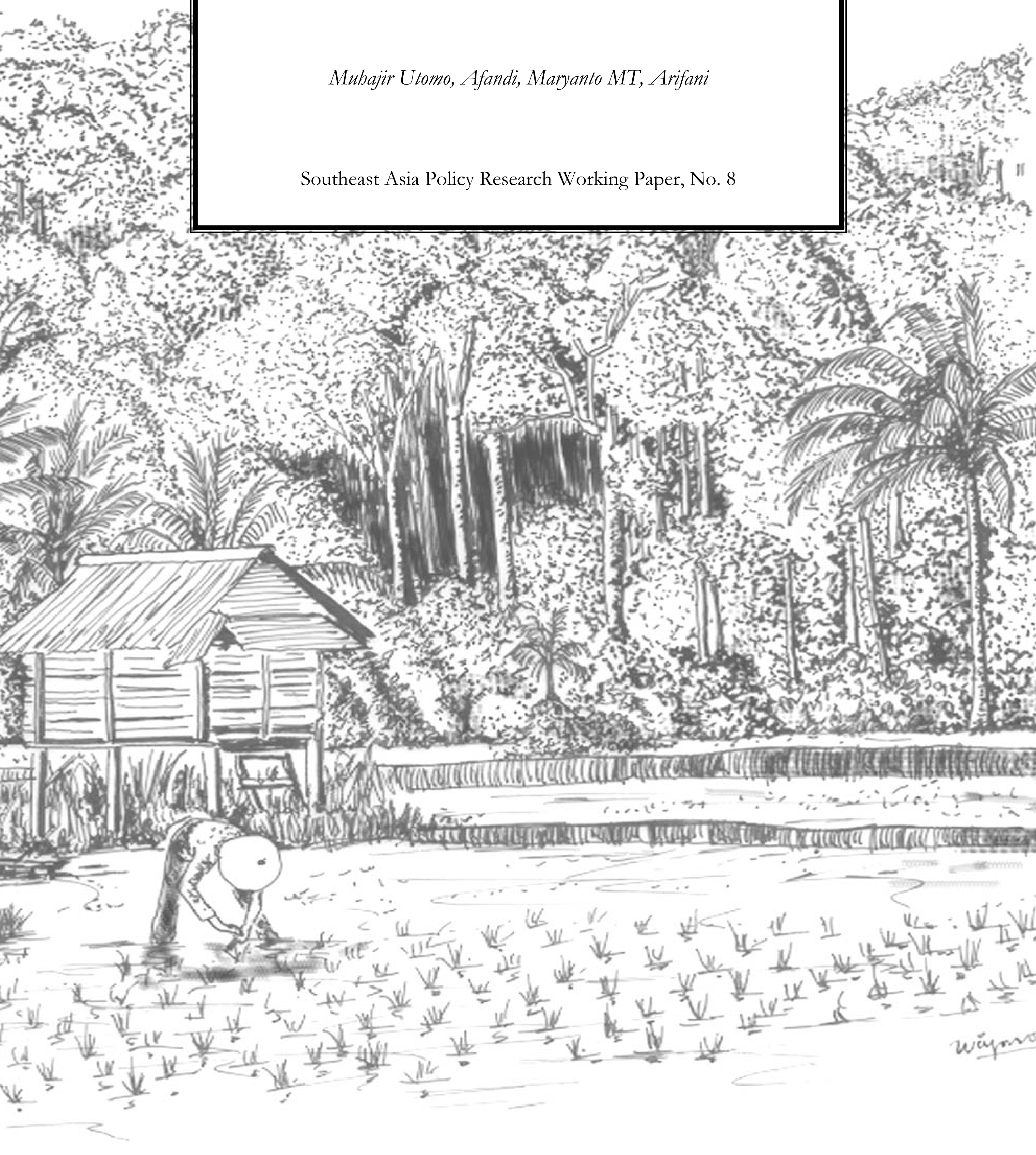
Watershed Erosion Analysis and Simulation Modelling of River Channel Erosion in Tulang Bawang River Basin

Muhajir Utomo, Afandi, Maryanto MT, Arifani

Southeast Asia Policy Research Working Paper, No. 8



Acknowledgement

This report is part of the ASB Project in Indonesia. The Asian Development Bank, under RETA 5711, financially supported this specific work.

Further information please contact:

ICRAF SE-Asia
Southeast Asian Regional Research Programme
PO Box 161
Bogor 16001
Indonesia
Tel: 62 251 625415, fax: 62 251 625416
Email: icraf-indonesia@cgiar.org
ICRAF Southeast Asia website: http://www.icraf.cgiar.org/sea

Cover design: Dwiati N. Rini
Illustration design: Wiyono

Declaimer

I. INTRODUCTION

1.1. Background

Lampung Province is the southernmost province in Sumatra Island. Geographically the province is located in 3°45' - 6° S and 103°40' E- 105°50'E. The total area is around 35,376 km^2 including the small islands around the province. Several large rivers are flow from the mountain range to the sea in Lampung Province:

- Way Sekampung (way means river in Lampung language), which is 256 km in length and draining a catchment area of 4,795 km^2 ;
- Way Seputih with 190 km in length and a catchment of 7,149 km^2;
- Way Jepara with 50 km length and an area of 1,540 km^2;
- Way Tulang Bawang with 136 km in length and a catchment area of 1,285 km^2; and
- Way Mesuji with 220 km length and the area is 2,053 km^2 (most of this catchment is located in South Sumatra Province)(Wiryawan,1999).

The Tulang Bawang watershed, which is located in the northern part of Lampung Province, and is important for agriculture in Lampung. Four regencies are included in Tulang Bawang watershed: West Lampung and North Lampung (the origin of the river), Way Kanan and Tulang Bawang. The upper part of this basin is mountainous areas which mainly covering with coffee plantation and forest areas. Sugarcane, cassava, and oil palm plantation as well as irrigation paddy field dominate in the middle part; and in the lower part, paddy field, fisheries and aquaculture are common. A runoff river dam for electric power plant is now under construction at Sumber Jaya and will become operational in 2001; the Way Rarem dam which was built about fifteen years ago supports an irrigation in the southern part of the basin.

The humid tropical climate of Tulang Bawang basin is characterized by abundant rainfall in the wet season, with an average annual precipitation of 2500-2600 mm/year.

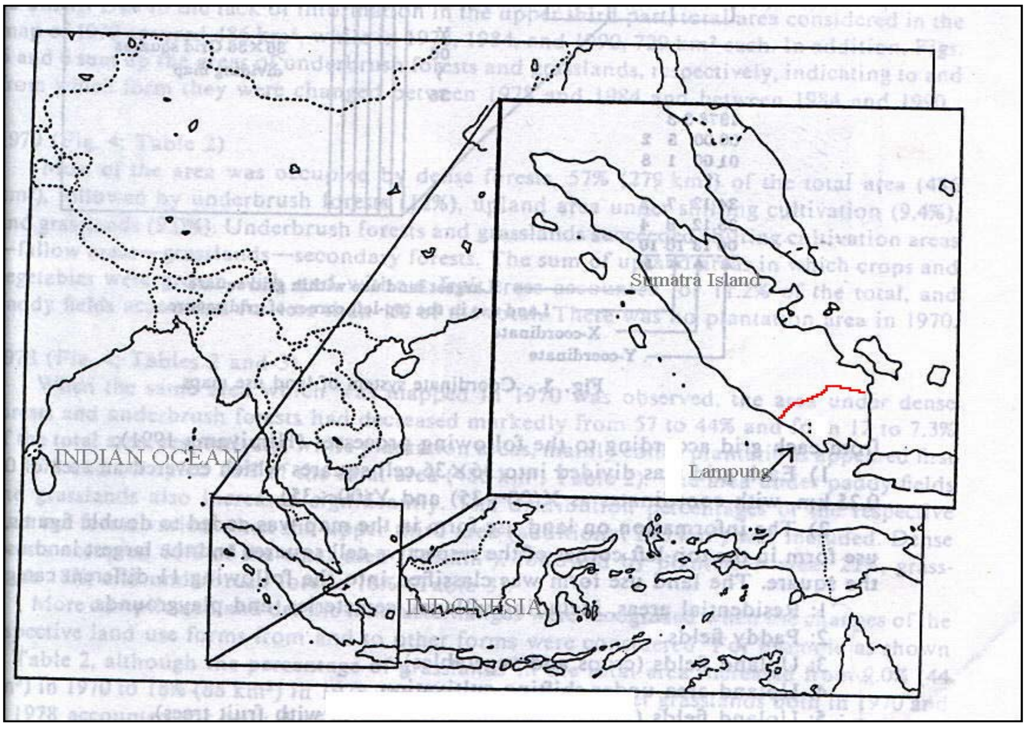


Figure 1.1. Location of Lampung Province

Due to the high rainfall, the potential risk for soil erosion is very high. The problems of soil erosion vary from soil degradation, downstream channel and reservoir sedimentation to nutrients and contaminants carried by sediment. An erosion study in the rainy season 1996/1997 in a coffee plantation in the upper part of the watershed established an annual soil loss rate of 11-25 t/ha for coffee with traditional management and 0.1 t/ha for coffee with full ground cover (Afandi et al., 1999).

It is expected that the erosion problem in the Tulang Bawang watershed will increase due to the rapid changes in the land use, especially in the upper part of the watershed. The study conducted by Syam et al.(1997) in the upper part of Way Besai catchment showed that in 1970 the forest occupied 57% of that areas but only 21% in 1990; on the other hand the coffee gardens increased from 0% in 1970 to 42% in 1990. The land use change has effected the chemical and enzyme activities as reported by Salam et al.(1998). It is very easy to predict that due to the "booming" of coffee price in 1998 and the "reformasi" era that relaxes government control over forest conversion will increase the coffee plantation area and further decrease forest area.

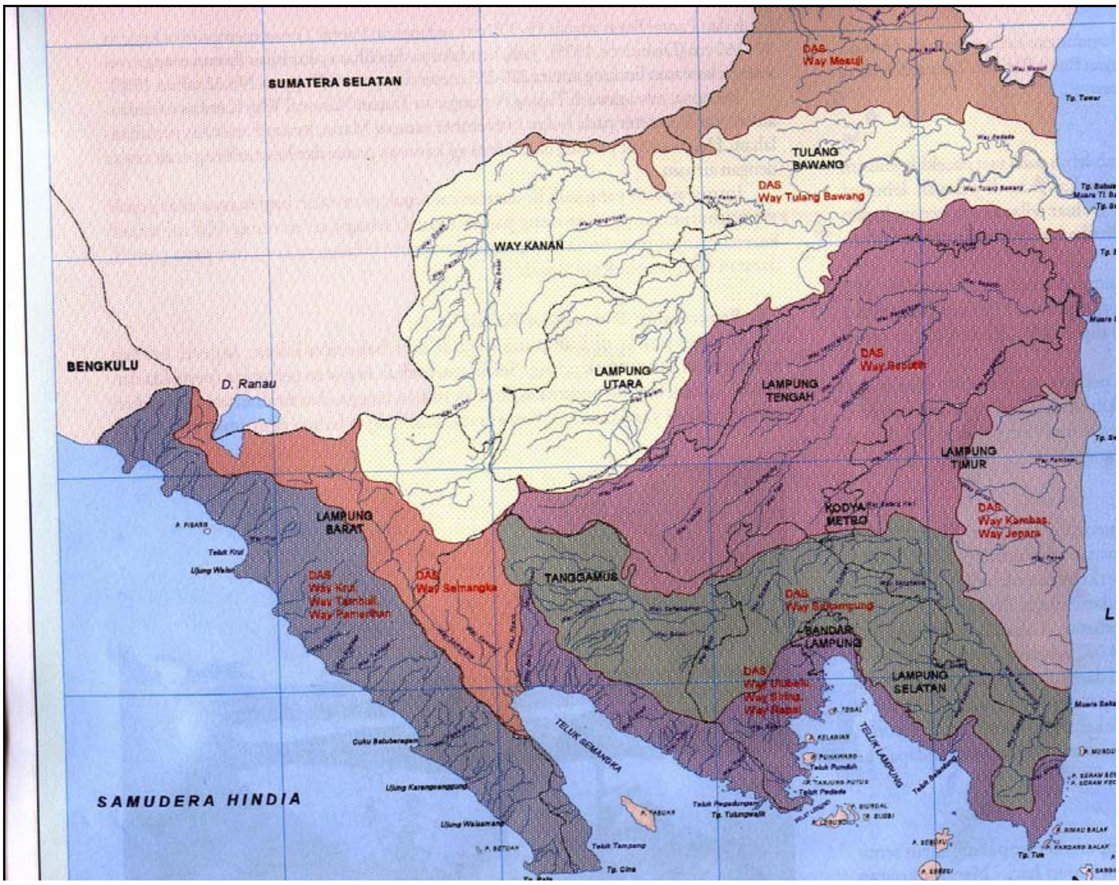
Soil erosion is an intermittent process and as such it is difficult to capture in short-term research. The consequences of soil erosion are more obvious than the process itself, as evident from eroded soils, erosion forms, and sediment deposition fans. At watershed scale, soil erosion is not the only source of sediment movement, as ‘hotspot’ phenomena such as landslides (mass wasting) and the colluvial soil in which they result, roadsides, construction sides, and footpaths lead to soil movement as well. Soil on the move can become sediment when the rate of transport slows down below a critical threshold. Therefore, any attempt to develop quantitative understanding (‘a model’) of soil erosion at landscape scale must consider these very complex variables.

