Catchment Size and Land Management Systems Affect Water and Sediment Yields

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Abstract: The largely plot-scale research and extrapolation of the results to catchment scale caused an overestimation of catchment-scale soil loss and in turn a blame of poor upland farmers as the main contributor of stream and river sedimentations. We initiated in Central Java in 1999 research with the objective to compare sediment yield and runoff from three micro catchments having different sizes and land uses. Babon micro-catchment, in which this research was conducted, covers an area of about 285 ha. Three (sub-)micro catchments of interest are located within the Babon micro-catchment and they are Tegalan (1.1 ha; used for annual upland crops and a few irregularly-spaced trees), Rambutan (0.9 ha; used for Rambutan orchard (*Nephelium lappaceum*)), and Kalisidi (13 ha; also used for Rambutan) micro catchments. Each of the micro catchment has inter-mitten flow, but the Babon micro catchment has a perennial flow. Automatic water-level recorders for five minutely water level recording and staff gauges for three-times-daily water table manual recording have been installed for the determination of runoff water volume. A six-minutely recording rain gauge was installed about the centre of the Babon catchments. On 7 February 2001 during which the total rainfall was 56 mm, the peak of the runoff discharge was reached 18 minutes after the peak of rainfall intensity for Tegalan compared to 24 minutes for the other two catchments. The total water discharge per unit area of Tegalan, Rambutan and Kalisidi catchments were 6.4 mm, 1.3 and 9 mm, or corresponded to 12, 2, and 16 % runoff coefficient, respectively for this particular event. Tegalan catchment with the least plant and litter covers was most exposed to the raindrops and thus readily yields water. The lower 4 ha area of Kalisidi catchment, however, has been encroached by the local villagers who claimed their right for the land. Although the rambutan trees remained intact in this catchment, the orchards' floor near the outlet was exposed to both direct raindrops and rambutan canopy drips. Thus Kalisidi catchment did not have longer lag time for peak run-off discharge than the Rambutan catchment. One year discharge record was started in March 2000 and runoff coefficients for all catchments were very low, and was the highest (0.14) for Kalisidi catchment and followed by Tegalan and Babon catchment of about 0.05 and 0.02, while for Rambutan catchment it was 0.01 despite the high amount of annual rainfall (3,800 mm). As expected, sediment yield was the highest from the Tegalan catchment because of minimal soil surface litter and little canopy cover. We also noted that for Tegalan and Kalisidi catchments the suspended sediment contributed significantly to total sediment yield because of soil surface exposure to rain and/or canopy drip drops.

Keywords: land use, catchment size, discharge, sediment yield

1 Introduction

Land degradation brought about by soil erosion intensified due to more intensive land use, but there has been lesser protection measures implemented for erosion prone steep lands. Soil conservation implementation has been considered as a low priority among most farmers because many recommended conservation technology options are expensive and do not promise direct and short term profits for the rural poor (Agus *et al*., 1998). Researchers in many parts of the world have not successfully developed on-farm technologies that can address both the very needs of the poor farmers and securing the upstream as well as downstream natural resources (Garrity and Agus, 1999; Shaxson, 1999).

Recognition the greater threat to natural resource sustainability led us to a re-examination of approaches to research on sustainable land management. A participatory catchment management research using an integrated and interdisciplinary approach has evolved and has been adopted by the Management of Soil Erosion Consortium (MSEC) of the International Water management Institute (IWMI) in its research network, including for the current work in Indonesia. The overall objectives of this research is to develop natural resource- and community-based land management options for sustainable and profitable land uses and evaluate their effects on soil loss, runoff, and farmer's profit. This paper addresses specific objective on quantifying and evaluating water and sediment outflow from catchments having different sizes and land use systems.

2 Materials and methods

2.1 The site setting

This micro-catchment scale research was started in late 1999 at Babon Micro Catchment, a portion of Kali Garang Watershed in Central Java province located at the lattitude of 07° 20′ S and Longitude of 110° E; at elevation between 390 to 510 m asl. The soil was classified according to Soil Taxonomy Classification (Soil Survey Staff, 1996) and the transect describing the land use and soil great groups have been presented in Agus *et al*. (2001). Slope ranged from 15 to 75%, and Tegalan catchment having a slope of 45—47 is the steepest one under this study. Brief description of the three microcatchments is given in Table 1. Kalisidi and Rambutan catchments are dominated by rambutan tree (*Nephelium lappaceum*). Their difference in size will give an idea whether the difference in catchment size will lead to a significant difference in sediment yield. Tegalan and Rambutan catchments have similar sizes but very different land management system.

