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HYDROLOGICAL IMPLICATION OF BAMBOO AND MIXED GARDEN IN THE UPPER CITARUM WATERSHED

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ABSTRACT

The assessment of important factors affecting runoff and erosion was carried out by collecting runoff and soil loss from four runoff/erosion plots. The runoff/erosion plots were set up in sloping areas of about 40% slope in the upper area of Ciwidey sub-watershed (upper Citarum watershed), West Java. The plots (6 x 10 m) were established in the following four sets of conditions: bamboo plantation, mixed garden, small shrub, and agricultural field with different species and stand structures. After 20 rainfall events, a treatment in the form of removing undergrowth and litter were applied to bamboo and mixed garden plots. The result of this before and after treatment are the following: runoff from bamboo plantation was increased from 0.40 to 1.02 litre/m^2 and erosion was increased from 1.47 to 11.65 gr/m^2. While the runoff and erosion in mixed garden were increased from 0.36 to 1.65 litre/m^2 and from 1.36 to 10.88 65 gr/m^2, respectively. When this compared to the runoff and soil loss in the agricultural plot, the soil erosion is much higher, 50.5 gr/m^2 (about 50 times higher). Stand/canopy structure appeared to be the important factors that determine the magnitude of soil erosion. While the role of these factors were less significant compared to rainfall in determining the magnitude of runoff.

Key words: runoff, soil erosion, bamboo and mixed gardens, upper Citarum watershed, West Java

INTRODUCTION

Tropical countries with typical high rainfall intensity and intensive agricultural activities, often without paying attention to soil and water conservation principles, are very susceptible to soil erosion. As noted in the *Indonesian Forestry Policy* [2003], Indonesia's islands have an estimated 458 watersheds, where 96,335,900 ha has been declared critical. Of this, 60 watersheds (31,306,800 ha) have been declared super critical and have been given first priority for rahabilitation through government assistance, community self-support, and private sectors. While the less critical areas of around 65,029,100 ha has been given second and third priorities for rehabilitation. The Citarum watershed in West Java, where Soreang is located at its upper stream area is one of the super critical watershed area. In general, the area of critical upland in Indonesia is increasing at the rate of about 1.5 – 2 million ha per annum. With population densities in these areas averaging 700 people per sq. km, with land holding averaging 0.20 ha or less (>70% of total population), with 30% of the population being landless, and with yields for upland rice and corn averaging 0.5-1.0 ton per ha, the general pattern is one of poor, predominantly subsistence households seeking to increase their immediate basic food requirements by using inappropriate cropping systems [*Anonymous,* 1995]. This results in high soil erosion level and causes the disruption of irrigation canals, dams and water systems and supply, the losses to agriculture, aquaculture and fishing in the lowlands, the disruption of coastal fisheries, and reduces the hydropower capacities.

The uplands erosion problem is part of the overall problem of resources management. Any disruption to lowland resources from upland erosion will inevitably induce greater costs in the allocation of Indonesia's already scarce water supplies, especially during dry season. As Indonesia's population and economy continue to expand, water demands for various competing uses such as drinking water and other residential uses, irrigation, industrial purposes, power generation, recreation, transportation and waste disposal will also increase. While on-site erosion is more quickly observed and falls within the area of the land managers' responsibilities, off-site erosion is not readily observed but can be very serious and generate greater public concern [e.g. *Gilmour et al.*, 1982; *Hewlett,* 1982]. On-site soil erosion affects chemical and physical fertility of the soil. The loss of top soil rich in nutrients and organic matter causes a decrease in soil fertility, land productivity to sustain plant growth, and land degradation [*Ebisemiju,* 1990]. While off-site impacts of soil loss include increased sedimentation and turbidity, increased levels of nutrients and pollutants that diminish water quality, siltation of dams and irrigation channels [*Riekerk*, 1983; *Hopmans et al.*, 1987; *Craswell et al.*, 1997].

In most humid tropical areas, upland users are often inadequately informed about the consequences of their agricultural and other land-based activities on the sustainability of the whole ecosystem (upstream-downstream areas of a watershed ecosystem). The feedback loop after initial planning and implementation of upland resource use back to the planning stage is usually not closed, thus management systems at a watershed scale can be described as not integrated one. Consequently there have been several initiatives to close this loop through appropriate integrated planning, implementing, and monitoring activities [*Smyth and Dumanski*, 1993; *Gomez et al.*, 1996]. On-site erosion study in the upland area as in the case of this study should be used to link with any physical and social consequences in both upstream and downstream areas. In the last few years, the quality of water resource, both surface and ground water became another critical issue. This is partly caused by water pollution from non-point sources which is associated with land-based activities in the upper catchment areas.