In recent years, the development of predictive models of soil erosion focusses on processes of soil detachment, deposition, and sediment transport both spatially and temporary. Erosion-transport-sedimentation models that aim at representing the major processes include the USDA_WEPP, CREAMS, ANSWERS and RUNOFF models. These models are fundamentally different from the empirical Universal Soil Loss Equation (USLE) that depends on calibration in standardized-plot experiments, but can not account for processes beyond plot scale. Process-based erosion equations can be validated by evaluating the functional dependency of the mathematical solution for various independent variables with experiment data.

1.2. Purpose of the study

The main purpose of this research was to analyze the role of filter zone in landscape mosaics in reducing sediment load and influencing surface runoff at different scales in the Sumber Jaya area that contains the Way Besai subwatershed in West Lampung. The Way Besai subwatershed was chosen as the basis of the study with the following specific purposes :

(1) to develop and test effective methods for measurement sediment transfer across field boundaries in at least four representatives land use types in Way Besai subwatershed.
(2) to analyze water flow data of Way Besai river and link to the descriptive system of the subwatershed. The analysis will include the land use changes and rainfall pattern in relation to water flow for several years in an area of roughly 300 km^2.
(3) to measure water flow and sediment loads on one microcatchment, and to test the validity of ANSWERS model in describing erosion and sedimentation process in the catchment.



Source: Wiryawan et al. (1999)

Figure 1.2. Situation map of Lampung Province

II. MEASUREMENT OF SEDIMENT TRANSFER ACROSS FIELD BOUNDARIES IN VARIOUS LAND USE TYPE
Developing and Testing A Method

2.1. Previous Erosion Measurement Methods

Many methods have been proposed to measure soil erosion. The amount of soil loss from a certain field is usually calculated based on the measurement in plot scale and extrapolated to farms and watershed scale, or estimated based on equations such as USLE. The results are frequently under or over estimated due to the facts that soil erosion takes place in the uncontrolled field condition which posses high variability, and the soil erosion frequently does not occur as an isolated phenomena, taking place with other phenomena, such as landslide, roadsides and construction sides. The existence of ‘filter’ zones, such as shrubs or grassy weed strips between or at the edge of a field or farm also affect the transport of sediment.

The simplest method to measure soil loss in field scale is using leveling (geodetic) methods, in which the changes in the level of the soil surface are measured by a leveling instrument, or a leveling rod or a vertical post (Zachar, 1982). Zachar (1982) reported that Gerlach (1964) s retched a level wire between the pegs and measured the vertical distance between the wire and the soil surface at interval of 20 to 50 cm. Kelly and Gomez (1998) also use the same methods by using 10 mm steel reinforcing rod were cut to 1.8 m and hammered into the soil, and more than about 1 m was left exposed above the ground (Figure 2.1). To enable measurement, a nylon string was stretched from a pin at the top of the slope to a pin at the bottom of the slope and then connected to each pin in between.

Another method of measuring sediment loss and runoff is using Gerlach trough, a simple metal gutters 0.5 m long and 0.1 m broad with a movable lid (Figure 2.2). Daniels and Gillam (1996) also designed a simple runoff collector using a-buried 1-L bottle with a floating plastic ball (Figure 2.3).

The rate of soil loss is normally expressed in units of mass per unit area per unit time, such as ton ha^{-1} $year^{-1}$. However, because erosion process involved the movement of soil particles from a place of origin to a place of sedimentation, Van Noordwijk et al. (1998) proposed the using of another unit- mass x length per unit area or kg m^{-1} $year^{1}$. This unit is also applicable to pin methods, because this methods measures soil movement and not necessarily soil erosion (Kelly and Gomez , 1998). In case of the Gerlach trough, the amount of soil loss could be express per unit width of the gutter, and if an areal assessment is required, it is necessary to assume a catchment are equal the width of the gutter times the length of the slope (Morgan, 1979).

2.2. Purpose

The purpose of this research is to develop and test effective methods for measuring sediment transfer across field boundaries in at least four representatives land use types in Way Besai subwatershed.

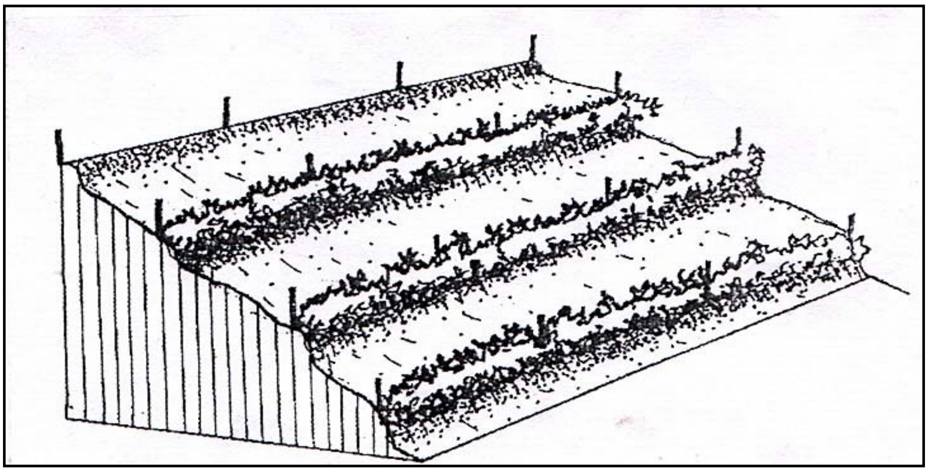


Figure 2.1. Placement of erosion pins (Kelly and Gomez, 1998)

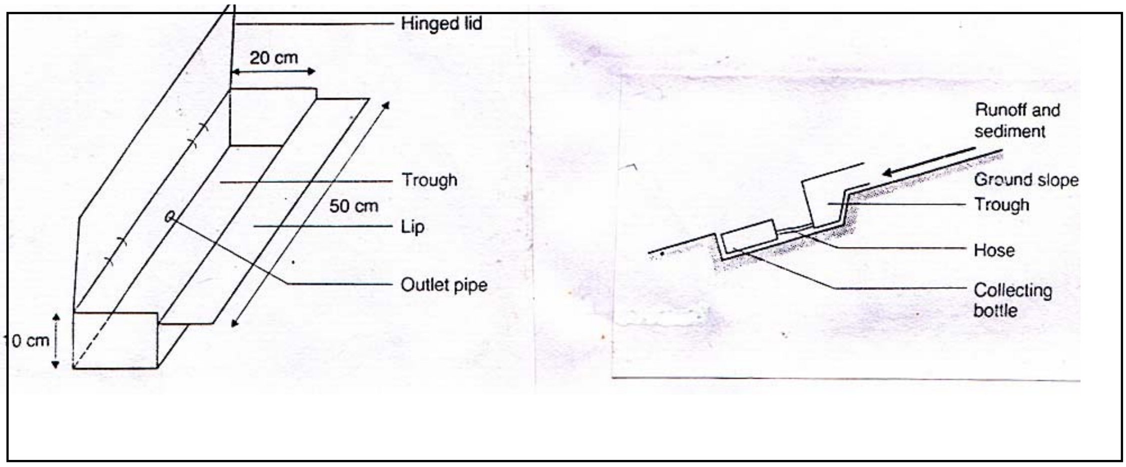


Figure 2.2. Gerlach trough (Morgan, 1979)

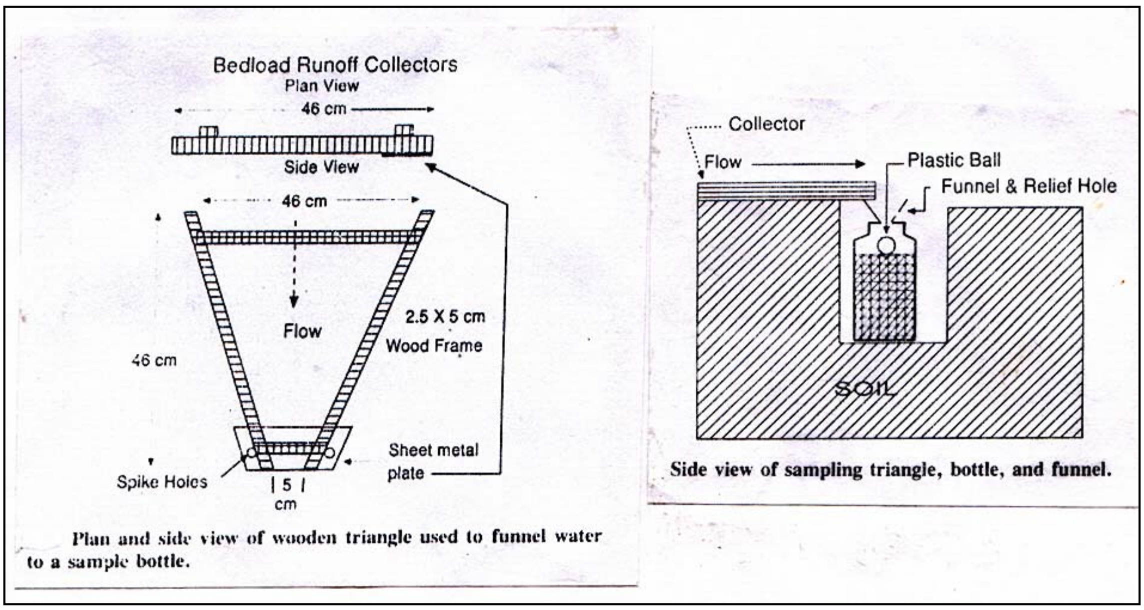


Figure 2.3. Runoff and sediment trap used by Daniels and Gilliam (1996)

2.3. Methodology

2.3.1. Location

The experiment was located around Sumber Jaya Sub District, Western Lampung, around 180 km from Bandar Lampung (Figure 2.4). Five representative land use were chosen :

(a) multistrata systems with coffee, trees and surface mulch,
(b) tegalan in the valleys with horticultural crops,
(c) pioneer zone coffee with clean weeded soil,
(d) natural forest remnants,
(e) reforestation zone with *Calliandra* in former coffee gardens.

