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Hydrological Implication of Traditional Farming Systems: A Case Study in the Upper Citarum and Cimanuk Watersheds, West Java

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Abstract: The assessment of important factors affecting runoff and erosion was carried out by collecting runoff and soil loss from runoff/erosion plots. The runoff/erosion plots were set up in sloping areas of about 40% slope in two different places of the upper parts of Citarum and Cimanuk Watersheds, West Java, Indonesia. The plots (6×10 m) at the upper Citarum were established in the following four sets of conditions: bamboo garden, mixed garden, small shrub and agricultural crops 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 results of this before and after treatment are the following: runoff from bamboo garden was increased from 0.40-1.02 L/m^2 and erosion was increased from 1.47-11.65 g/m^2. While the runoff and erosion in mixed garden were increased from 0.36-1.65 L/m^2 and from 1.36-10.88 65 g/m^2, respectively. When this compared to the runoff and soil loss in the agricultural plot, the soil erosion is much higher, 50.5 65 g/m^2 (about 50 times higher). These results will then be compared to the similar field-plot based measured in the upper Cimanuk watershed for a comparative study purpose. For both cases, 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: Land use change, soil erosion, runoff, upper Citarum and Cimanuk watersheds, Indonesia, magnitude

INTRODUCTION

Tropical countries with typical high rainfall intensity and intensive agricultural activities, often without paying attention to soil and water conservation are very susceptible to soil erosion. As noted in the Indonesian Forestry Policy, Indonesia's Islands have an estimated more than 450 watersheds which indicates that the critical watershed is increasing overtime. In 1984, the number of very critical watersheds were identified to be 22 and increased to 39 watersheds in 1992 (Bruijnzeel, 1990). The very critical watersheds were then increased to be 62 in 2005 and in 2012, the critical watershed were becoming 108 (MF, 2012). These are critically degraded in dry land areas will be rahabilitated through government assistance, community self-support and private sectors. The Citarum and Cimanuk watersheds in West Java are among the 108 very critical watershed areas. In Java island, the area of critical upland is increasing at the rate of about 350,000 ha per annum and now totals over 2 million ha, approximately one third of Java's cultivated uplands (Lloyd and Marques, 1988). With population densities in these areas averaging 700 people per km^2 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/ha, the general pattern is one of poor, predominantly subsistence households seeking to increase their immediate basic food requirements by using inappropriate cropping systems. 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 (Brooks *et al*., 1994).

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

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uses such as drinking water and other residential uses, irrigation, industrial purposes, power generation, recreation, transportation and waste disposal will also increase (Bosch and Hewlett, 1982). While on-site erosion is more quickly observed and falls within the area of the land manager's responsibilities, off-site erosion is not readily observed but can be very serious and generate greater public concern, e.g. (Gregersen *et al*., 2007). 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 (Gregersen *et al*., 2007).

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 (Asdak, 2010; 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 year, the quality of water resource, both surface and ground water became another critical issue. This is partly caused by water pollution from non-point a source which is associated with land-based activities in the upper catchment areas.

Objectives: This study investigated the impact of land use change and agricultural activities on surface runoff and soil erosion at a plot level. The objectives are: to measure and calculate runoff and soil erosion from mixed cropping systems (with and without soil and water conservation measures) and monoculture *Pinus merkusii* forest areas and to measure and calculate the loss of macro nutrients of N, P and K as a result of soil erosion.

Experimental sites: The experimental sites are located in the uppermost part of Citarum and Cimanuk Watersheds, West Java, Indonesia. 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 1500-1550 m above sea level. The soil type in this area is mainly dominated by regosol and clay humic 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 2548 mm over 11 years (1990-2000) of rainfall measurement at Citarum and an average of 2500 mm of upper Cimanuk watershed. Most of the rain is convective in origin. Storm sizes can exceed 100 mm on occasions and rainfall intensities can average 20-25 mm per hour for considerable periods. The average annual temperature is around 24°C with atmosphere humidity ranged from 68-83%.