Soil erosion measurement can be carried out on-site (at plot level) and off-site (at sub-catchment and catchment levels). The advantages and disadvantages of these two approaches are currently the subject of debate. Many studies on soil erosion have been conducted at sub-catchment or catchment levels. Although this kind of approach can better describe the response of a catchment to certain management practices, instream monitoring is expensive and time-consuming. Upslope or on-site soil erosion measurement, on the other hand, is relatively simple to conduct and inexpensive. This type of measurement is best suited to portraying soil erosion processes and soil disturbances on-site [*Corner et al.*, 1996]. This paper concentrates its analysis on a plot level measurement.

Objectives

This study investigated the impact of different land use types on surface runoff and soil erosion at a plot level. The objectives are: i) to measure and calculate runoff and soil erosion from bamboo, mixed garden, shrubs and agricultural crop; and ii) to measure and calculate the runoff and erosion of bamboo plantation and mixed garden after the undergrowth and litter were removed.

Experimental site

The experimental site is located in sub-district of Soreang, about 20 km southern direction of Bandung in the upper part of Citarum Watershed, West Java (Fig. 1). This research was carried out in the rainy season of November 2004 to April 2005. Slopes are variable but can be as steep as 70%. The site was selected as being representative of the natural vegetation and regional topography of the upstream area of West Java. The research area is a typical upland in an area of hilly terrain with altitude of about 930 m above sea level. The research site is a private lands dominated by bamboo and mixed garden. The bamboo stand is dominated by main species of Bambu Apus (*Gigantochloa sp.*). While common trees found in the study area are locally known as Jengjen (*Albizia falcataria*), Mangga (*Mango sp.*), Akasia (*Accacia sp.*), and other fruit trees such as Nangka, Pete/Jengkol, and Cengkeh. The soil type in this area is mainly dominated by *Inceptisol/Latosol soils* which is sensitive to soil erosion.

The climate of this region is determined primarily by the East and West monsoons and by movement of the intertropical convergence zone. The average annual rainfall recorded at the closest weather station was about 1,200 mm. Most of the rain is convective in origin. Storm sizes can exceed 100 mm on occasions, and rainfall intensities can average 20 to 25 mm per hour for considerable periods. The average annual temperature is around 24°C with atmosphere humidity ranged from 68 to 83%.