Table 1 Characteristics of the catchment

Catchment	Area (Ha)	Runoff Coefficient[1)]	Dominant Soil Order/Subgroup	Landuse/ Farming System	Dominant slope (%)
Tegalan	1.1	0.05	Andic Eutropepts	Cassava, maize	45 — 47
Rambutan	0.9	0.01	Andic Dystropepts	Rambutan, Shrub	22 — 55
Kalisidi	13	0.14	Andic Dystropepts	Rambutan	22 — 55
Babon	285	0.02	Typic Tropaquepts	Combination of the above, plus several other uses	15 — 75

[1)] Based on the calculation from March 2000 to February 2001.

Around 55 % of the area is steep to very steep (25 to 55 % slope) and only a small portion of the valley bottom has gentle and undulating slopes. Most of the land, including parts of the annual upland area and the lowland rice fields, have been bench terraced but signs of serious erosion could be observed despite the terraces. At the valley bottom of the Babon catchment exist streams and this enables terraced lowland rice production system.

Land tenure system in Kali Garang watershed is variable. The lowland rice fields, having the size from 0.01 to 0.5 ha, are cultivated either by owners or shareholders. One farmer could farm on more than one small plot. The same pattern of tenure system and farm size are found in the upland areas especially on food-crop based upland fields. Land in Kalisidi and Rambutan catchments are owned by companies based in Semarang, the capital city of the province. Most villagers considered themselves as farmers although about one-third of them work off-farm from which several families can generate income higher than from the on-farm sources. During the off-season many villagers take off-farm employment in construction, sand mining and trading sectors to complement the on-farm income. From the on-farm sources only about 22 % of the villagers can make > $ 200 annual income, while from the off-farm, around 40 % of the village work force could generate > $200 annual income. The main reasons for low on-farm income include small farm size, low inherent soil fertility, planting of low value crops, and low input technology implementation.

Field survey of land use conducted in April 2000 revealed 10 land uses in the 285 ha Babon catchment. Paddy fields are lying along the valley bottom, and various dryland crops, including rambutan (*Nephelium lappaceum*), annual food crops, bushes, nutmeg (*Myristica fragrans*) and intercropping of cassava (*Manihot esculenta*) with various parennial crops including coconut (*Cocos nucifera*), sego (*Arena pinnata*), robusta coffee (*Coffea robusta*), durian (*Durio zibethinus*) and banana (*Musa paradisiaca*) are found on the upper and the middle slope. Further landuse description is given by Agus *et al*. (2001). In general the local farmers implement low input agriculture. For annual upland crops, farmers usually plant cassava, peanuts and corn with cassava being the most preferred one because of low input requirement, resistance to drought, pests and diseases and adaptability to low soil fertility. Long-term investments for soil conservation is unattractive among farmers and thus low cost and direct income generating or food producing investments are more preferred.

2.2 Hydrological characterization

Each of cathcment Tegalan, Rambutan, and Kalisidi is delineable micro catchments within the Babon catchment and thus the calculation of each of their hydrological characterization could be done separately. Four units of automatic water level recorders (AWLR), one at each microcatchment outlet, has been installed. V-notch weirs were installed at the outlet of each of catchments with intermitten flow (Rambutan, Tegalan and Kalisidi) and a unit of Parshal Flume was installed at the outlet of Babon catcment. Each set of water level/water discharge measuring instrument was supplemented with a staff gauge and one unit of automatic weather station have been installed for the entire Babon catchment.

For sediment traps of Rambutan, Tegalan and Kalisidi, before the water level reaches the base of V-notch weir, discharge was calculated as the change in the water volume in the trap divided by time interval between measurements. When the water level reaches the V-notch, the discharge is calculated according to the following relationship:

$$Q = 8/15 \times SQRT\,(2g) \times CD \times \tan(\theta/2) \times h^{2.5} \times 60{,}000$$

Where, Q is discharge (l/minute)

g is the gravity (9.8 m/sec^2)

CD is the correction factor of discharge

θ is angle of V-notch

h is the water level, measured from the base of V-notch.

60,000 is conversion from m^3/h to L/min

Five minutely water level data is obtained from the automatic recorder and compared for accuracy with the manual readings of staff gauges. The staff gauge reading were done three times daily at 08.00, 12.00, and 16.00 h. Water discharge from each cathment was determined in terms of water thickness (mm) to make direct comparizon with rainfall. Bed load from different sediment traps were weighed and determined for water content after every rainfall event. Rating curve for suspended sediment concentration were developed and frequent check was conducted for selected rainfall event.

