Comparing Runoff, Soil and Nutrient Losses from Three Small Watersheds in Indonesia

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ABSTRACT

The effects of land cover at the watershed scale on soil and nutrient losses are important criteria for improved soil conservation management. The objective of this study was to assess runoff, soil and nutrient losses from 3 neighboring small agricultural watersheds in Java, Indonesia, in relation to the prevailing land use. In the area, Inceptisols and Alfisols are dominant. The three watersheds are characterized by distinctly different land uses, i.e., annual cropping (in the *Tegalan* watershed), perennial cropping (in *Rambutan*) and mixed cropping (in *Kalisidi*). Field measurements were carried out over a two-year period (2000 and 2001). The mean annual rainfall in the area was about 3180 mm. The annual sediment yields (soil losses) from the watersheds were 9.6 t ha^{-1} (in 2000) and 15.4 t ha^{-1} (in 2001) for *Tegalan*; 1.0 t ha^{-1} (in 2000) and 0.2 t ha^{-1} (in 2001) for *Rambutan*; and 0.5 t ha^{-1} (in 2000) and 0.8 t ha^{-1} (in 2001) for *Kalisidi*. The annual runoff from the watersheds in 2000 and 2001 were 1,980 m^3ha^{-1} and 1,190 m^3ha^{-1} (*Tegalan*), 230 m^3ha^{-1} and 80 m^3ha^{-1} (*Rambutan*), and 6,090 m^3ha^{-1} and 6,200 m^3ha^{-1} (*Kalisidi*). Enrichment ratios for P ranged between 1.2 and 2.3, for Mg between 1.1 and 2.4, and for K between 1.2 and 1.3. No significant overall correlation was observed between enrichment ratio (E_R) and soil loss, but the differences between the watersheds were significant. Soil losses did not systematically increase with runoff. Overall, land cover has shown to be the most likely determinant of soil loss, and hence, nutrient losses in the study area. Nutrient losses due to erosion appear to be a major cause of soil fertility depletion in the area. Soil management practices to improve the levels of P, K and organic matter would be required to compensate losses of plant nutrient and to improve soil-quality in general.

Keywords: nutrient losses; runoff; sediment yields; erosion; watershed; Indonesia

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1. INTRODUCTION

Erosion is an endemic problem in Indonesia. It is the main cause of nutrient depletion and soil and land degradation, with direct implications for land productivity (Hashim et al., 1998). Over the last decades, the pressure on the land resources increased significantly, especially on the island of Java. From 1990 until 2000, the population of the island increased from 107.58 million to 121.35 million (BPS Statistics Indonesia, 2003). The land is farmed more intensively, without adequate conservation measures. As a consequence, land degradation increases and millions of hectares of agricultural land have already been lost to agriculture. About 20 million ha (33%) of productive arable land have been degraded into marginal land of low productivity (Sinukaban, 2000).

The underlying causes of land degradation in Indonesia are rooted in the complexity of social and economic conditions and they are aggravated by over-exploitation and poor land management (UNCCD, 2000).

Since 1968, the government of Indonesia has initiated and implemented a number of soil and water conservation projects to address land degradation, such as the National Reforestation Programme (NRP), the Regreening and Reforestation Project (RRP), the Upland Agriculture and Conservation Project (UACP), followed by the Sustainable Upland Farming System (SUFS) and the National Watershed Management and Conservation Project (NWMCP) (Sinukaban, 2000). NWMCP was established in 1994 to strengthen the performance of the National Regreening Program. An important output of this project has been the development of a community participation approach for the management and development of watersheds (Abdurrachman and Agus, 2000). In a cooperative effort, farmers, local communities, government extension agents and technical officers jointly plan, implement and supervise development activities. Non-governmental organizations (NGOs) and consultants are sub-contracted to facilitate the participation of farmers and the communities (World Bank Group, 2004). Since these projects began, research on erosion and conservation at the watershed level has increased considerably, mainly to test alternative mechanical soil-conservation measures (Agus et al., 1998). Studies of the soil physical and chemical processes related to erosion, however, have been very limited; the lack of scientific explanation of the processes involved often leads to the promotion of inappropriate conservation measures (Agus et al., 1998).