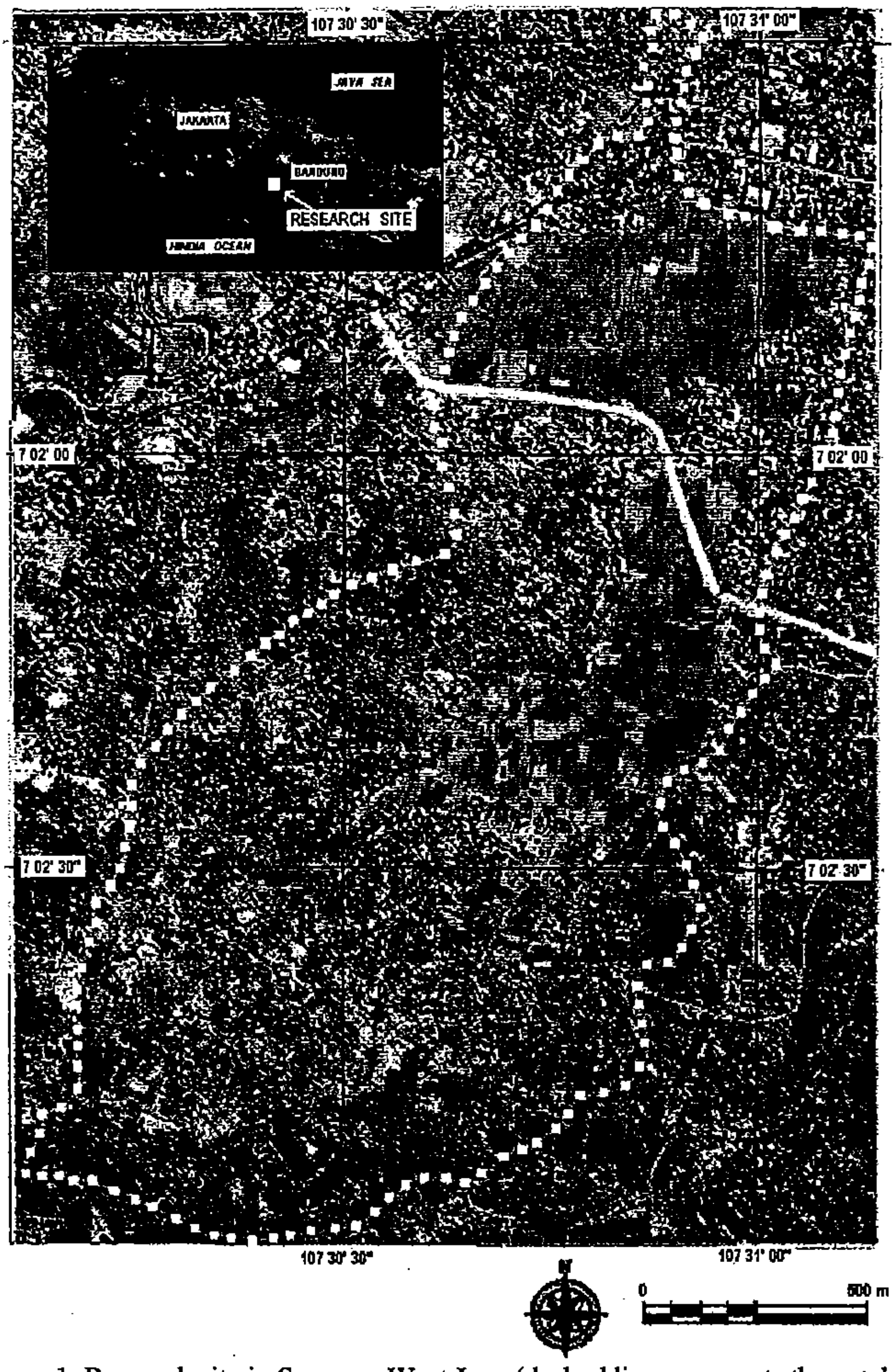

Figure 1. Research site in Soreang, West Java (dashed line represents the catchment area)

THE METHODS

Experimental Design

Four runoff and erosion plots were set up in different sets of land use types. The first runoff and erosion plot was installed in a bamboo plantation, the second plot was installed in a mixed garden, the third was in small shrub, and the fourth plot was in the agricultural field. Special for bamboo plantation and mixed garden, a treatment by removing undergrowth and litter were applied after the first 20 rainfall events. These two land use types with treatment and the other two land types without treatment were then evaluated for runoff and soil erosion comparison. These plots were set up against the contour line. All of these four plots were located in areas with slope steepness around 45%. These four land use types are dominant upland landscape of the Soreang sub-district area.

Grosss rainfall

Gross rainfall was measured using one 0.2 mm tipping bucket rain gauges (ARG100, Campbell Scientific UK) and two simple rain gauges, comprising a combination of an 18.3 cm diameter funnel and a 5 dm^3 plastic container. The tipping bucket rain gauges were erected at a height of 15 m above the ground surface to reduce disturbance caused by their surrounding environment. The two funnel and plastic container rain gauges were installed in an open space, 1 m above the ground. These two manual and one automatic rainfall gauges were located within the same rainfall regime. The purpose of using different rainfall gauges is to investigate whether there will be a significant different between rainfall gauges. Rainfall data were collected after each rainfall event, where a rainfall event was defined as a period of rain with no falls for more than eight hour before and after [*Lloyd and Marques*, 1988]. The rainfall data were collected from November 2004 to April 2005. Unreliable data containing spurious counts resulted from electrical interference, failure in the cable connection, or other disturbance to the manual rain gauges were discarded. Because of these problems, the rainfall data selected for analysis were fewer than all the data collected during the period of field measurement. Data for the analysis of surface runoff and soil loss amounted, therefore, to 20 rainfall events for before treatment and 33 rainfall events for after treatment.

Runoff and Erosion Plots

Runoff and soil erosion were measured using the standard runoff/erosion plots as described in *Morgan* [1996]. The plot borders were made of solid waterproof materials (metals). The edges of the runoff/erosion plots were about 15 cm above the soil surface to prevent splashes of water and soil particles entering the plot. The surface runoff and soil erosion were collected through water collectors (tanks) with the size of 6 m × 0.3 m × 0.2 m. Two collecting tanks of the same size were used for each runoff plot. Surface runoff and sediment from the plot enters the first collecting tank, which splits overflow into seven equal parts and passes one part, a sample, into the second collecting tank of 40-litre size. The number of plots used in this research were four plots with the dimension of 6 × 10 m of each. Volume of surface runoff was calculated by measuring runoff water collected in the available tanks. A sample of 200 ml of water was taken from the tank after thorough mixing to bring all the sediments into suspension. The sample was then taken to the laboratory where the sediment was filtered, oven-dried at 105°C and weighed. For each rainfall event, runoff volume and sediment loss from the plot were calculated.