3 Results and discussion

3.1 Water discharge

Fig.1 illustrates the relationship between rainfall and water discharge from each of the three micro catchments and the Babon catchment on 7 February 2001 during which the total rainfall was 56 mm. The Tegalan catchment was most responsive to rainfall. With a light rain intensity at the beginning of the event, from 13:18 to 13:54 hr there was measurable discharge already occurring. When the rainfall intensity increased and reached the peak at 14:12 the increase in Tegalan catchment discharge followed and the peak of the discharge was reached at 14:30, that was only 18 minutes following the peak of rainfall intensity. The discharge from the other two catchments (Rambutan and Kalisidi catchments) commenced after the rainfall reached the peak intensity and the peak discharge was reached at 14:36, that was 6 minutes later than that of Tegalan catchment. For the whole Babon catchment (with perennial stream) the peak discharge was reached at 14:48 and that was 36 minutes following the peak rainfall intensity (Table 2). From the hydrograph it is also noticeable that the total water discharge per unit area (area below the discharge graph) coming out of the Tegalan catchment, was considerably higher than that of Rambutan and slightly higher than that of Kalisidi catchment.

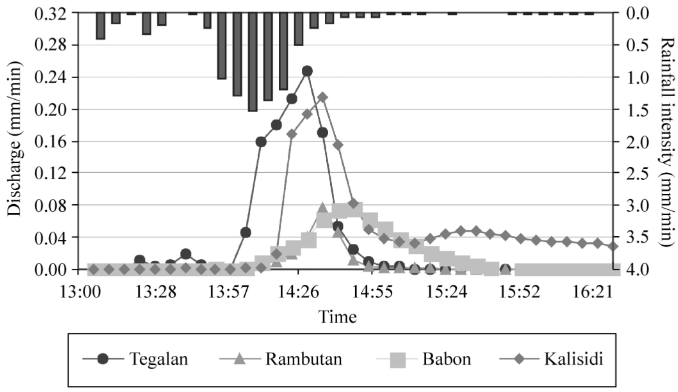

Fig.1 The relationship between rainfall intensity and runoff water discharge from Tegalan, Rambutan, Kalisidi, and Babon catchments for the rainfall event of 7 February 2001

Table 2 Rainfall, discharge, and runoff coefficients for Tegalan, Rambutan, Kalisidi, and Babon catchments for the 7 February event with the rainfall of 56 mm

Variable	Catchment			
	Tegalan	Rambutan	Kalisidi	Babon
Discharge (mm)	6.9	1.3	9.0	3.3
Runoff coefficient	0.12	0.02	0.16	0.06
Time lag from peak rainfall to peak discharge (minutes)	18	24	24	36

Data trend in Table 2 seems to be attributed to the difference in land cover. Tegalan catchment with the least average plant and litter covers (mostly annual upland crops) was most exposed to the raindrops. Being a relatively small sized catchment, the travel distance of the runoff water was the shortest such that the water reached the catchment outlet the quickest.

Kalisidi catchment showed a very long tail in its hydrograph. During the rainy season the catchment almost continually yielded water and this could be attributed to the relatively large catchment size and good cover by the Rambutan trees on most parts of the catchment, but there was also influence of spring water in the upper part of the catchment that was not measured. The lower slope of this catchment (near the outlet), however, has been encroached by the local villagers who claimed their right for the land that is now legally titled to a city based company in Semarang. They planted these part to annual crops such as taro and cassava. In February 2001 about 4 ha of the 13 ha catchment has been encroached. Although the rambutan trees remained intact, the orchards' floor near the outlet was exposed to both direct raindrops and rambutan canopy drips. Thus Kalisidi catchment did not have longer lag time to reach peak run-off intensity than the Rambutan catchment despite its considerably larger size. Kalisidi catchment behaved similar to Tegalan catchment in terms of releasing runoff water and similar to other large catchment in terms of the long tail in its hydrograph following the rainfall event.

Yearly run-off coefficient for most catchments in general was low, and was the highest (0.14) for Kalisidi catchment (Table 1). Runoff coefficient for Tegalan was 0.05, for Babon catchment was about 0.02, while for Rambutan catchment it was 0.01 which is very low considering the high rainfall amount and intensity and steep slope of the area. For the Rambutan catchment measurable amount of runoff happened only for high rainfall events. For the Kalisidi catchment, the presence of spring make our interpretation difficult, but a rough estimate is that the spring contributed to as high as half of the annual water yield.