Although, studies on erosion in small agricultural watersheds have been conducted in a variety of different countries in different agroecological regions, e.g., Bangladesh (Gafur et al., 2003), Norway (Øygarden, 1996), China (Kimoto et al., 1998) and Southeast Asia (Agus et al., 2002), research of this nature is somewhat scanty in Indonesia.

A major facet of land degradation is nutrient depletion. Besides the removal of nutrients by crops, several other processes lead to nutrient losses, such as runoff, erosion, leaching and volatilization (in the case of nitrogen) (Hashim et al., 1998). Under tropical conditions, erosion is a significant agent responsible for nutrient losses and, hence, soil-fertility decline (Zöbisch et al., 1995: Gachene et al., 1997). Erosion also affects other chemical and physical soil properties, and is often linked to the loss of soil organic matter and the exposure of subsoil (Frye et al., 1982). Losses of plant nutrients due to erosion can be assessed using enrichment ratios (E_R). The E_R is defined as the ratio of the nutrient content in eroded sediment to that of the source soil (Gachene et al., 1997; Hashim et al., 1998; Gafur et al., 2003).

Runoff, soil erosion and nutrient depletion are strongly interrelated watershed degradation processes. The objective of the present study was to assess the extent and effect of these processes on the soil in relation to the prevailing land use.

2. MATERIALS AND METHODS

2.1 Site description

The study was conducted in three small watersheds, which belong to the *Babon* watershed, Java, Indonesia (Figure 1). The area lies within 7°07'08" – 7 ° 07'33"S and 110 ° 22'23" – 110 ° 22'58"S. The altitude ranges between 400 and 560 m above mean sea level.

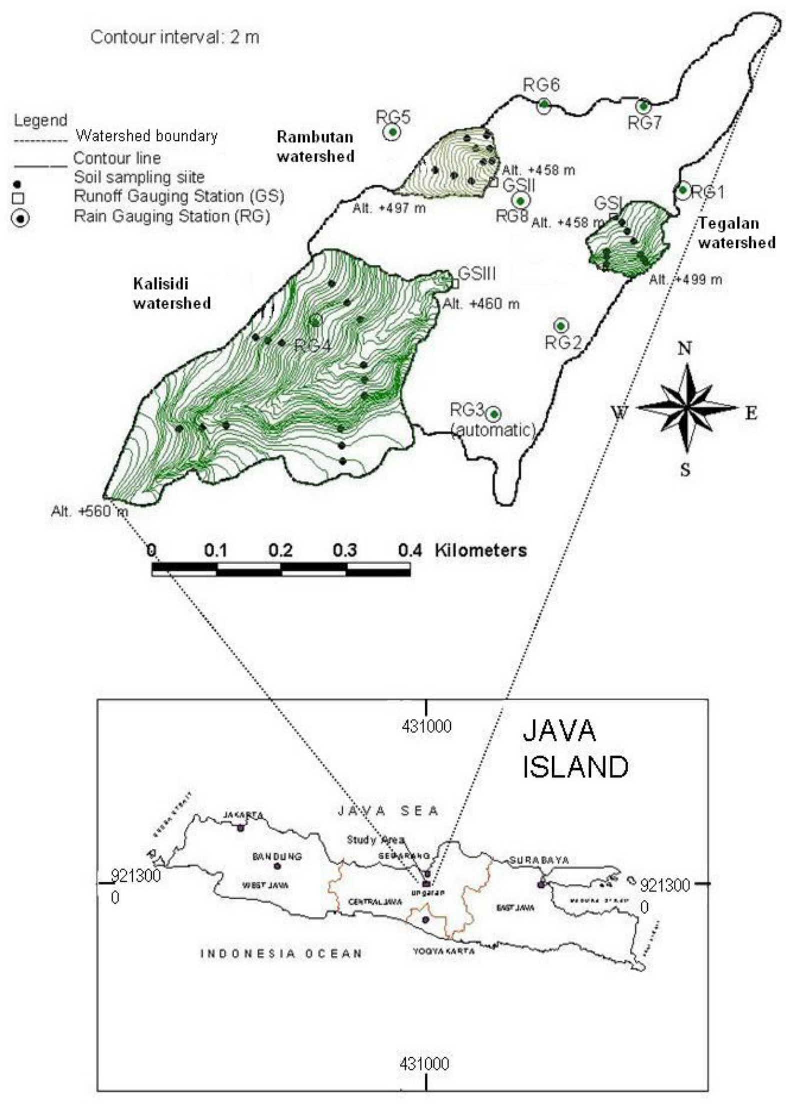

Figure 1. Location map of the study watersheds
West to East: Kalisidi, Rambutan and Tegalan