Data Analysis

Collected data were analysed using a standard *T-test* statistical analysis to determine the effect of different treatments on surface runoff and soil loss from the soil. Similar analysis was also performed to determine whether there is a significant different in gross rainfall measured by manual and automatic rainfall gauges.

RESULTS AND DISCUSSION

The average each rainfall event recorded during the first 20 rainfall events (before treatment condition) was 12.12 mm and ranged from 0.8 mm to 27.96 mm. While the total gross rainfall during the period of study was 242.43 mm. The rainfall data were from three manual rainfall gauges and one automatic 0.2 mm tipping bucket rain gauge. The data were tested by *T-test* showed that there were no significant differences between the rain gauges. These results suggest that the gross rainfall data were sufficiently reliable to be used for hydrological comparison analysis between plot. Table 1 shows the comparison of runoff and soil erosion as a result of different land use types and the removal of undergrowth and litter.

During the before treatment study, the surface runoff was variable according to rainfall event and to the land use and its physical measures. The average surface runoff calculated from the bamboo plantation was found to be 0.40 litre/m^2. About the same compared to surface runoff under mixed garden, but much lower than surface runoff found in both shrub (0.69 litre/m^2) and cash crop condition (0.99 litre/m^2). The logical explanation to these results is that in the steep slope lands, a combination of different perennial tall vegetations, especially in a multi-structure such as natural bamboo and mixed gardens with stratified layers and densed undergrowth or litter, surface runoff is smaller compared to that of the cash-cropping system but with less or without undergrowth. In the case that bamboo plantation's surface runoff is slightly larger than the mixed garden, this is a typical surface runoff from an bamboo plantation with relatively "clean" ground cover and plenty of not-so easy decomposed litters. If this is the case, then it was understood that the "clean" ground cover was held responsible for the higher surface runoff. Similar research result was also reported by *Sinukaban* and *Zubair* [1987 in *Utomo et al.*, 1998] that surface runoff under *Pinus merkusii* forest with also no undergrowth was more than 40% of net precipitation. This is also consistent with research result from other area of the upper Citarum watershed which showed no significant different in surface runoff between *Pinus merkusii* forest without undergrowth and mixed cropping system without soil conservation measures [*Asdak et al.*, 2003].

Table 1. Average runoff and soil erosion in the bamboo and mixed gardens, shrubs, and cash-crop plots, before and after treatment.

	Before treatment	After treatment	Change (times)
Plot 1:			
▪ Runoff (litre/m^2)	0.40 (from 0.003 to 0.98)	1.02 (from 0.03 to 5.59)	2.5
▪ Erosion (gr/m^2)	1.47 (from 0.19 to 6.51)	11.65 (from 0.20 to 122.2)	7.9
Plot 2:			
▪ Runoff (litre/m^2)	0.36 (from 0.01 to 0.98)	1.65 (from 0.02 to 8.27)	4.5
▪ Erosion (gr/m^2)	1.36 (from 0.13 to 5.95)	10.88 (from 0.07 to 176.6)	8.0
Plot 3*:			
▪ Runoff (litre/m^2)	0.69 (from 0.01 to 1.00)	-	-
▪ Erosion (gr/m^2)	5.53 (from 0.10 to 6.12)	-	-
Plot 4*:			
▪ Runoff (litre/m^2)	0.99 (from 0.02 to 3.68)	-	-
▪ Erosion (gr/m^2)	50.5 (from 0.45 to 357.6)	-	-

Notes: treatment is removing undergrowth and litter; Plot 1: bamboo garden; Plot 2: mixed garden; Plot 3: shrubs and Plot 4: agricultural crop (*kacang kecapi/long bean*); * no treatment

When treatment was applied by removing undergrowth and litter in both the bamboo and mixed garden plots, runoff for both land use types increased significantly, from 0.40 to 1.02 litre/m^2 (2.5 times) and from 0.36 to 1.65 litre/m^2 (4.5 times), respectively. This after treatment surface runoff is comparable to that of agricultural condition and higher than small shrub condition. This is indicating that undergrowth including small shrubs and litter are playing an important factor in reducing runoff. But when the statistical analysis was used to investigate the different treatments on surface runoff. The result indicates that the difference was not significant at $p = 0.05$. This may be because runoff was strongly determined by ranfall events, and when different rainfall events were standardized (by keeping rainfall as covariate in the analysis), runoff on the different plots was not significantly different. This is also in line with similar study of runoff and soil loss in logged and unlogged tropical forest areas of Central Kalimantan [*Hartanto et al.*, 2003].