3.2 Erosion and sediment yield

Figure 2 presents monthly sediment yield reflected as bed load and suspended load components. As expected, sediment yield was the highest from the Tegalan catchment because of minimal soil surface litter and little canopy cover. Monthly rainfall exceeding the amount of 200 mm caused measurable sediment yields for Tegalan catchment. November with the rainfall amount of nearly 600 mm, which is the planting month of annual upland crop (meaning that the soil surface was very bare and the soil aggregates were loose because of tillage), caused sediment yield as high as over 5 t/ha. The following months such as January, March, and April with the rainfall amount exceeding 400 mm gave sediment yield higher than 3 t/ha. On the other hand, Rambutan catchment, being well covered, gave minimal sediment yield and its considerable amount of sediment yield was only observed in January 2001 which was the middle of the rainy season. It appears that the soil has to reach a certain level of water saturation and the amount of rainfall should be high enough for erosion to occur in the Rambutan catchment. For Kalisidi catchment, considerable amount of erosion may have occurred near the outlet (where encroachment occurred as mentioned earlier), but since we averaged the figure into per hectare basis, this effect has been mathematically diluted.

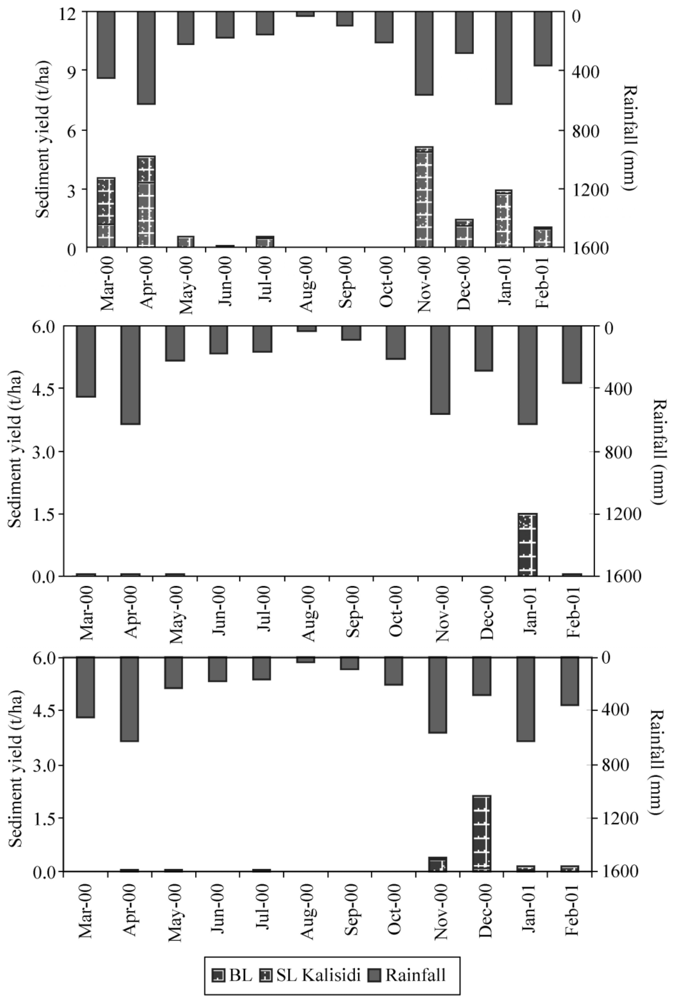

Fig.2 Monthly rainfall and sediment yield (bed load (BL) and suspended load (SL)) for Tegalan, Rambutan, and Kalisidi catchements from March 2000 to February 2001

Annual sediment yield as shown in Fig.3 showed that the total sediment yield for Tegalan, Rambutan, Kalisidi, and Babon catchments were 20, 1.7, 2.9, and 0.04 t/ha under annual rainfall of 3800 mm. Despite alarming figures of soil loss usually obtained from plot-scale measurements, the amount of sediment actually leaving the catchment was relatively low, and it gets lower as the catchment size is larger. Plot-scale erosion measurement usually reflect alarming figure. For example, Haryati *et al*. (1998) from a four month plot-scale measurement in Garut, West Java, on an Oxic Dystropept, with cumulative rainfall of only about 800 mm, presented soil loss value of 13 to 15 t/ha/year. One year data with normal annual rainfall of 2800 in this area may have given the soil loss value of over 30 t/ha. Thus this study confirms that direct extrapolation of soil loss data from plot-scale to small catchment and from small catchment to large catchment will lead to over estimations (van Noordwijk *et al*., 1998).

A closer look at Fig.2 and 3 revealed that for the small catchments, the Tegalan and Rambutan catchments, most of the sediment measured in the trap was of the larger sized aggregates or particles (sediment load) while for the larger catchment, the finer sediment (suspended load) dominated. This reflects that during the erosion process, relatively small portion of soil aggregates was dispersed, especially for the Rambutan catchment with no tillage and with ideal cover. This also reflect that the source of most sediment reaching the sediment trap was relatively close to the trap and the larger the catchment size, the less is the bedload contribution to sediment yield because the large sized aggregates or particles have a greater chance to be deposited before reaching the outlet. Suspended load from Rambutan catchment was negligible while from Tegalan and Kalisidi was considerable. This again is attributed to exposure of soil surface to rain drops in the latter.