The experiments sites of (a), (b), (c), and (d) were located at Bodong Jaya subvillage. At first, the test site for Calliandra forest was at Way Tebu subvillage, because the re-occupied by farmers one month after the experiment began, a new site was established in Dwikora village. Unfortunately, the last location was also opened on October 1999, and after that it was very difficult to seek another location because most of Calliandra forest in Sumber Jaya areas were cleared and change into tegalan and coffee.

The sediment trap was set up before and after field boundaries with at least 4 replications. The experiment started by the end of January 1999. The description of the each site was tabulated in Table 2.1. The location of the test site and the detail location of the each site were shown in Figure 2.5-2. 8.

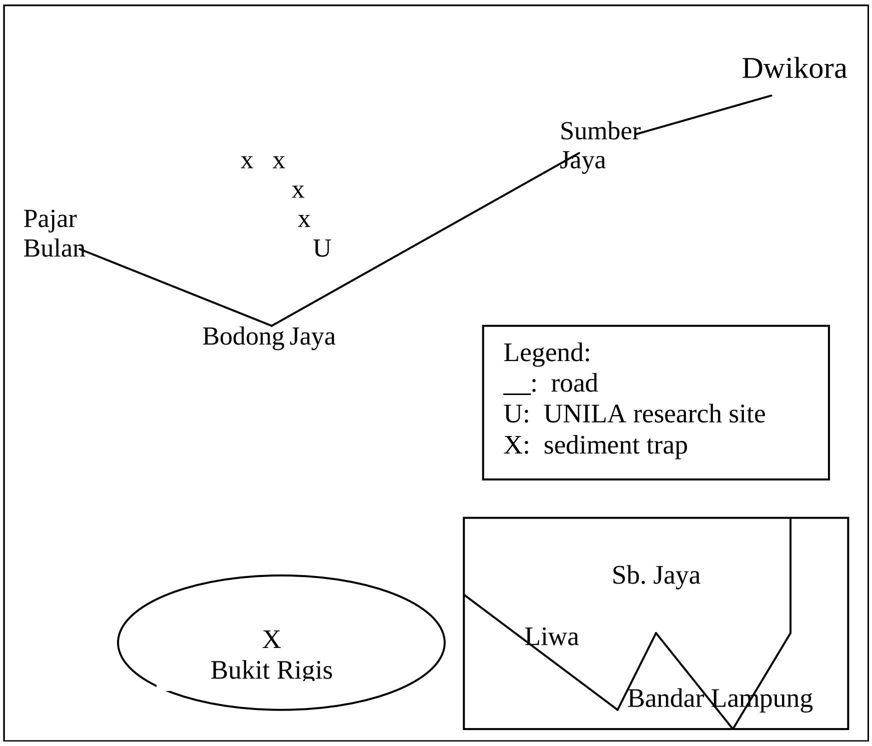


Figure 2.4. Location of sediment trap

Table 2.1. Description of each representative land use

Code	Land use	vegetation name	number	height (m)	distance (m)	slope (%)	length (m)	Note
A1	multistrata system	coffee bananas jack fruit guava durian	main 10 2 3 1	2 2 4 4 5	3 x 2.5	37	9-10.5	Below this land use is A2. Surface cover by litter (25%)
A2	tegalan	beans chilli+	10 furrows			45	15-22.5	Jan-March (beans) Ap-June (cowpea/chili) Jul-Oct(fallow) Nov-Dec (fallow)
A3	Grass (filter)	small grass		0.05-0.1	dense	5-9	1.5	Below this filter is sawah/paddy field
B1	Coffee (mixed)	coffee bananas trees	main 5 3	2 2 6	3 x 2,5	25	9.5	Below this land use is B2
B2	Shrubs (filter)	Weeds (woody weeds, ferns)	dense			82	3	Below this filter is sawah The weeds were dominated by Clibadia surinamenses
C1	coffee	coffee		1.65	2 x 2	65	18.5	Clean weeded Below this field is C2
C2	Shrubs	Weeds (woody weeds, ferns)	main	dense		90	12	Below this filter is a creek; Clibadia sp.
D1	coffee	coffee	main	1.65	2 x 2	42	33.5	clean weeded Below this filed is D2
D2	coffee	coffee	main	1.65	2 x 2	42	13.5	clean weeded Below this field is an intermittent creek
H1	forest	mixed (trees,bamboo, rattan,etc.)			dense	90	>300 m to the top	
H2	forest (open)	surface covered with trumble trees				70	40	opened at the end of January, 1999;
K1	Calliandra	coffee Calliandra pine				55	15	destroyed on October 1999
K2	Calliandra	the same as K1				55	5	

Note: There is an outlet from A2. We installed a sediment trap at the outlet.

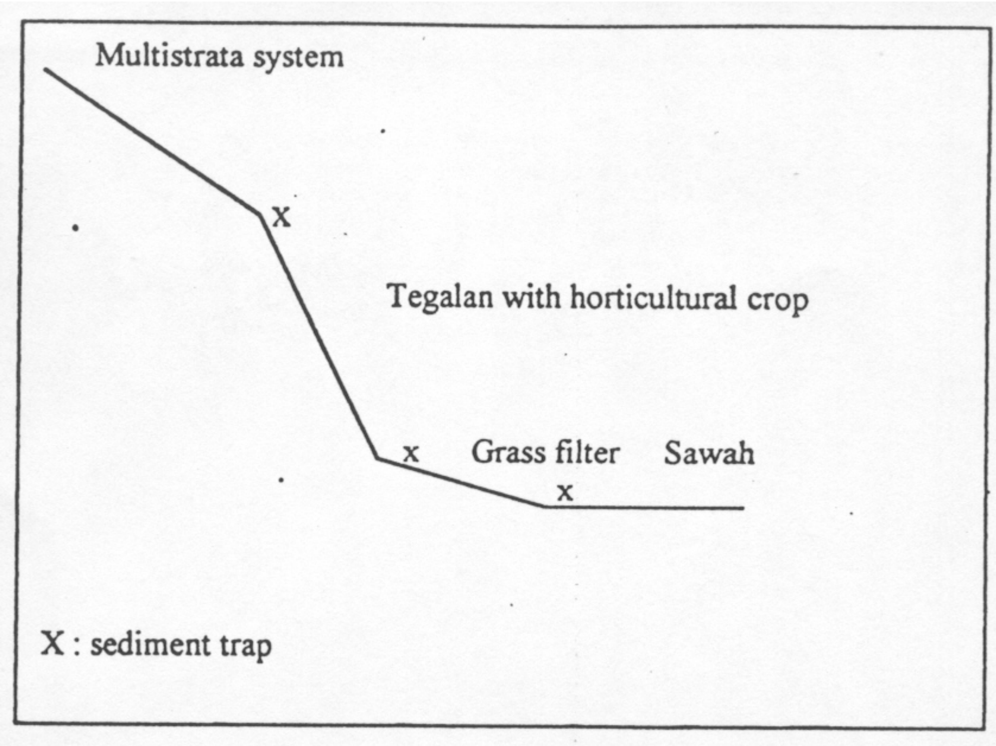


Figure 2.5. Cross section of multistrata system followed by tegalan and grass filter

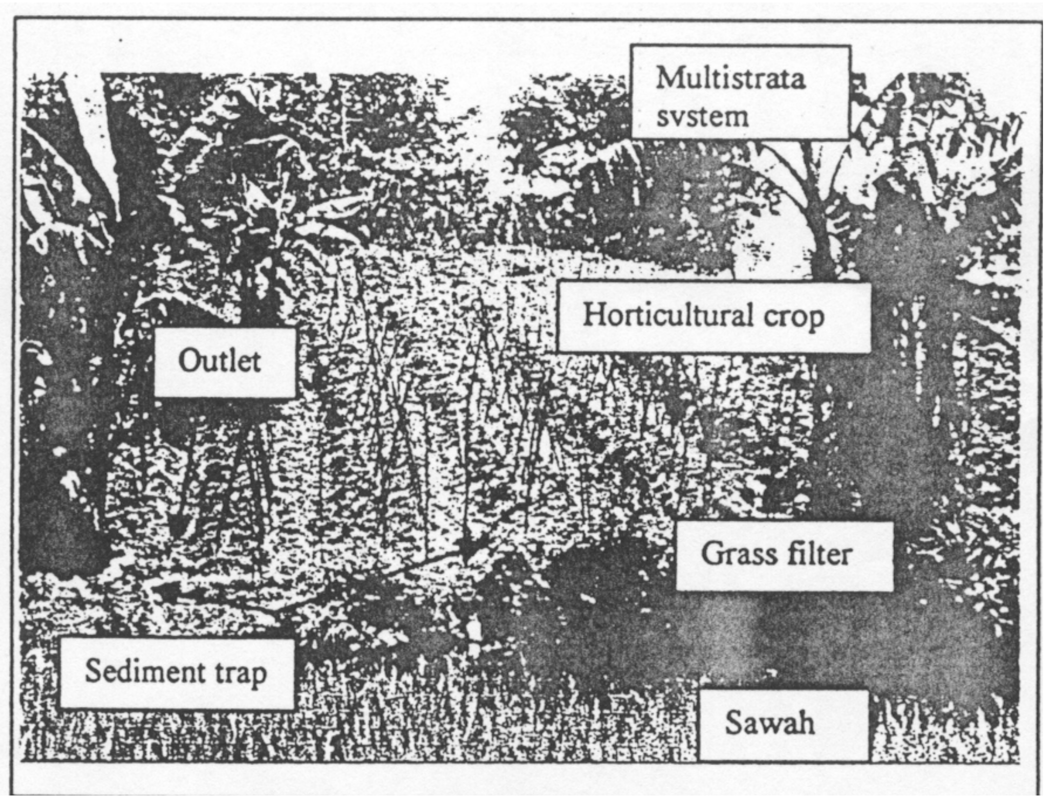


Figure 2.6. Multistrata system followed by tegalan with horticultural crop, grass and banana filter