Two soil orders predominate in the area –Alfisols and Inceptisols. These were formed by Central Ungaran ashes and volcanic rocks and originate from the Pleistocene-Holocene (quaternary) age (MSEC, 2000). The soils are well-drained, very deep (>150 cm), dark reddish brown to very dark brown friable clays. The average topsoil bulk density is 1.17 g cm^{-3} (see Table 1).

The area has a humid climate with tropical rain-forest vegetation. According to the Schmidth–Ferguson Classification, the study area falls into climate type B (Schmidth and Ferguson, 1951) (Figure 2). The mean annual rainfall of the research site is 3,181 mm. The average monthly rainfall of the three driest months is less than 60 mm, while the average monthly rainfall of the nine wettest months is significantly higher than 100 mm (up to about 500 mm). The dryer months are July to September, while the wet months usually fall between October and June. Only during the dryer months, does reference evapotranspiration (ET_0) exceeds the rainfall.

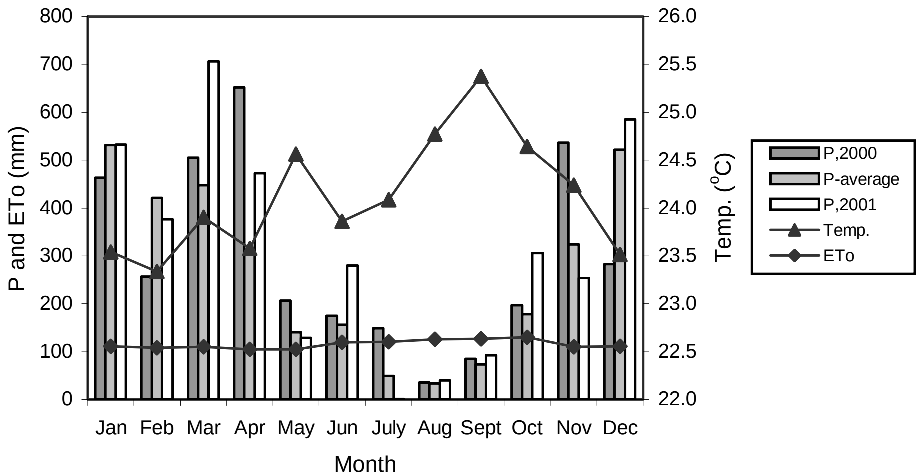

Figure 2. Monthly climatic data for the study area (rainfall (2000, 2001), average rainfall (1985-2001), air temperature and reference evapotranspiration (2000-2001)).

The three small watersheds studied within the *Babon* watershed are characterized by distinct land uses. The *Tegalan* watershed (1.0 ha) is used for annual food crops, such as cassava, groundnut and maize; there is also some grassland. The *Rambutan* watershed (1.1 ha) is dominated by perennial rambutan fruit orchards and some bushland, which is not used. The *Kalisidi* watershed (11.2 ha) is dominated by mixed garden cultivation. The main watershed characteristics are summarized in Table 1.

To reduce erosion in the upland crop areas, farmers constructed forward-sloping bench terraces. These terraces are irregularly shaped. Most farmers apply only urea (50-120 kg ha^{-1}) and farmyard manure (cattle and buffalo dung at a rate of approximately 5 t ha^{-1}), but some farmers only apply manure to their annual food crops, especially maize and groundnut. For cassava, most farmers do not apply fertilizers at all. For the rambutan orchards –since 1997– the plantation manager decided to reduce the level of management of the plantation due to a raising insecurity of the land holding and increasing incidences of encroachment from farmers into the plantation for cultivation of seasonal crops. In *Kalisidi* farmers occupied about 22 percent (2.4 ha), while in *Rambutan*, they occupied 89 percent (1.0 ha) of the total area. Therefore, no fertilizers and other chemicals were applied, leading to a reduction of yields. Previously, urea, triple super phosphate (TSP), and potassium chloride (KCL) were applied to the trees two times a year, usually at the beginning and the end of the rainy season. For each tree, 4 kg urea, 2.5 kg TSP, and 1.25 kg KCl used to be applied.