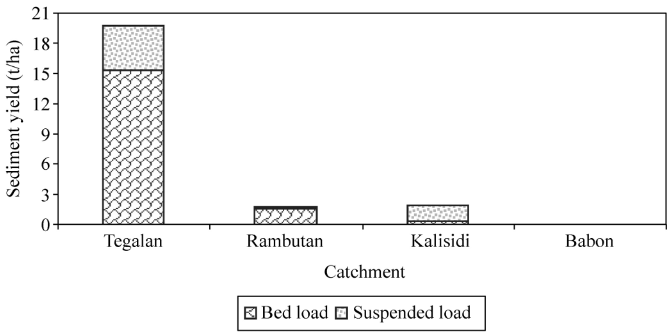

Fig.3 Sediment yield from Tegalan, Rambutan, Kalisidi and Babon catchments from March 2000 to February 2001

4 Conclusions

With similar catchment size, but the difference in land use between Tegalan (covered mostly by annual upland crop) and rambutan (covered by *Nephelium lappaceum*) catchments, there was distinct difference in their hydrological behavior. The peak discharge intensity was reached earlier and the total volume of discharge was larger in the former suggesting higher soil infiltration and lower runoff water velocity in the later.

The amount and size of sediment originating from the catchments largely depended on land management systems and catchment size. For small catchment, because larger size sediment travels in short distance, the major contributor of sediment yield is the bedload, while for larger catchment the bedload component is negligible on a unit area basis. Intensive soil tillage and minimal surface cover for Tegalan catchment made it not only relatively susceptible to bedload transport, but also to suspended sediment transport. Suspended sediment was almost undetected for Rambutan catchment because of good soil contact cover.

Although the major part of kalisidi catchment was covered by Rambutan, but the encroachment activities in the lower (near the outlet) part contributed to measurable suspended sediment. The total annual soil leaving the catchments under 3800 mm of rainfall were relatively low (especially for catchment covered by perennial tree crops or large size catchments), 20, 1.7, 1.9, and 0.05 t/ha, respectively for Tegalan, Rambutan, Kalisidi, and Babon catchment.

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References

Agus, F., Sukristiyonubowo, T. Vadari, and C. Setiani. 2001. Catchment approach to managing soil erosion in Kaligarang Catchment of Java, Indonesia. pp. 129-151 *In* Proceedings of the 5th MSEC Assembly, Semarang Indonesia 7-11 Nov. 2000. International Water Management Institute, Southeast Asia Regional Office, Bangkok, Thailand.

Agus, F., A. Abbas Id. and R.L. Watung. 1998. Implementation problems of soil conservation measures in Indonesia. pp. 1-13 *In* A. Sajjapongse (ed.) Farmers Adoption of Soil-conservation Technologies. IBSRAM Proceedings No. 17. International Board for Soil Research and Management, Bangkok.

Garrity, D.P., and F. Agus. 1999. Natural resource management on a watershed scale: What can agroforestry contribute? pp. 165-193 *In* R. Lal (ed.) Integrated Watershed Management in the Global Ecosystem, CRC Press, Washington, D.C.

Haryati, U., D. Sudjarwadi, and Kartiwa. 1998. Pengaruh tanaman penguat teras terhadap erosi dan produksi tanaman pangan di DAS Cimanuk Hulu. p. 133-148 *In* Alternative dan Pendekatan Implementasi Teknologi Konservasi Tanah. Pusat Penelitian Tanah dan Agroklimat, Bogor, Indonesia.

Shaxson, T.F. 1999. People's involvement in watershed management:Lessons from working among resource poor farmers. pp. 345-363 *In* R. Lal (ed.) Integrated Watershed Management in the Global Ecosystem, CRC Press, Washington, D.C.

Soil Survey Staff. 1996. Keys to Soil Taxonomy. SMSS Technical Monograph No. 19, USDA.

van Noordwijk, M., M. van Roode, E.L. McCallie, and B. Lusiana. 1998. Erosion and sedimentation as multiscale, fractal processes: Implications for models, experiments and the real world. pp. 223-253. *In* F. W.T. Penning de Vries, F. Agus, and J. Kerr (Eds.) Soil Erosion at Multiple Scales: Principles and Methods for Assessing Causes and Impacts. CAB International, Wallingford, UK.