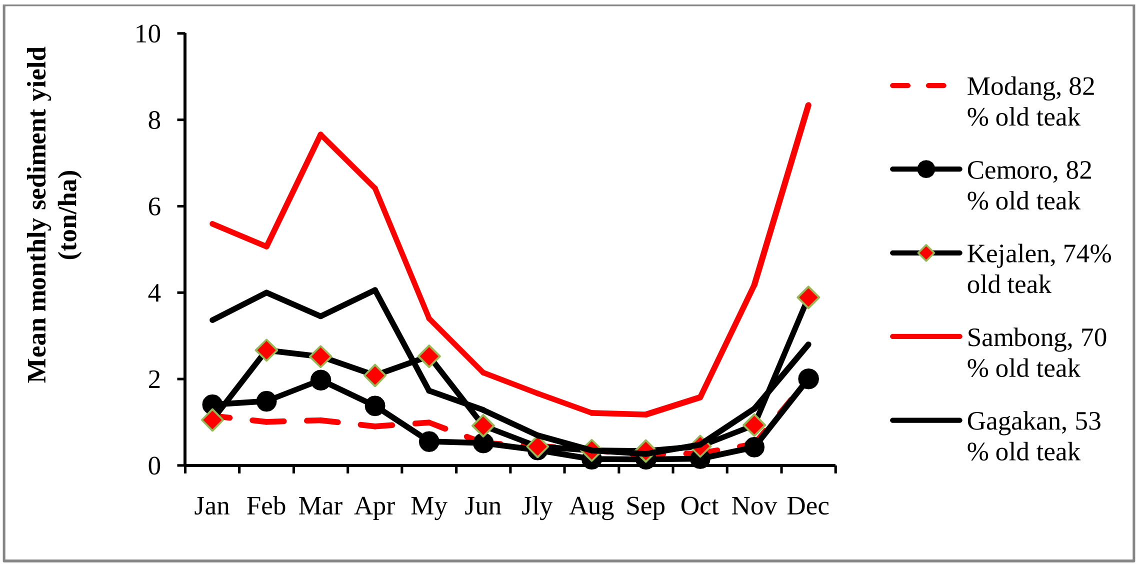

Figure 10. Mean monthly sediment yield of the study area based on data analyses 2008-2015