MATERIALS AND METHODS

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 rainfall data were collected during rainy season from October-December 2014. Data for the analysis of surface runoff and soil loss are 19 rainfall events in the upper Citarum and 30 rainfall events in the case of upper Cimanuk watershed.

Runoff and erosion plots: Runoff and Soil erosion were measured by using the standard runoff/erosion plots as described by Morgan (1996). The plot borders were made of solid waterproof materials (metals). The edges of the runoff 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 4×0.3×0.3 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. The number of plots used in this research were six plots with the dimension of 4×20 m of each plot. These six plots represent three treatments which will be evaluated their impact on runoff and soil erosion including the macro nutrient loss resulted from the soil erosion. In the case of the upper Cimanuk, the number of plot were three with dimension of 4×22 m of each plot laid out in agroforestry formation. These runoff and soil erosion measurements were conducted at area with slope steepness between 45 and 50%.

Volume of surface runoff was calculated by measuring the height of the water in the first and second collecting 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.

RESULTS AND DISCUSSION

During the period of the study (19 rainfall events), the surface runoff was variable according to rainfall event and to the land use and its physical measures. The average surface runoff calculated from mixed cropping system with soil and water conservation measures was found to be 18.23 L per plot (ranged from 0.23-61.73 L). Lower than surface runoff found in the *Pinus merkusii* forest (26.01 L and varied from 0.60-160.25 L) and much lower than surface runoff from mixed cropping system without soil and water conservation measures of 27.63 L (varied from 0.30-92.48 L per plot). The logical explanation to these results is that in the steep slope lands, a combination of different crops (seasonal and perennial), especially in a multi-cropping system such as agroforestry system with stratified layers and densed undergrowth, surface runoff is smaller compared to that of the similar multi-cropping system but with less or without undergrowth. In this experiment, the two mixed cropping systems were generally comparable in terms of crops combination and stratification. The only difference was that the first mixed cropping system was combined with terrace and drainage system (water ways) and the second mixed cropping system was not. It seems that the non-existence of the terrace and water ways have increased the surface runoff. In the case of *Pinus merkusii* forest, the surface runoff was higher than the mixed cropping with soil and water conservation measures and only slightly lower than that of the mixed cropping without soil and water conservation measures. This is a typical surface runoff from an even age Pine forest plantation with single layer and relatively "clean" ground cover. In the case of *Pinus merkusii* forest, it was found that this forest stand produces a substance that prevents undergrowth from growing (Manan, 1998). If this is the case, then it was understood that the single layer of this *Pinus merkusii* forest stand and the "clean" ground cover were responsible for the higher surface runoff. Similar research result was also reported by Utomo *et al*. (1998) that surface runoff under *Pinus merkusii* forest was >40% of net precipitation. Assuming that the present land use and other biophysical conditions remains the same, the estimated surface runoff in the mixed cropping system with soil and water conservation measures would be about 401,526 m^3/ha/year. Following the same assumptions, the estimated surface runoff in the mixed cropping system without soil and water conservation measures and in the *Pinus merkusii* forest areas would be 607,263 and 611,380 m^3/ha/year, respectively.

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 rainfall 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. In the mixed cropping system with soil and water conservation measures the results showed that soil loss varied from 0.13-4.75 g/m^2 with the average of 1.39 g/m^2. In the mixed cropping system without soil and water conservation measures, the soil loss was much greater and varied from 0.50-95 g/m^2 with an average of 13.08 g/m^2. In the monoculture forest plantation of *Pinus merkusii*, the soil loss resulted from the 19 rainfall events study ranged from 0.38-15.63 g/m^2 with an average of 3.69/m^2.