Table 1. Watershed characteristics

Characteristic	Tegalan	Rambutan	Kalisidi
Watershed size (ha)	1.0	1.1	11.2
Slope range (%)	30-65	30-65	30-65
Length of main waterway (m)	143	155	657
Average slope of main waterway (%)	29	25	15
Topsoil bulk density (Mg m^{-3}):	1.14 – 1.16	1.10 – 1.13	1.10 – 1.26
Hydraulic conductivity (cm h^{-1})	1.53 – 1.98	0.97 – 2.35	0.54 – 1.53
Soil depth range			
Very shallow, <25 cm	< 5% (Along waterway)	< 5% (Along waterway)	< 5% (Along waterway)
Shallow, 25-50 cm	5-10%	5-10%	5-10%
Moderately deep, 50-100 cm	30-40%	10-20%	20-30%
Deep, >100 cm	50-60%	70-80%	60-70%
Dominant land use in 2000-2001	*Annual cropping.* Cassava, maize, groundnut; some grassland	*Perennial crops.* Rambutan orchards, some bushland	*Mixed use.* Rambutan orchards, mixed gardens (home gardens: coffee, bamboo, banana, hibiscus, cloves, mangoes, rambutan), some bushland and grassland

2.2 Data collection and analysis

Topography, soil, and land use of each small watershed were mapped at the scale 1:1,000 using conventional terrestrial topographic field-survey methods and a GPS receiver. A field survey was conducted to characterize the biophysical conditions of the study area and develop an inventory of land use. On the basis of slope and land use, representative sites were identified for soil sampling and soil-profile description (*Tegalan* 3 profiles, *Rambutan* 3 profiles, and *Kalisidi* 5 profiles). In July 2001 (dry season), 33 topsoil samples (0-10 cm) were collected (*Tegalan* 9 samples, *Rambutan* 9 samples and *Kalisidi*15 samples). The soil samples were air dried and sieved through a 2-mm screen. The soil properties determined were particle-size distribution, soil organic carbon (SOC), total N, available-P, and the exchangeable cations K, Ca, Mg and Na. The particle-size distribution was determined by using pipette method (Day, 1965). Soil organic carbon was measured using the Walkley-Black method (Allison, 1965); total N was determined with the Kjeldahl method (Bremner and Mulvaney, 1982); and available-P was analyzed using Bray the P-1 method (Olsen and Sommers, 1982). The exchangeable cations K and N were determined by using ammonium acetate 1N extraction at pH 7 (Knudsen et al., 1982) and Ca and Mg were extracted using ammonium acetate 1N at pH 7) (Haby et al., 1990).

For hydrologic monitoring, 7 manual rain gauges and one automatic weather station were installed (locations given in Figure 1). Rainfall erosivity (R) was estimated with the formula proposed by Morgan (1995) using annual rainfall data:

$$R = (9.28\,P - 8838) \cdot 75/1000 \qquad (1)$$

where: R = rainfall erosivity (MJ ha^{-1} mm h^{-1} y^{-1})
P = annual rainfall (mm)

Long-term rainfall data were collected from the *Rambutan* plantation meteorological station (near the *Kalisidi* watershed). The station was in operation from 1985-2001. During this period, 12 years of rainfall data were available. For 1991 and 1993-1996, rainfall data were not available. To measure sediment loads and water yields from the three small watersheds, automatic water-level recorders were connected to data loggers (OTT, Thalimedes) were installed at the outlets (Figure 1). Runoff from the watersheds was measured continuously during the runoff seasons of 2000 and 2001. Sediments were collected in stilling basins with capacities of 3 m^3 (2 m x 1.5 m x 1 m) at *Tegalan*, 4.5 m^3 (2.5 m x 1.8 m x 1 m) for *Rambutan*, and 6.3 m^3 (3 m x 2.1 m x 1 m) for *Kalisidi*, depending on the watershed area of the watersheds. Bed-load yields were collected from the stilling basins after each rainfall event. Sediment was sampled three times, i.e. on 12, 15, and 18 December 2001. The samples were analyzed using the same methods used for the soil analysis. Sediment rating curves were used to estimate the annual suspended sediment yields. Reference evapotranspiration (ET_0) was approximated using the formula proposed by Doorenbos and Pruitt (1984):