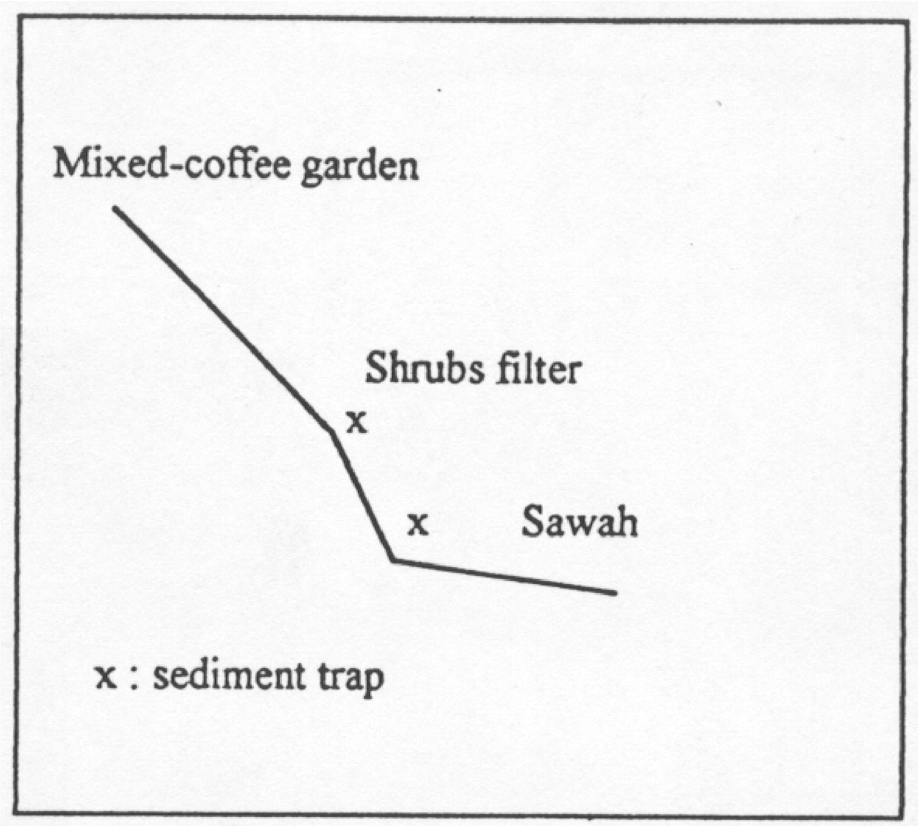


Figure 2.7. Cross section of mixed-garden followed by shrubs filter

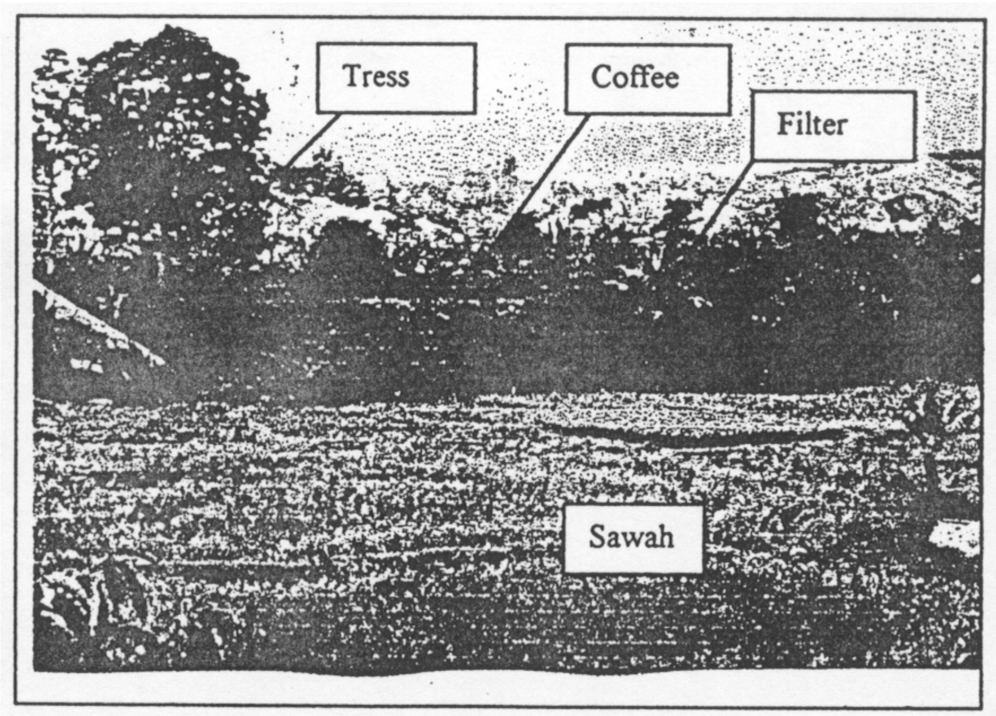


Figure 2.8. Mixed-coffee garden with a short shrubs filter

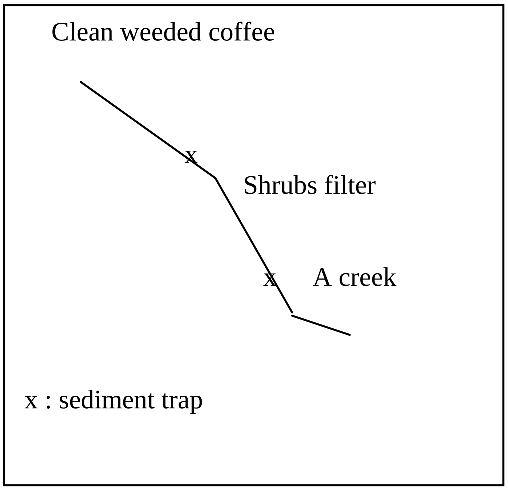


Figure 2.9. Cross section of clean weeded coffee followed by shrubs filter

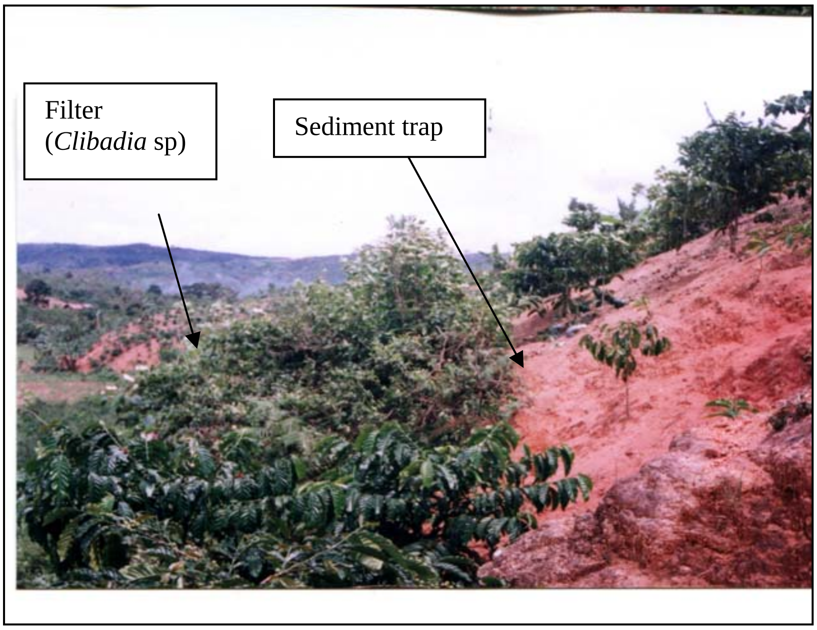


Figure 2.10. Placement of sediment trap at the edge of clean weeded coffee tree

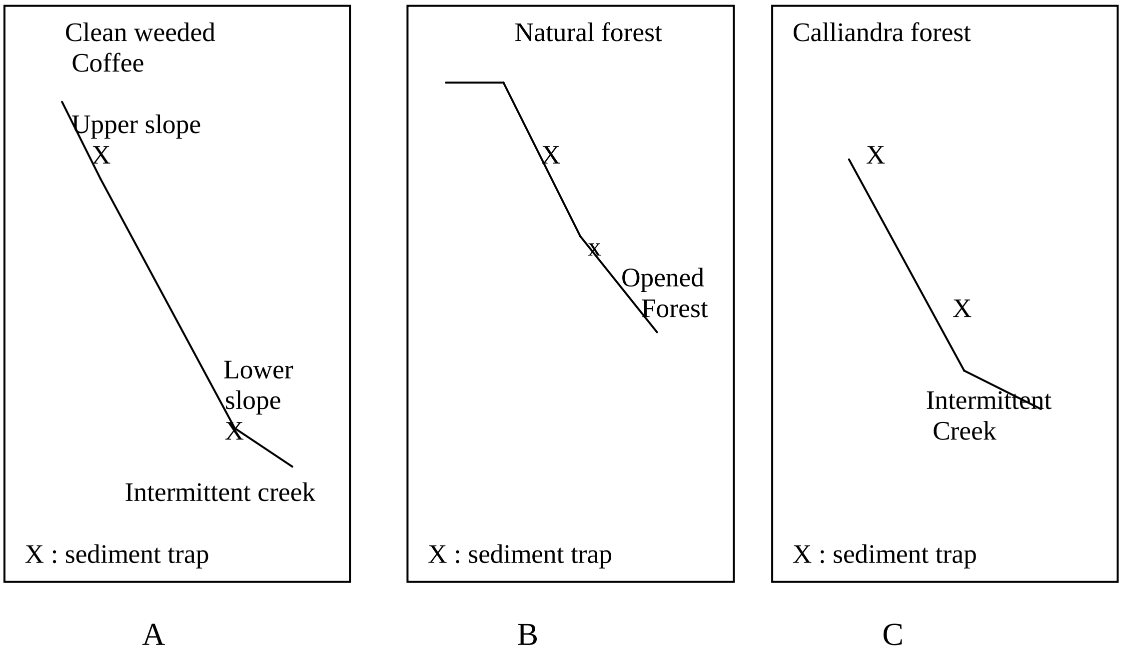


Figure.2.11. Cross section of land use sites: (A) clean weeded coffee, (B) Natural forest followed by opened forest, (C) Calliandra forest

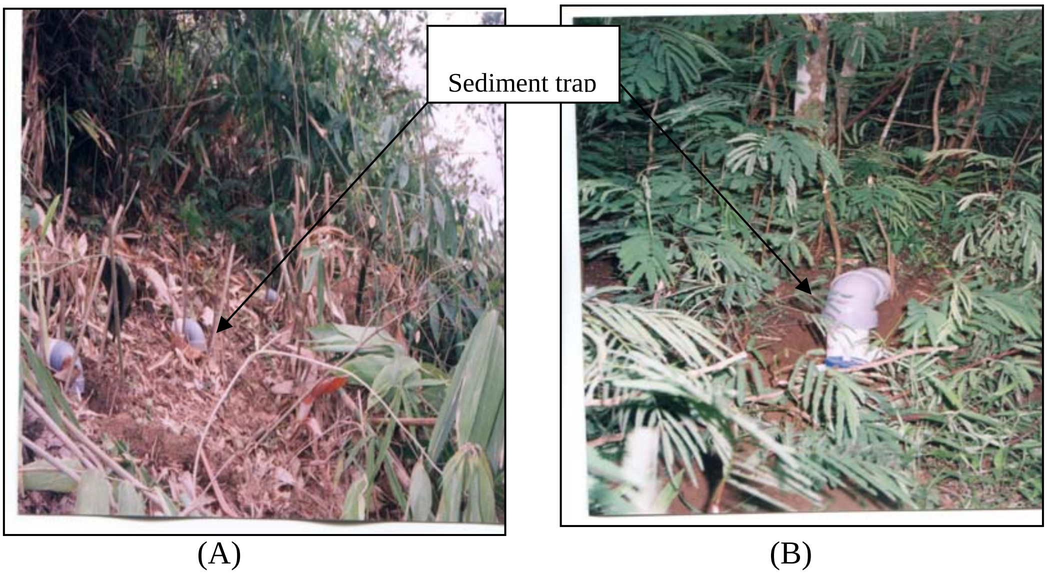


Figure 2.12 . Sediment trap under opened forest (A) and Calliandra (B)

2.3.2 *Designed of Sediment Trap*

The sediment trap was designed based on the method used by Daniels and Gilliam (1996) (Soil Science Society American Journal 60 (1996): 245-251); the coffee filter methods used by ICRAF in Jambi (Van Noordwijk, pers. comm.); and tube sampler method by IPB (Sinukaban et al.). The sediment trap (as shown in Figure 2.13) consisted of four parts:

(a) a sediment collector, made of PVC-L- tube with 10-cm in diameter,

(b) a plastic funnel inside the L-tube,

(c) PVC tube; the pipe was bored with nine holes at the wall side, and one hole was connected to small plastic bucket; a filter paper was placed at the bottom of the tube and supported by a cloth .

(d) small plastic bucket, consisted of filter paper and cloth

(e) other equipment, such as rubber ring.