A simple t-test analysis was used to investigate the effect of land use (agriculture and forest practices) and engineering measures (terracing, drainage system) on soil loss including macro-nutrients of N, P and K. The results of the test indicate that there were a significant different (at $p = 0.05$) in soil erosion between the mixed cropping system without soil and water conservation measures and the mixed cropping system with soil and water conservation measures. The same result was also found when comparing the mixed cropping system without soil and water conservation measures with the monoculture of *Pinus merkusii* forest stand. However, there were no significant different (at $p = 0.05$) in soil loss between the mixed cropping system with soil and water conservation measures and the *Pinus merkusii* forest stand. This results showed that in sloping lands of the research site, an appropriate terracing combined with a proper drainage system in a well maintain condition could give a good hydrological effect. In a little less effective way, the *Pinus merkusii* forest stand had also reduced soil erosion. The effect of this forest plantation in reducing soil loss was not better than the mixed cropping system with soil and water conservation measures 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. 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 *Accacia* sp., in Jatiluhur, West Java. Under natural condition (multi-layers, undisturbed ground cover and litter), soil erosion 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 (Asdak, 2010). This indicates clearly that the forests were not always better in preventing or reducing soil erosion unless they have multi-layers canopies with undisturbed undergrowth and forest litter. This is not the case for the *Pinus merkusii* forest in the study site.

The laboratory analysis showed that the average Nitrogen loss resulted from soil erosion in the *Pinus merkusii* forest area was the highest with 1.70% followed by the mixed cropping with soil and water conservation measures (0.60%) and the smallest was in the mixed cropping without soil and water conservation measures (0.39%). Other macro-nutrient loss as a result of soil erosion was Phosphor. The average loss of Phosphor during the period of the study was also variable with the average loss of about 1.87 ppm for both mixed cropping systems (with or without soil and water conservation measures) and about 2.80 ppm in the *Pinus merkusii* forest area. And finally, the highest amount of Kalium loss as a result from soil erosion was found to be 21.60 me/100 g in the *Pinus merkusii* forest area. Followed by the mixed cropping system with soil and water conservation measures (10.63 me/100 g) and the mixed cropping system without conservation measures (8.53 me/100 g). However, the different in macro-nutrient (N, P and K) loss between treatments was found to be not significant (t-test analysis at $p = 0.05$).

In the case of the upper Cimanuk watershed, Devianti (2015) shows that structure and density of the vegetation canopy determines the amount of run-off and soil erosion. In her plot-level observation on agroforestry landscape at maximum rainfall of 88 mm, measured run-off and erosion from three run-off plots were as follow: 1.49 mm and 16.57 kg/ha (the most dense canopy structure), 1.59 mm and 275.01 kg/ha (the medium canopy structure) and 1.70 mm and 304.77 kg/ha (the least dense canopy structure). While, at a maximum rainfall intensity of 6.34 cm/h, the measured run-off and erosion from the same three plots are as follow: 0.8 mm and 29.67 kg/ha (the most dense canopy structure), 2.67 mm and 221.26 kg/ha (the medium canopy structure) and 5 mm and 464.78 kg/ha (the least dense canopy structure). These results indicated that as in the case of the upper Citarum, the structure of the canopy determines the amount of run-off and soil erosion.

CONCLUSION

It was found that rainfall, slope steepness, soils, soil and water conservation measures and especially stand/canopy structure are important factors that determine runoff and soil erosion. Setting the slope steepness and soils as constant factors, making rainfall, stand/canopy structure and soil and water conservation measures 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, poor constructed terrace and drainage system could increase runoff and soil erosion. For monoculture forest stand, the existence of multi-layering plant canopies, undergrowth and forest 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. Coster (Soemarwoto, 1989) in his hydrological study in Ciwedey (also in the upper Citarum), West Java showed that in only four to 6 months time, hydrological function (runoff and erosion) of a disturbed forest area had been back to its natural (before disturbed) condition provided that people can be kept off from the degraded areas. Available funding could then be channeled to create more off-forest economic activities so that population pressure on forest and critical lands can be reduced or eliminated.

Implication from this plot-level study of runoff and soil 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 continuously supported by the lowland users without being dependent on government “project” activities.

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