$$ET_0 = c\,[p\,(0.46\,T + 8)] \quad \text{(mm/day)} \qquad (2)$$

Where: ET_0 = reference evapotranspiration in mm/day for the month considered
T = mean daily temperature in ^oC over the month considered
p = mean daily percentage of total annual daytime hours obtained from the table for a given month and latitude
c = adjustment factor which depends on minimum relative humidity, sunshine hours and daytime wind estimates.

Spreadsheet software (Microsoft Office Excel) and the statistical package SPSS Ver.11.0 for Windows (SPSS Inc.) were used for the data analysis.

3. RESULTS AND DISCUSSION

3.1 Rainfall Distribution

The distribution of rainfall over the study period (2000-2001) is shown in Figure 2. The rainfall values were the average rainfall obtained from the 7 rainfall stations. On the basis of analysis of variance (ANOVA), there was no significant spatial variability of rainfall ($P > 0.5$). The annual rainfall in 2000 was 3,547 mm over 154 raindays –i.e., days with ≥ 1mm rainfall; this is 12 % above the 12-year average. In 2001 there were 3,776 mm rainfall over 140 raindays; this is 19 % above the 12-year average.

Generally, the monthly rainfall distributions during 2000 and 2001 followed the long-term pattern. However, during these 2 years, the highest monthly rainfall occurred in March, whereas for an average season, the highest rainfall typically occurs in January.

The month of highest rainfall also exhibites the highest erosion risk. The annual rainfall erosivity (*R*) (Table 2) is comparable to estimates from similar environments (Gafur et al., 2003). Because the annual rainfall in 2001 was higher than in 2000 and the number of rainy days in 2001 was lower than in 2000, rainfall erosivity in 2001 was higher than in 2000. These conditions contributed to higher runoff and erosion in 2001.

Table 2. Annual rainfall (*P*), reference evapotranspiration (ET_0) and annual erosivity (*R*)

Year	Annual rainfall, *P*	Reference evapotranspiration, ET_0	Annual erosivity, *R*	
	(mm)	(mm)	SI units*	US customary**
2000	3,547	1,298	30,730	1,806
2001	3,776	1,303	33,442	1,965

* MJ ha^{-1} mm h^{-1} y^{-1}; ** 100 foot-ton $acre^{-1}$ inch h^{-1} y^{-1}

3.2 Runoff

The monthly runoff distribution during 2000 and 2001 is shown in Figure 3. In general, the runoff follows the rainfall pattern. Highest runoff rates occurred during the months of January – April and November – December. This is particularly obvious in *Tegalan* and *Kalisidi*; in *Rambutan*, runoff is low. Figure 4 shows the relationship between accumulated monthly rainfall and runoff in the three watersheds during 2000 and 2001.

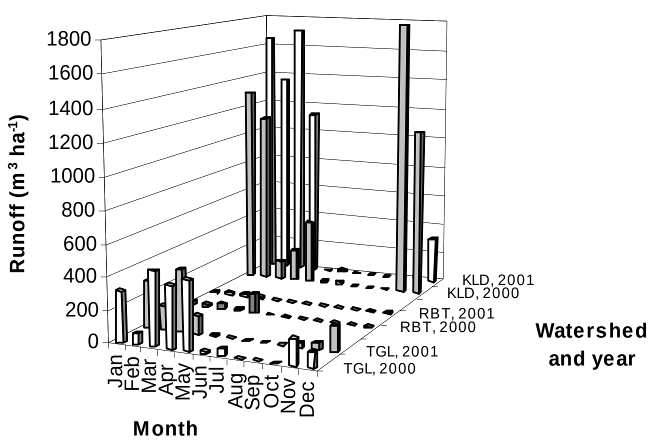

Figure 3. Monthly runoff for the years 2000 and 2001. (TGL – *Tegalan*; RBT – *Rambutan*; KLD – *Kalisidi)*

Interpretation of the variability of the annual runoff (*Q*, Table 3) from the three watersheds turned out to be more complex than expected, probably associated with the relatively small scale of the watersheds studied (Gafur et al., 2003) and also affected by the land use (Bosch and Hewlett, 1982; Ward, 1995).