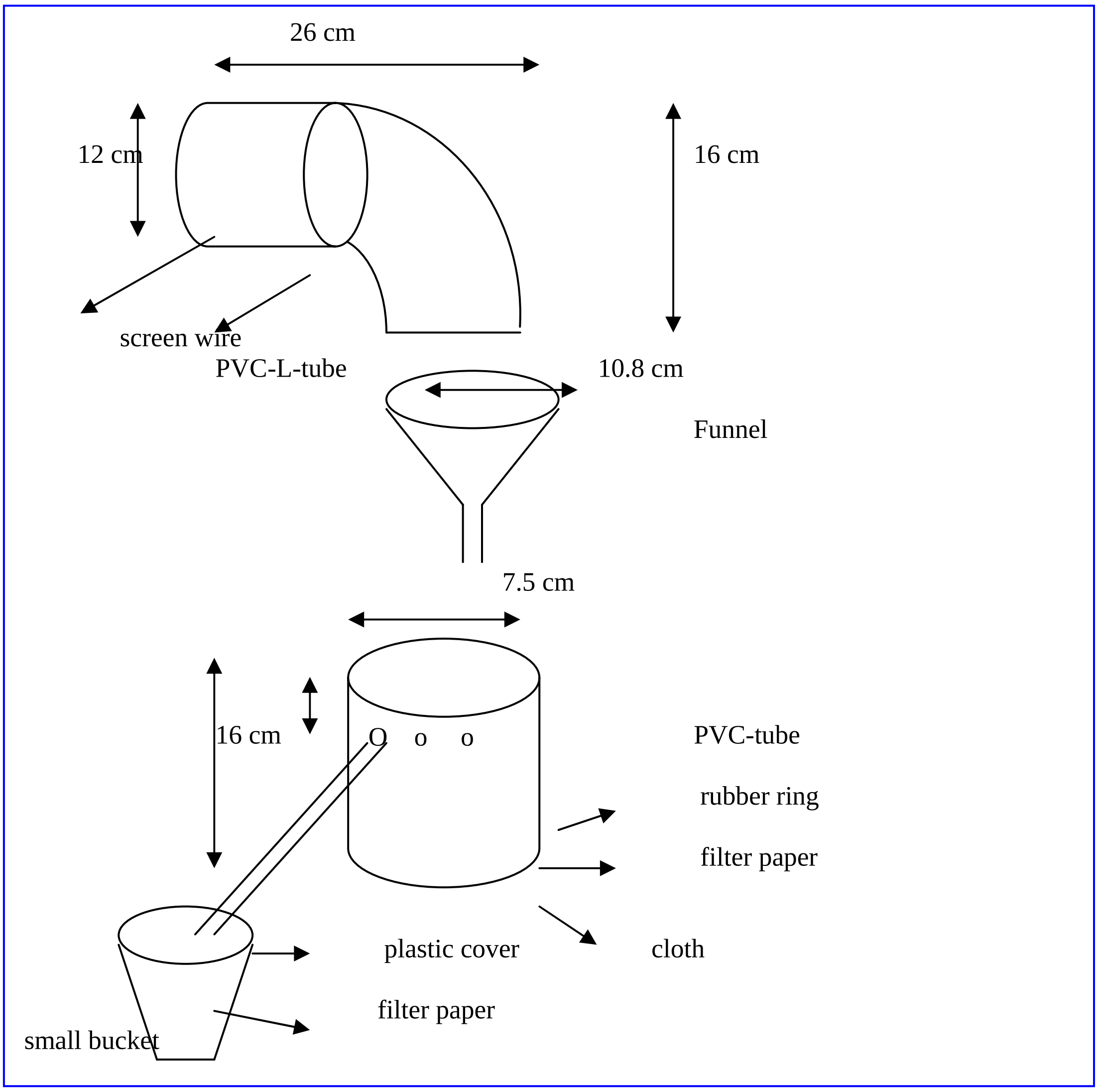


Figure 2.13. Sediment trap *designed* by UNILA teams

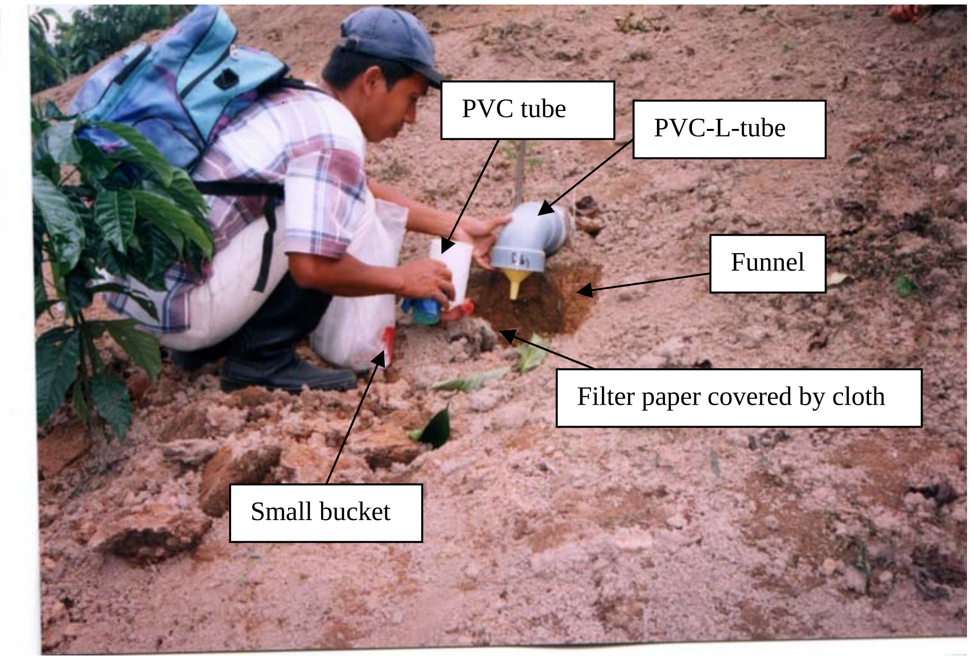


Figure 2.14. Set up a sediment trap

2.3.2. Sampling and handling

Samples of sediments were collected at least once in a week, depend on the amount of the rainfall. The sample was taken by changing the filter paper with a new one (known weight) and packed into a plastic bag. The sediment was taken to laboratory, dried and weighed. If the samples was too big it was weighed fresh, a sub sample was taken and dried and used for converting the total sample weight to a dry-weight basis.

2.3.4. *Supporting data*

Some data were also collected such as: (a) daily rainfall data, and (b) physical properties related to test site, such as slope length and steepness, vegetation type and density, and soil texture.

2.3.5. *Data analysis*

Data was expressed on a dry weight based and calculated in a time series (monthly). The average weight of the sediment as well as the standard deviation and coefficient of variation were also calculated .

Because of different conditions among the land use types, the soil movement was expressed in total sediment per unit slope length g m^{-1} . It is more rationale to use this unit because no source area can de delineated. Using this unit, the transport of sediment across field boundaries or along the slope can be measured.

To test the effectiveness of the various filter zones, a simple comparison was made between the amount of the sediment before entering the filter and the sediment entrapped by the filter:
Filter efficiency = 1 - Soil_movement_after_filter/ Soil_movement_before_filter

2.4. Results and Discussion

2.4.1. *Sediment flow from multistrata system followed by tegalan with horticultural crop and grass filter*

The total sediment yield measured from multistrata system , tegalan with horticultural crop and grass filter are shown in Figure 2.16 and Table 2.2.

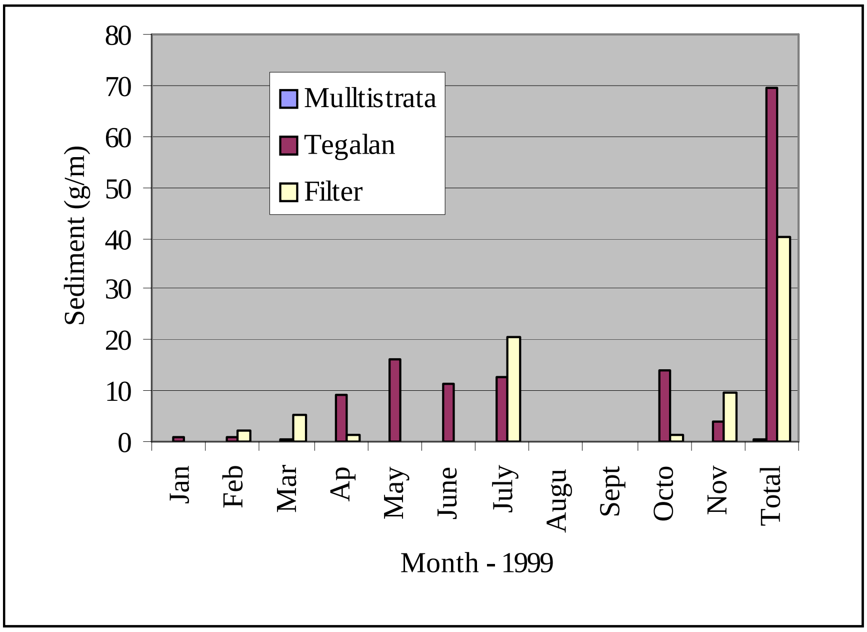
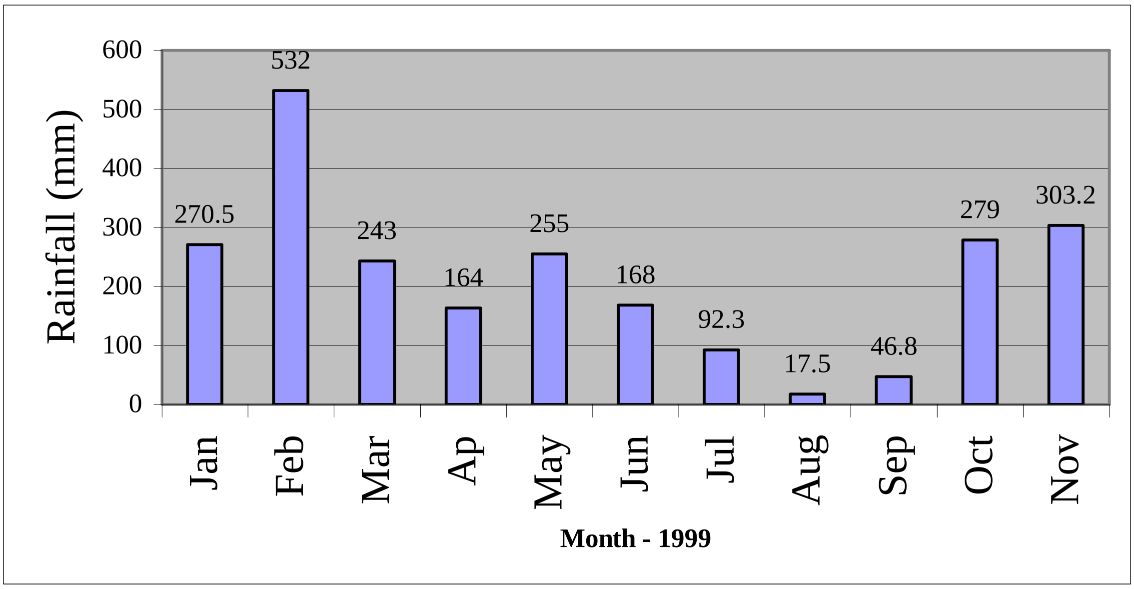


Figure 2.16. Sediment yield from multistrata system followed by tegalan and grass filter

As shown in Figure 2.16 and Table 2.2, the sediment yield from multistrata system was very low. The amount of sediment flow from multistrata system was only 0.24 g/m in one year measurement, compared to horticultural crops which could transfer 69.40 g/m of sediments. Table 2.2. showed that the grass filter could entrap the sediment as much as 42 % in average. As shown in Figure 2.6, some sediment traps were installed after the grass and banana filter, and one sediment trap was installed next to the outlet. This experiment showed that although the grass and banana filter was very short (1.5 m length), it could entrap the sediments up to 60%, and the rest was transferred to the next system (rice field/sawah). However, the grass filter which was located near the outlet could only entrap 17% of the transfer sediment, and about 83.% passed through the filter and transfer to the sawah system.

Table 2.2. Total sediment flow from multistrata system followed by horticultural crops and grass filter

Land use type	Sediment Flow to the next system g/m	Sediment entrapped by the filter %	Sediment passed the filter %
Total			
Multistrata	0.24	-	
Tegalan (horticul.crop)	69.40	-	
Filter	40.13	42.17	57.83
Hort-grass filter			
Horti	66.55	-	
Grass filter	26.50	60.18	39.82
Outlet-grass filter			
Outlet	80.80	-	
Filter next to outlet	67.38	16.61	83.39



(Source : January -June: Automatic Weather Station of UNILA-JAPANESE experiment site; July-November : manual raingauge of UNILA-JAPANESE experiment site)

Figure 2.17. Monthly rainfall data during the experiment time

It is also interesting to note that the sediment transfer during "the dry season" is still very high. As shown in Figure 2.16, the sediment yield on May, June, and July were bigger than that of the rainy season (January-April). Even for grass filter, the major contribution of sediment yield was occurred on July (about 51.4 %), although the monthly rainfall was low (Figure 2.17).