In the case of soil loss, different land use and its associated physical measures had given significant effects on soil erosion, especially between those plots with densed and stratified canopy structures and intensive agricultural condition. In bamboo plantation and mixed garden, the average soil loss were about the same, i.e. 1.47 and 1.36 gr/m^2, respectively. This is much lower than soil loss in the small shrub at Plot 3 (5.53 gr/m^2). But, if compared to soil loss under intensive agricultural condition (Plot 4), the soil erosion in the bamboo and mixed garden is much smaller (around 50 times smaller). This high erosion rate from intensive agricultural field is in line with research result from other upland area in the upper Citarum watershed. *Asdak et al.* [2003] reported that average erosion from mixed cropping system in the uppermost Citarum watershed, especially if no soil conservation measure is applied, was 13.08 gr/m^2 compared to only 3.69 gr/m^2 from monoculture forest plantation of *Pinus Merkusii.*

The likely reason why the soil erosion in these two land use types are greatly different seems to do with large portion of soil agregates in the agricultural land was exposed directly to rainfall. This argument is consistent with the fact that when undergrowth and litter in both the bamboo and mixed garden were removed, soil loss increased from 1.47 to 11.65 gr/m^2 (7.9 times) and from 1.36 to 10.88 gr/m^2 (8.0 times), respectively.

The above research results, particularly the effect of land cover on soil loss confirms previous studies that the important factor for preventing soil erosion is determined more by the stratification of plant canopies and the condition of undergrowth including ground litter. The multi-layers of plant canopies and dense undergrowth provide a good mechanism for preventing or reducing soil erosion. This is in line with the result of erosion study in a plantation forest of *Acacia sp.* in Jatiluhur and mixed forest in Ciwidey, West Java as shown in Table 2.

Table 2 shows that under natural condition (multi-layers, undisturbed ground cover and litter), soil erosion in mixed forest was found to be 14.95 kg/plot. The soil erosion was increased by 2.5 times (38.65 kg/plot) when the undergrowth of the same forest stand was taken out. And the increased in soil loss became 39 times (586.65 kg/plot) when both undergrowth and the forest litter were removed. Similar result was also found in *Acacia* forest condition where removing undergrowth and litter increased soil erosion by 146 times. Even though much smaller in magnitute, similar result was found in bamboo plantation and mixed garden in Soreang, West Java. This indicates clearly that the forests or tall vegetation stands were not always better in preventing or reducing soil erosion unless they have multi-layers canopies with undisturbed undergrowth and ground litter.

Table 2. The role of undergrowth and litter on soil erosion

Treatment	Mixed Forest[1] [kg/plot]	*Acacia* Forest[2] [kg/m^2/yr]	Bamboo Garden[3] [gr/m^2]	Mixed Garden[3] [gr/m^2]
Control	14.95	0.003	1.47	1.36
w/oundergrowth	38.65 [2.5]	0.006 [2.0]	-	-
w/o undergrowth and litter	586.65 [39]	4.39 [146]	11.65 [7.9]	10.88 [8.0]

Source: [1]*Coster* [1938]; [2]*Institute of Ecology* [1983]; [3]*Asdak* (this research)

CONCLUSION

We found that rainfall, slope steepness, stand/canopy structure, and soils are important factors that determine runoff and soil erosion. Setting the slope steepness and soils as constant factors, making rainfall and stand/canopy structure played key roles in determining the magnitude of runoff and soil erosion. For the mixed cropping systems, the existence of well maintained terrace and drainage system is very important in preventing soil detachment and slowing down running water, and hence, making more rainfall to infiltrate into the soil. But, in sloping lands with high rainfall intensities, the existence of multi-layering plant canopies, undergrowth, and ground litter is very important to reduce both runoff and soil erosion. This suggests that in the humid tropical areas such as most parts of West Java, for critical or degraded forest areas to be hydrologically functional, the degraded areas could be left natural so that natural mechanism could do its self-recovery processes.

Implication from this plot level study of runoff and erosion suggests that it is important to produce regulations, insentives, and other means that encourage upland users manage their agricultural lands in a way that compatible with the soil and water principles. If one can make the upland users to do this, and at the same time, lowland users of water resource can be made understand that the water that they use is depend on the way the upland users manage their lands, thus a financial mechanism where downstream users of water resource contribute to support upland users of land to be more conservative can be established. With this, the benefits and costs can be evenly distributed to both upland and lowland users. It is expected that the funding required by the upland farmers for their participating in soil and water conservation programs can be continously supported by the lowland users without being dependent on government "project" activities.

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