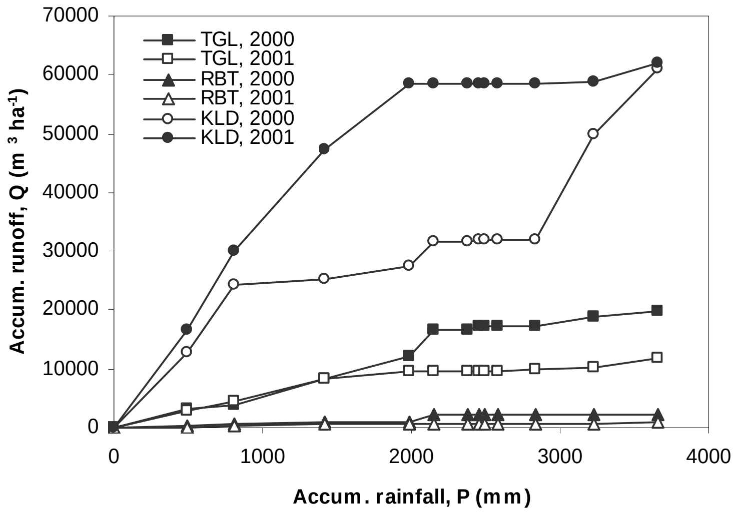

Figure 4. Rainfall-runoff relationships for 2000 and 2001
(TGL – Tegalan; RBT – Rambutan; KLD – Kalisidi)

Table 3. Annual runoff (*Q*), runoff ratio (*Q*/*P*), rainfall excess (*P* – *Q*), and ratio of rainfall excess to reference evapotranspiration ((*P* – *Q*)/ ET_0)

Year	Watershed	*Q* (m^3 ha^{-1})	*Q*/*P*	*P* – *Q* (m^3 ha^{-1})	(*P* – *Q*)/ ET_0
2000	Tegalan	1,980	0.056	33,490	2.58
(3,547 mm rain)	Rambutan	230	0.006	35,230	2.71
	Kalisidi	6,090	0.172	29,380	2.26
2001	Tegalan	1,190	0.032	34,270	2.63
(3,776 mm rain)	Rambutan	80	0.002	35,390	2.72
	Kalisidi	6,200	0.164	29,270	2.25

The annual runoff (*Q*) from the three watersheds varied from 230 to 6,090 m^3 ha^{-1} in 2000 and from 80 to 6,200 m^3 ha^{-1} in 2001 (Table 3), corresponding to 0.6 to17 % of the annual rainfall in 2000 and 0.2 to 16 % of the annual rainfall in 2001. There are consistent differences between the watersheds. The highest runoff occurred in *Kalisidi*, followed by *Tegalan* and *Rambutan*.

It is apparent that the differences of annual runoff between the three watersheds were caused by the differences in watershed area and land uses. *Kalisidi* is about 10 times larger than either *Rambutan* or *Tegalan*. It was therefore to be expected that *Kalisidi* had much higher annual runoff than the other two watersheds. Generally, the larger the watershed size, the higher the annual runoff. However, higher runoff does not always indicate higher rates of erosion. In the case of the 3 watersheds studied, land use and land management have an important role in limiting erosion. The differences between *Tegalan* and *Rambutan* –which are almost identical in size–, were mainly due to the differences in land use. The dominant land use in *Rambutan* is rambutan orchards with grass cover and some bushland.

This land cover has a much higher rainfall interception and retention capacity than the land cover in *Tegalan*, which is characterized by seasonal cropping of cassava, maize and groundnut with periods of unprotected soil surface between field tillage and crop establishment.