Tillage activity and the time lag of sediment transportation may induce the above results. During the heavy rainfall event on the rainy season, part of the soil surface at tegalan were covered by the weeds and the beans, so the soil erosion process would be reduced by this vegetation. After the beans were harvested on April, the farmer started to prepare the land for growing chili and cowpea, and this land preparation would strongly effect the soil condition and surface cover; the soil surface was clear and the soil was loose. This condition would stimulate the soil erosion process.

Time lag of sediment transportation will also influence the sediment transfer, especially in the filter area. The accumulation of sediment yield which produced during the rainy season was transported on the dry season. The amount of rainfall on May and June were 255 and 168 mm respectively, a little bigger than that of March and April (243 and 164 mm respectively).

2.4.2. Sediment flow from mixed-coffee garden followed by shrubs filter

The amount of sediment flow from mixed-coffee garden and entrapped by the shrubs filter are shown in Figure 2.18. The filter was dominated by a woody weeds species, which was identified as *Clibadia surinamenses*. The other species was ferns.

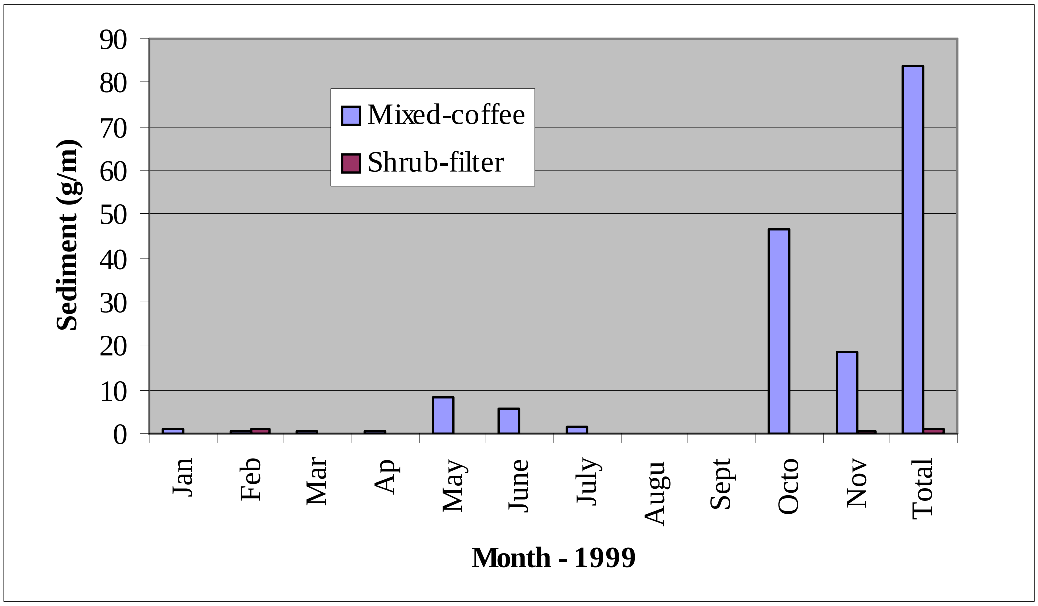


Figure 2.18. Sediment flow from mixed-coffee garden followed by shrubs filter

Although the shrubs filter was very steep (82 %) and the width was only 3 m, it was very effective to entrap the sediment flows from the above system. As shown in Figure 2.18, most of the sediment transfer from mixed-coffee garden was entrapped in the filter (98.7 % in average), only small part was passed (about 1.3%) and transfer to the next land use (sawah – rice field).

However, on February 1999 a significant amount of sediment passed through the filter due to the high rainfall during that month. About 0.78 g/m of sediment left the shrubs filter compare to the mixed-coffee system which transferred 0.74 g/m of sediment.

The biggest contribution of sediment transfer at the mixed-coffee garden was occurred on October. Even on the “dry season” (June and July), the sediment yield from this land use was bigger than the rainy season.

Due to the abundant of water during the rainy season, the weeds under the coffee tree grew very fast, so the farmer will start to clear the weeds at the end of rainy season (May or June). This activity will also be done at the beginning of rainy season (early October), due to some reasons such as for the ease of fertilizer application, weeding, or just cultivated the soil to make it more friable. The fact that there was no sediment or a very small amount of sediment entrapped by the filter during the dry season proved this argument. If there is a concentrated flow during the dry season or the rainy season, the sediment will be transferred to the lower slope (filter area).

2.4.3. Sediment flow from clean weeded coffee followed by shrub filter

The total of sediment yield flow from clean weeded coffee and shrubs filter are shown in Figure 2.19. It is very interesting to note that the total sediment yield which passed through the filter (37.32 g/m) is greater than the sediment yield entered the filter from the coffee area (30.23 g/m), or increase 23%.

The biggest contribution of sediment yield which flowing out of the filter was occurred on October 1999, about 35. 89 g/m or 96% of the total sediment yield. The major contribution was from the sediment trap No.4 which gave 177.69 g/m; the other three traps were zero, and one trap was 1.76 g/m.

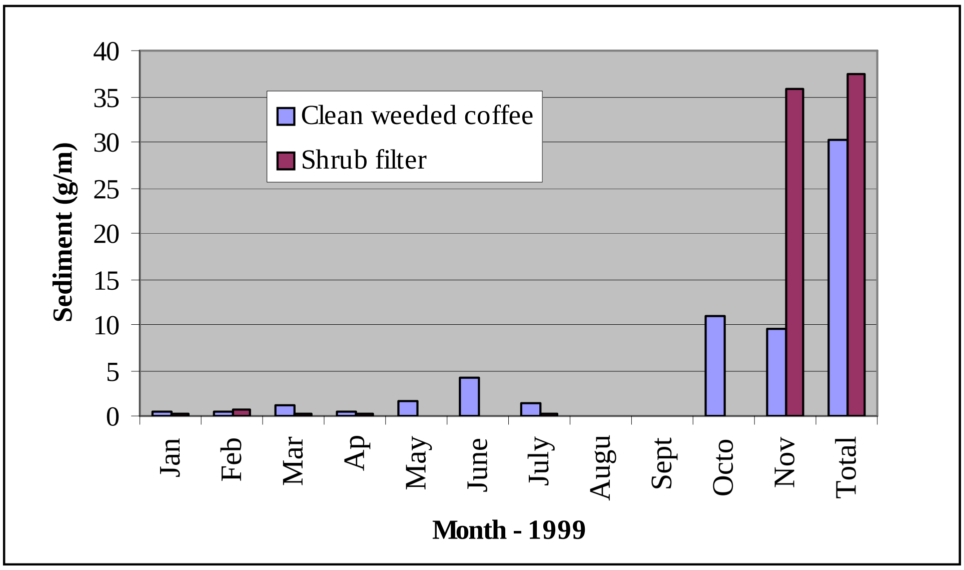


Figure 2.19. Sediment yield before and after entering a shrub filter

It is fairly difficult to decide which process was responsible of the high sediment transfer. Although field checking showed that a rill was developed at the upper part of the sediment trap No.4, an evidence of sediment accumulation indicated that a small landslide might be responsible too.

The other possibility is the side effect of weeding activity by the farmer. As explained on the previous discussion, the farmer usually have a lot of activities at the end of rainy season and at the beginning of the rainy season, including in weeding, fertilizer application, and soil tillage. As shown in Figure 2.18, the results of this activity was surprising because there was a sediment transfer during the dry season (June and July) from the coffee area. During the next rainy season (October), the sediment will be transferred to the lower slope.

2.4.4. Sediment flow from clean weeded coffee

The sediment yield from upper and lower slope of clean weeded coffee areas without any conservation measure or filter are shown in Figure 2.20. As shown in Figure 2.20, the amount of sediment at lower slope was increase remarkably almost ten times, from 10.12 at upper slope to 110.3 g/m at the lower slope.

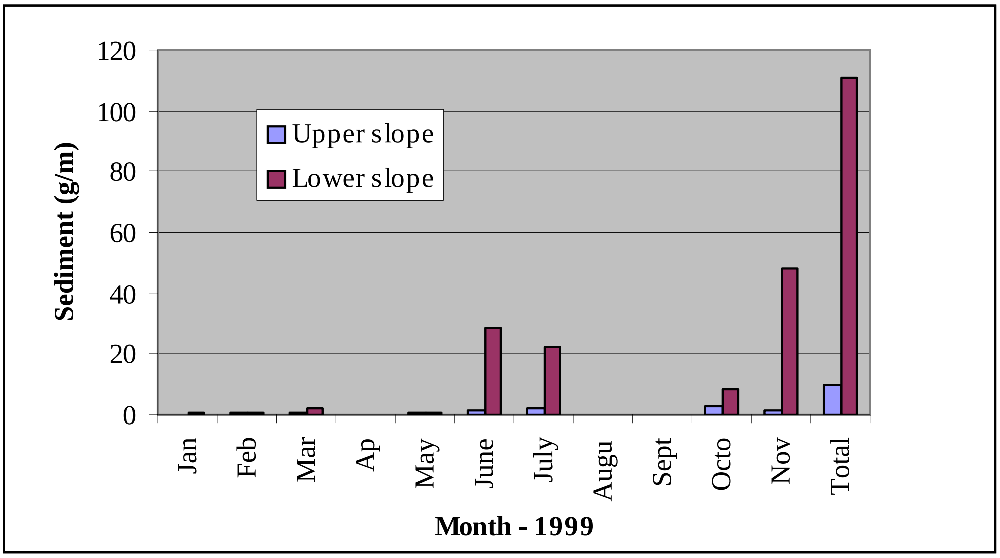


Figure 2.20. Sediment yield from clean weeded coffee without filter

As shown in Figure 2.19, the major part of the sediment transfer was occurred on June, July, and November, and a small amount of sediment was occurred on October. Instead of farmer activities that have been discussed above, the litter of coffee leaves also affected the sediment transfer especially on October. As shown in Figure 2.23, the litter have blocked the sediment trap , so reduced the transportation of sediment.

2.4.5. Sediment flow from forest and opened forest areas

The total sediment yield from forest areas and new opened forest areas are shown in Figure 2.21. Although the slope is very steep (> 90%), the sediment yield left the forest area was very low, almost zero (0.0086 g/m). The reduction of rainfall energy by the canopy of the trees and the dense of vegetation at the surface which serve as barrier were responsible of the low sediment yield.

However, an increasing about five times of the sediment flow was occurred when the forest was opened. The total amount of sediment transfer from the new opened forest area was 0.5 g/m, which is bigger than sediment transfer from multi strata system (0.2 g/m).