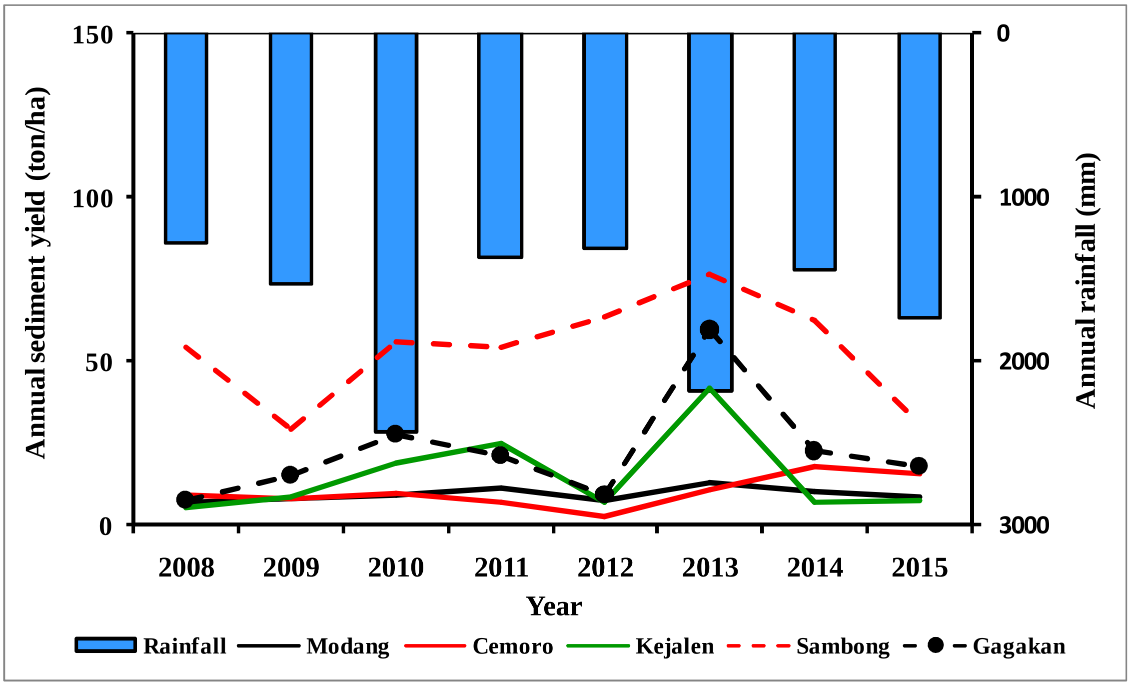

Figure 11. Annual distribution of rainfall and suspended sediment of the study areas

Alternative conservation practices

Eventhough the observed catchments have relatively high teak coverages, in fact erosion and sedimentation remain happen. Therefore, some soil conservation practices should be applied. In this regards the first step is identifying and mapping the sources of erosion especially to recognize the highest erosion-sedimentation source. Afterwards, applying soil conservation practices according to site specific. Considering the easily dispersed Vertisols, it is necessary to stabilize the aggregate soil by maintaining the existing understories and litter plants as source of soil organic matter as well as maintaining soil moisture content. At a sloping land, additional treatment such as vertical mulching or combination of contour terrace with mulching can prevent or reduce soil erosion. Arya et al. (2011) have conducted a study at Vertisols in northen of Ethiopia by applying treatments: 1). a conventional (CT) with no tree tillage operation and removing crop residue, 2). *Terwah* (TR) which consists of CT plus applying contour furrows with 1.5 m intervals, and 3). *Derdero*$^+$ (DER$^+$) is a treatment by applying permanent raised beds with a furrow and bed system, adding standing crop residues and without tillage. This study shows reduction in soil erosion which are from 24.5 t/ha from CT, 20.1 t/ha from TER, and the lowest is from DER$^+$ which is 5.2 t/ha. In addition to Arya's studied as mentioned above, Shabtai et al. (2014) have observed saturated hydraulic conductivity (*Ks*) in Vertisols at northen Ethiopia. It has been observed that in the soil with higher soil organic matter such in Savvanah-woodland, then the *Ks* is higher than in the cultivated land. The higher soil organic matter leads to increase stabilize soil aggregate and *Ks* as well infiltration, and consequently reduces clay dispersion and soil erosion.

Besides soil conservation practices in the agricultural areas, preventing fire during dry period is essential. Fire will burn understory, litter, and soil organic matter in the forest floor. It leads destructtion of soil aggregate and creates soil compaction. Therefore firebreaks must be applied. The firebreaks can be green firebreaks (vegetation), natural or artificial channels

Streambank erosion has a major contribution to sediment yield, therefore conservation practices should be applied to prevent or reduce further damage of the streambank erosion. Stabilization of streambank should be applied. It can be conducted by vegetative methods, civil engeenering structures or combination both of the methods. In addition to those methods, local areal protection along the river basin should applied.

Conclusions

The sources of sediment yield of the observed catchements are from soil erosion at the cultivated areas and from streambank erosion. Quantity of sediment yield of a catchment is not just determined by the area of teak plantation, but also the others land uses which present in the catchment and also rainfall depth. The highest annual sediment yield was 76.5 t/ha with annual rainfall of 2182 mm, this occured in Sambong catchment with 70% old teak coverage. The lowest annual sediment yield was measured in Cemoro catchment with 82% of old teak coverage in 2010 with total suspended sediment of 2.7 t/ha and rainfall of 1309 mm. Soil conservations practices must be applied both in the cultivated areas as well as along the streambank. The application of soil conservation should consider the properties of the soil which is easier to swell in wet condition and to srink in dry condition and consider also the other site specifics. For the future research, quantifying streambank erosion and application of soil conservation practices for stabilizitation of the streambank is a challenge.

Acknowledgements

The research was funded by Watershed Managemnet Technology Center. The author gratefully acknowledge the reviewers for their constructive comments. High appreciation is for my colleagues for helping data collection.

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