Generally the runoff ratio (*Q/P*) of the three watersheds is low (<20 %) (Table 3). This means that more than 80 % of the rainfall was intercepted and to a large extent infiltrated into the soil. The overall lowest *Q/P* was observed in *Rambutan*, which is characterized by a permanent orchard-type land cover. These observations go along with the calculated rainfall excess (*P*-*Q*) and the ratio of rainfall excess to reference evapotranspiration ((P-Q)/ET_0), which are other indicators of the rainfall retention efficiency of a watershed (Table 3). Rainfall excess ranges from approximately 29,000 to 35,000 m^3 ha^{-1}; (P-Q)/ET_0 ranges from about 2.25 to 2.70. This can be considered as high (Gafur et al., 2002). Again, the most favorable conditions were observed in *Rambutan*, while *Kalisidi* showed the least favorable conditions.

3.3 Sediment yield

The overall soil losses from the three small-watersheds are shown in Figure 5. Per unit area (ha), the highest soil losses were recorded in *Tegalan* (annual crops). In 2000, losses recorded from this watershed were about 9 times higher than in *Rambutan* and 17 times higher than in *Kalisidi*, despite its significant larger size. In 2001, they were 76 times higher than in *Rambutan* and 19 times higher than in *Kalisidi*. In *Tegalan* and *Kalisidi* the extent of soil losses, represented by sediment yield, increased with increasing rainfall (Table 4). In *Rambutan*, a decrease in annual soil loss was observed for 2001, despite the increase in annual rainfall (Figure 2 and Figure 3). The higher soil loss of *Rambutan* in 2000 might have been caused by the farmers' tillage for cassava cultivation under the rambutan trees during encroachment into the fruit-tree plantation. Since 2001, cassava cultivation in the plantation has ceased.

Table 4. Annual sediment yields

	Annual sediment yield (kg ha^{-1})		
Year	*Tegalan*	*Rambutan*	*Kalisidi*
2000 (P = 3,547 mm)	9,549	990	525
2001 (P = 3,776 mm)	15,393	203	776

3.4 Enrichment of Eroded Sediment

The composition of the topsoil (0 – 10 cm) and of the eroded sediment is shown in Table 5. The data show that there has been a selective removal of P, Mg and K (E_R>1) from the watersheds. On average, the sediment washed from these watersheds was enriched by 10 to 120 % for P, 10 to 110 % for Mg, and 20 to 30 % for K, in comparison to the soils from which the sediment originated.

To prevent nutrient depletion, these nutrients, especially phosphorus and potassium, would have to be replaced by the farmers with commercial fertilizers, usually super-phosphate-36 (SP-36) or KCl. This would be an expensive task for small-scale farmers. Therefore, soil conservation measures that prevent nutrient losses should be of high priority for the land users. The highest E_R for phosphorus (i.e., 2.3) was measured in

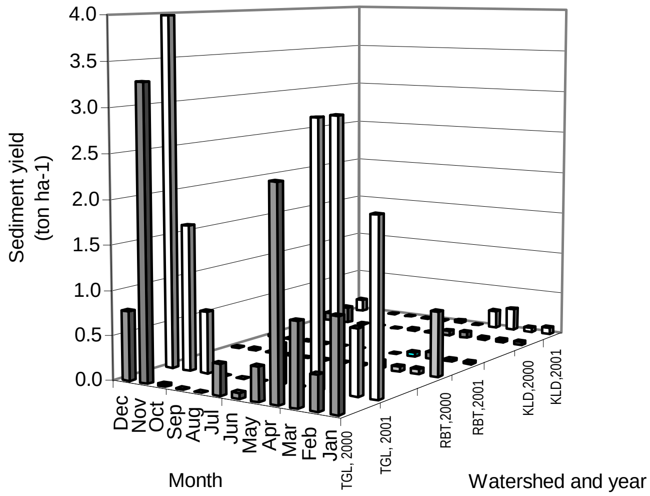

Figure 5. Monthly sediment yields for the years 2000 and 2001.
(TGL – Tegalan; RBT – Rambutan; KLD – Kalisidi)