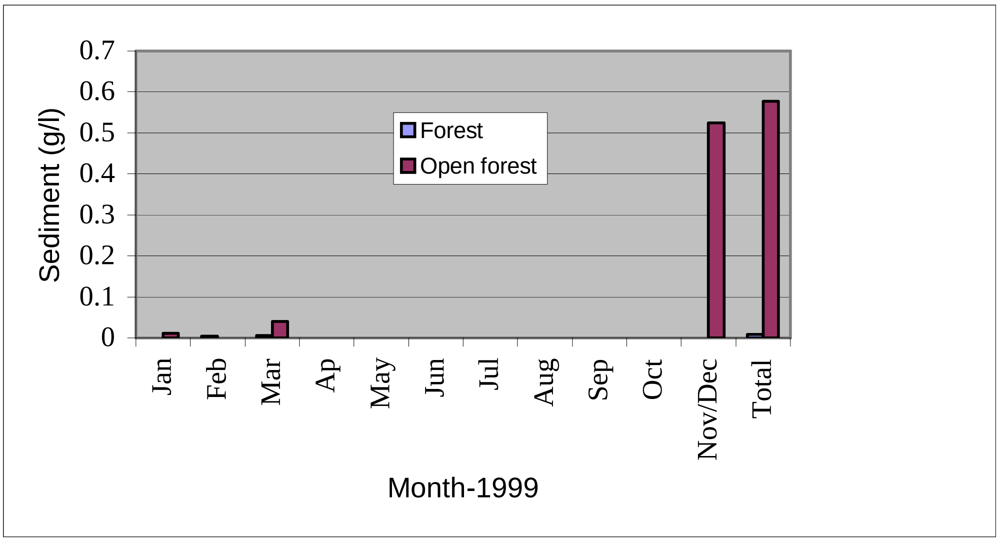


Figure 2.21. Sediment yield from forest areas

2.4.6. Sediment yield from Calliandra system

No sediment was found in Calliandra system. As shown in Table 2.1, instead of Calliandra, pines tree is also found in this land use. The dense of soil surface coverage by pines litter gave a major contribution of this result.

2.4.7. General discussion

Sediment yield from various land use

The total sediment yield of transfer from each land use are shown in Figure 2.21.

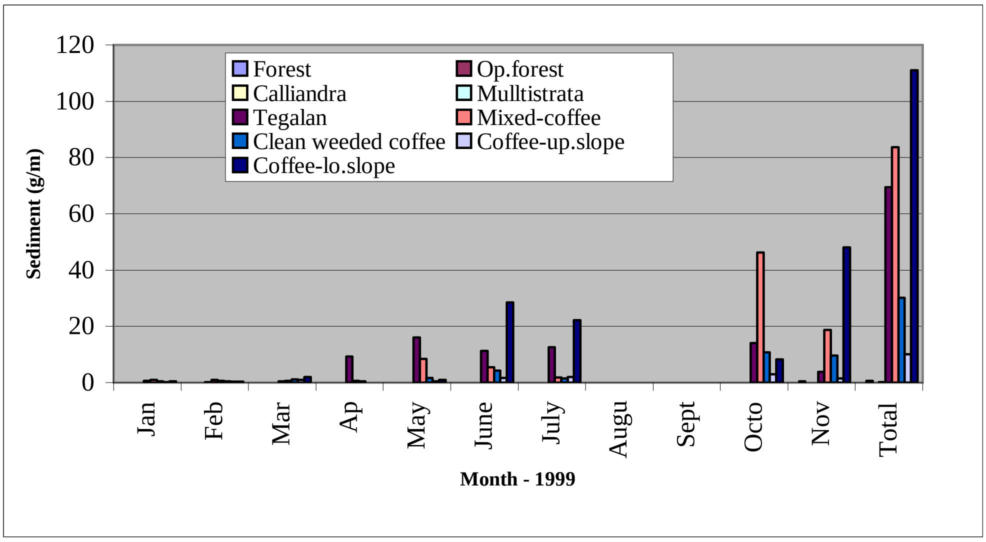


Figure 2.22. Sediment transfer from various land use

As shown in Figure 2.22, the coffee garden have the biggest sediment yield, on the other the sediment yield from the forest areas (Calliandra and natural forest) were zero or almost zero. The multistrata system also produced a very low sediment yield, which indicated that this *agroforestry* system was a good way to protect soil against water erosion.

It seems that the surface cover condition of the land use system gave a high contribution on sediment transfer other than soil erosion factors. Although forest area and Calliandra have steeper slope than clean weeded coffee areas, they have better performance in modifying the erosion process. The amount of rainfall have a little effect on sediment transfer. The highest monthly rainfall event was occurred on February, and the highest sediment transfer (as shown in Figure 2.16-2.20) was occurred on October.

The effect of farmer activities (weeding, tillage) gave a high contribution in promoting sediment transfer. Theses activities will effect the soil surface condition, such as vegetation coverage and soil condition. If soil erosion process could be defined as the process of soil detachment and transportation by erosive agent, then the soil detachment process has been done by the farmer activities.

Filter effectiveness

Filter in general sense can include a range of landscapes elements: depression, cut-off drains, ditches, embankment, vegetated strips, hedgerows, and riparian vegetation (Van Noordwijk et al., 1998). We recognized one natural vegetative strips which is abundant in the study area, i.e. shrubs filter which consisted of various weeds species, mainly *Clibadia surinamense* and various type of ferns. *Clibadia sp*. is a woody species which could reach 1.5 m in height. The effectiveness of the natural vegetative filter in trapping sediment is shown in Table 2.3.

Instead of the vegetation type of the filter ,the effectiveness of natural filter strip in trapping or transferring sediment also depends on other factors, such as slope length and the location of the slope. This study showed that short filter cover with small grass or shrubs was very effective to entrap the sediment than a very long one. Runoff will have a chance to accumulate in the longer slope, and a rill will be created if there is a concentrated flow. The energy of runoff will also decrease when it reaches at the bottom of the slope. Although there will be an accumulation of sediment at the bottom of the slope, it needs an extra energy to remove the sediment to another place (transport-limited).

Table 2.3. Effectiveness of various natural vegetative strips in the study area

No	Description of filter	% sediment entrapped	% sediment passed
1	*Grass filter* : consists of small grass and sparse bananas; located at bottom of the slope (5-9%); 1-3 m length (Fig. 2.6). The sediment source is tegalan with horticultural crops.	42.17	57.83
2	*Shrubs filter* : consists of woody species (Clibadia sp. and various ferns); located near at foot slope with length 3 m and gradient of 82% (Fig.2.8). The sediment source is mixed-coffee garden.	98.7	1.3
3	*Shrubs filter*: consists of woody species (Clibadia sp. and various ferns are dominant) and small grass at bottom of this filter; located at mid-slope with 12 m in length and gradient 90% (Fig.2.10). The sediment source is clean weeded coffee.	0	100% + 23%

However, further study is still needed to see the role of the filter in sediment transfer. One year experiment is not enough, because some processes in the filter is still unclear, such as

(a) the accumulation effect of sediment within the filter created by erosion in the past ; this is very important because the filter has a certain capacity in trapping the sediment, and if the capacity has been filled, the filter could not entrap the sediment anymore.

(b) the process within the filter, including in the possibility of landslide occurrence and the soil formation due to the accumulation of the sediment. This aspect concerns with the capability of the filter against runoff destruction.

2.4.8. Problem , Strength and Weakness

The sediment trap designed by the UNILA team was very simple and very easy to operate. The data could be collected on rainfall event basis or daily basis. However, because the measurement have been done in the natural condition, some weakness with related to statistical aspect are appeared. Problems related to security of the instrument and location of the test site was also faced during the experiment.

The variability among the replication could be expressed by calculating the standard deviation (SD) and the coefficient of variation (CV). The calculation of SD and CV are shown in Table 2.4.

Table 2.4. Standard deviation (SD) and coefficient of variation (CV) among the replication

Land use type	Mean	SD	CV %
Multistrata	0.24	0.17	70.04
Tegalan	69.4	15.32	21.95
Filter	40.13	28.60	71.26
Mixed-coffee garden	83.7	75.2	89.77
Shrubs filter	1.08	1.07	98.64
Clean weeded coffee	30.23	23.91	79.1
Shrub filter	37.43	79.10	211.33
Clean weeded coffee upper slope	10.11	5.93	58.71
Clean weeded coffee lower slope	111.03	52.24	47.06
Forest	0.08	0.01	112.76
Opened forest	0.57	1.06	183.56
Calliandra upper & lower slope	0	-	-

The lowest variability was found in tegalan with horticultural crop. As shown in Figure 2.6, the farmer have cultivated the soil as uniform as possible because he would grow a high value crops that need the same distance and soil management.

At least there are three reasons why the high coefficient of variation among the replications appeared. Instead of a rill development or a concentrated flow of runoff above a sediment trap, the activity of the farmer and the existence of litter at the soil surface highly effected the sediment transfer as shown in Figure 2.23.

Figure 2.23. Litter of coffee leaves could change the direction of runoff and also block the collector of sediment trap

Figure 2.24. Coffee tree under Calliandra reforestation

Forest squattering has destroyed two experiment sites : natural forest and Calliandra forest. We did not move the sediment trap from the opened forest and we added as a treatment. The calliandra location has been destroyed twice: at the end of January and on October 1999. In case of Calliandra, it is very difficult now to see the calliandra forest around Sumber Jaya, because mostly has been cleared. As shown in Figure 2.24, the calliandra was grown in the former coffee garden as part of reforestation. Since “reformasi”, the people encouraged to open the forest area, and the former coffee garden under calliandra was the priority because of the high coffee price in 1998/1999.

Problems relating to security of the instrument was faced in forest area and Calliandra area. People were interested in taking some parts of the sediment trap such as, funnel and the PVC-L-tube. The first location of sediment trap in Calliandra area have been totally destroyed , so we moved to another site. On October 1999, this location was cleared and the five pieces of PVC-L tube were lost. In forest area, we were very lucky. Because it is not far from Bodong Jaya subvillage, we only lost one piece of funnel and two PVC-L-tube during the experiment. The people around the subvillage have known that the instruments were belong to UNILA for measuring soil erosion.

III. STREAM FLOW PATTERN OF WAY BESAI RIVER
(Related to Land Use Changes and Rainfall Pattern from 1970 To 1997)

3.1. Introduction

The land use changes of Way Besai upper catchment shown as follow:in 1970 the forest occupied 57.38% of that areas which become 21.39% in 1990; on the other hand the monoculture plantations (coffee plantation) increased from 0% in 1970 to 41.77% in 1990 (Syam et al., 1997). Lately, the "booming" of coffee price in 1998 and "reformasi" have made the people encouraged to open the protected forest and reforestation zone around Sumber Jaya District, and change into coffee plantation. During reformation time in 1998-1999, a very intensive forest squattering has been occurred in Bukit Rigis, one of the protected forest areas. The forest clearing in this area began on early January 1999. As shown in Figure 3.1. , the forest squattering has reached the top area of the mountain.

Salam, Katayama, and Kimura (1998) reported that deforestation in several areas within the Way Besai subwatershed caused the decrease of enzymatic activities ranged 4-12 % in uppermost 0-20 cm layers in 1984 and 7-20% in 1990, while those in underlying layer 20-40 cm ranged 6-18%. Lumbanraja et al. (1998) also reported that the land use change in that areas have resulted in deterioration of soil properties related soil fertility. Lumbanraja et al. (1998) estimated that the decrease of organic matter at the surface layer was 4.1% from 1978 to 1984, and 5.9 % from 1978 to 1990. Some soil chemical properties, such as total N, available-P, total P, CEC, also decreased in the range of 1.6% until 7.8%.

The problem in Way Besai subwatershed is not only caused by deforestation, but also arise from the poor management of the coffee plantation in the areas. The farmers prefer to clean all the weeds under the coffee tree that promote soil erosion more higher. We can see such management as shown in Figure 3.2.