Table 5. Nutrient losses during peak flow periods in 2001.
Composition of the topsoil and eroded sediment (stilling basin), estimated nutrients loss in kg/ha, percent of total topsoil content, enrichment ratios and statistical significance (Sig.) with ***: 0.001; **: 0.01; and * 0.05. (TGL – *Tegalan*; RBT – *Rambutan*; KLD – *Kalisidi)*

Component	Unit	Topsoil (std.)			Eroded sediment (std.)			Estimated annual loss from the topsoil, kg ha-1			Enrichment ratio (E_R)			
		TGL	RBT	KLD	TGL	RBT	KLD	RBT	KLD	TGL	TGL	RBT	KLD	Sig.†
SOC	%	1.41 (0.11)	1.64 (0.36)	1.69 (0.55)	0.98 (0.10)	1.09 (0.08)	0.83 (0.17)	154	1.98	0.57	0.7a	0.7a ‡	0.6a	(ns)
N	%	0.18 (0.04)	0.16 (0.02)	0.19 (0.04)	0.12 (0.03)	0.13 (0.03)	0.1 (0.02)	19	0.24	0.07	0.7a	0.8a	0.6b	(***)
P	mg kg-1	14.1 (4.96)	15.2 (3.18)	16.8 (3.86)	15.5 (1.8)	22.7 (5.0)	36.6 (4.5)	0.24	0.004	0.003	1.2a	1.6a	2.3b	(***)
Ca	cmol kg-1	10.8 (2.12)	7.4 (0.72)	10.7 (2.22)	6.1 (1.3)	6.1 (0.1)	5.5 (1.8)	38.4	0.445	0.152	0.6a	0.8b	0.5a	(***)
Mg	cmol kg-1	2.3 (0.20)	1.1 (0.04)	1.2 (0.39)	2.5 (0.1)	2.3 (0.2)	2.5 (0.2)	9.5	0.102	0.042	1.1a	2.1b	2.4b	(*)
K	cmol kg-1	0.28 (0.01)	0.34 (0.13)	0.44 (0.14)	0.36 (0.11)	0.4 (0.06)	0.51 (0.16)	2.2	0.028	0.014	1.3a	1.2a	1.2a	(ns)
Na	cmol kg-1	0.20 (0.03)	0.28 (0.09)	0.27 (0.10)	0.06 (0.02)	0.05 (0.03)	0.10 (0.02)	0.22	0.002	0.002	0.3a	0.2a	0.4b	(***)

Note: SOC = soil organic carbon.
† significance of ANOVA comparisons between watersheds in terms of enrichment ratio.
‡ values within row, followed by the same letter, are not significantly different (Duncan's multiple range test at P = 0.05)

Kalisidi (Table 5). There are significant differences in E_R of N, P, Ca, Mg, and Na between the watersheds. These differences are likely to have been caused by the differences in land use and land management practices, and also many other factors, e.g. location of an agricultural field with respect to the water course. Nutrient losses associated with erosion are a major cause of fertility depletion of the soils in this region, where erosion control measures are not effectively applied. The total nutrient losses from the watersheds are assumed to be even higher than reported in this study, because there are also expected losses caused by leaching and runoff that were not measured.

Although $E_R > 1$ were only observed for P, Mg, and K, the losses of other nutrients due to erosion, and also soil organic matter are still considerable. Especially soil organic matter is important, because its presence –or absence– in the soil affects other soil physical, chemical, and biological characteristics such as water holding capacity, aggregate stability, the ability to retain nutrients within the soil, microbial population and activities in nutrients mineralization and absorption by the plants.

4. CONCLUSIONS

Annual rainfall and erosivity during the study period were within the normal expected range for the area. Differences in erosion from the 3 watersheds –estimated in terms of sediment yield– can be mainly attributed to differences in land cover. A clear example is the higher runoff rates and sediment yields –despite lower rainfall and erosivity values– from the *Rambutan* watershed during 2000 when there has been significant soil disturbance due to temporary encroachment on about 89 percent of the area into the rambutan fruit-tree plantations for the cultivation of cassava. The data indicate that nutrient losses due to erosion are a major cause of soil fertility depletion in the area. Adequate soil management practices to improve the levels of P, K and organic matter would be required to compensate losses of plant nutrients and to improve soil-quality in general.

5. ACKNOWLEDGEMENTS

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