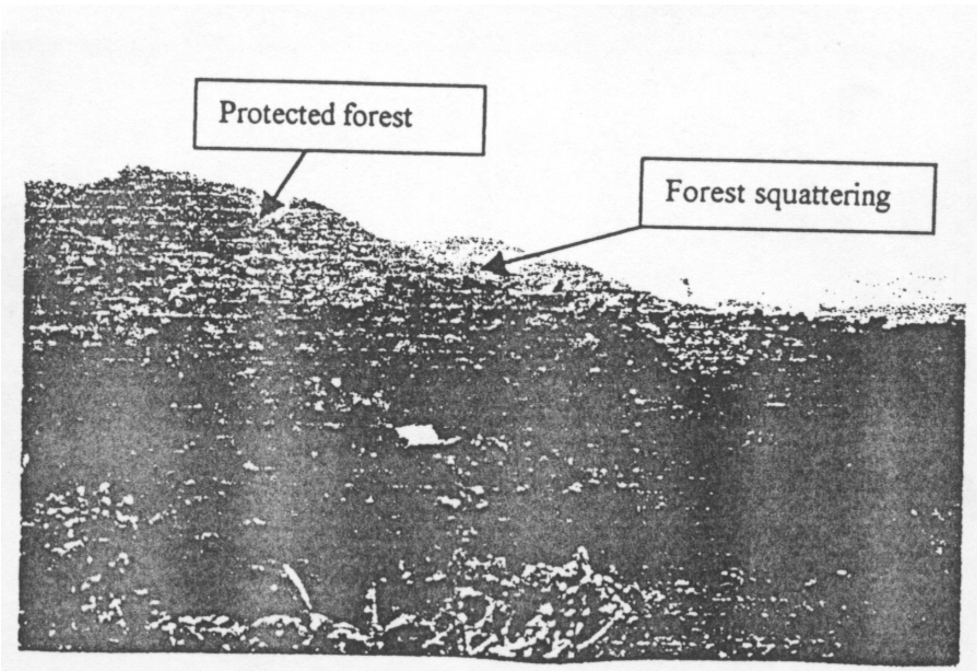


Figure 3.1. Forest squattering at Bukit Rigis (taken on July, 1999)

Figure 3.2. *Cleaning* as general practice management in coffee plantation

3.2. Purpose of the study

The main objective of this research was to analyze the stream flow of Way Besai river at the location of the new dam at Sumber Jaya, to be related to rainfall pattern and land use changes of Way Besai subwatershed.

The responsible of UNILA team was collecting the basic data, and analysis was done by the IPB team. This report contained only basic data of Way Besai subwatershed, and the analysis was written by the IPB team in a separate report.

3.3. Data Collection

The main data collected in the form of secondary data were as follows:

(a) daily discharge data of Way Besai river at Sumber Jaya water gauge station,
(b) daily rainfall data from several rainfall station around the subwatershed;
(c) information of land use changes at the subwatershed for several years.

The daily discharge data and rainfall were collected from several offices in Lampung and Bandung (Centre for Water Research), and several reports related to this study which were listed in the references. The location of the rain gauge and water gauge station are shown in Figure 3.3.

The main information of land uses changes was the paper written by Syam et al. (1997). Because the study was not done exclusively for Way Besai subwatershed but also included the other upper catchment of Way Tulang Bawang watershed (however about 80% was located in Way Besai catchment), we traced again the land use change using the same map as used by Syam et al. (1979).

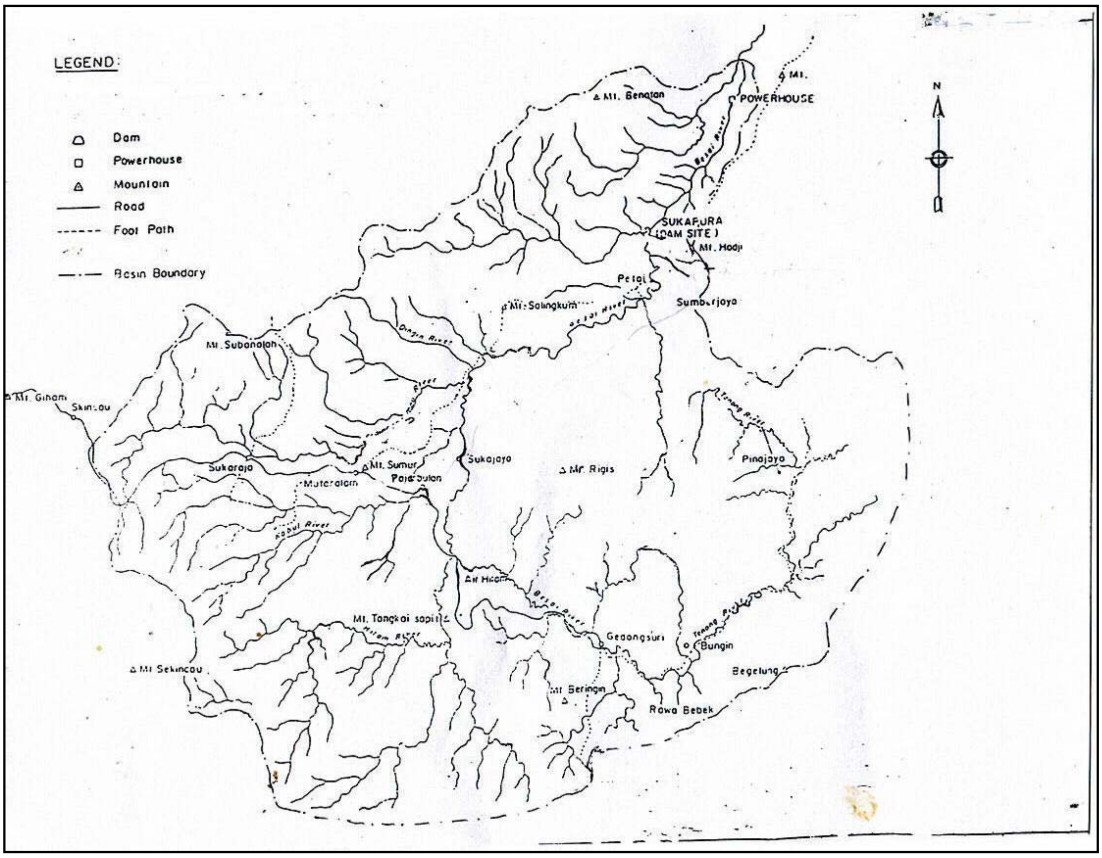


Figure 3.3. Maps of Way Besai river

3.4. Results and Discussion

3.4.1. Area and site

The area of Way Besai subwatershed measured above the outlet of Petai water gauge (Sumber Jaya) was 389 km^2. This area was chosen as the basis of this study. The total area of Way Besai subwatershed measured at Banjarmasin water gauge station before entering the main river was 604 km^2. The location of water gauge stations along Way Besai river are shown in Figure 3.3 and Table 3.1.

Table 3.1. List of water gauge station at Way Besai river

No	Station	Location	Alt m	Area km^2
1+	Sukajaya	105^{o}01’ E.L ; 04^o 34’ SL	740	268
2*	Petai	104^o 29’ E.L ; 05^o 00’ S.L	725	389
3*	Banjarmasin	105^o 33’ E.L; 04^o 46 ‘ S.L.	107	604

*)Source : Inoue and Danaluddin (1980);+: Balai Penyelidikan Hidrologi Pusair

3.4.2. Water flow

Mean monthly of water flow in Way Besai river are shown in Figure 3.4 and Table 3.5-3.7.

3.4.3. Climatic and Rainfall data

The mean monthly rainfall data from several raingauge station are shown in Figure 3.5. Monthly rainfall data are listed in Table 3.8-3.10. The average climatic data of this area are tabulated in Table 3.11.-3.12.

3.4.4. Soil condition

The general soil conditions of Way Besai catchment have been reported by some researches, such as Lumbanraja et al. (1998; 1999) and Salam et al. (1998). Some of the results are listed in Table 3.13.

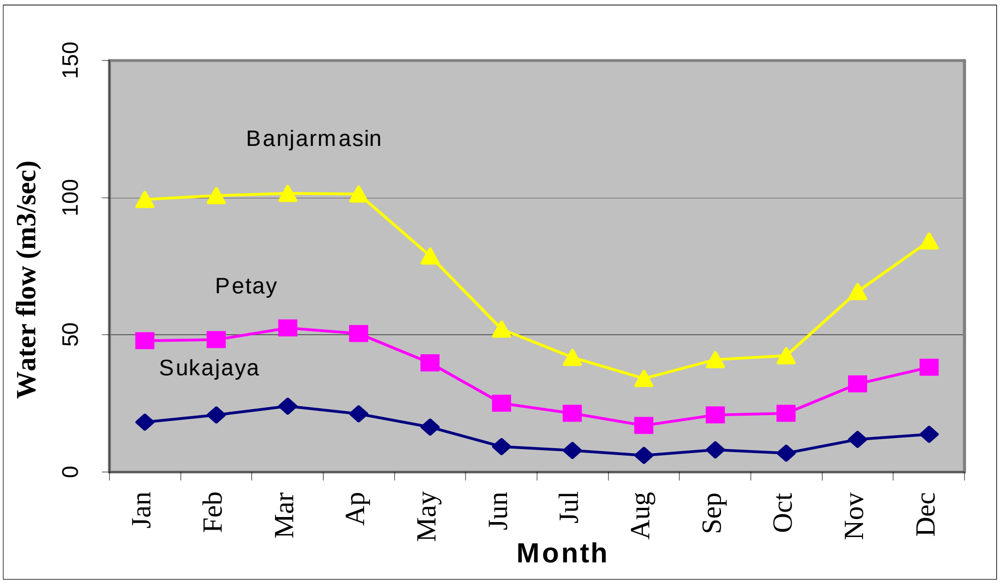


Figure 3. 4. Mean monthly of Way Besai river at three water gauge station

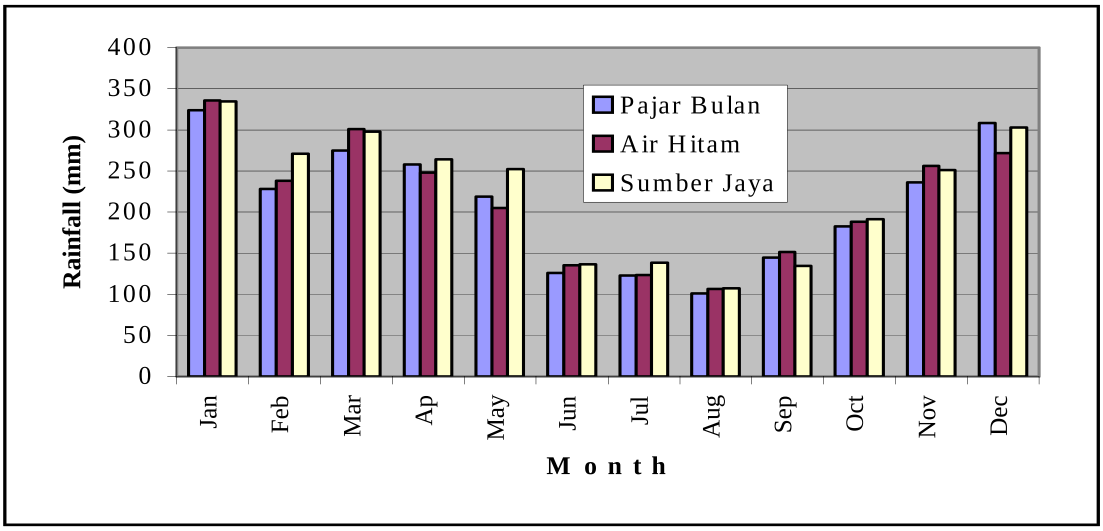


Figure 3.5. Mean monthly rainfall in Way Besai subwatershed (1972-1998)

3.4.5. Land use change

The land uses changes which was studied by Syam et al. (1997) covering 27 km x 27 km or 729 km^2. This study was based on the land use map produced in 1970, 1978, 1984, and 1990. The results are shown in Table 3.3. Using a planimetric method, Sub Balai Rehabilitasi Lahan dan Konservasi Tanah Way Seputih (Sub BRLKT) (The Sub Office of Land Rehabilitation and Soil Conservation) also calculated the land use areas in Way Besai catchment and the results are shown in Table 3.4.

Because the catchment area of Way Besai subwatershed is only 386 km^2 , we traced again the land use changes which only covering the area. We used the same maps as used by Syam et al. (1997) as shown in Table 3.2. The results was reported by the IPB team (Sinukaban et al., 1999).

Table 3.2. List of data sources for land use mapping (Syam et al., 1997)

Year	Scale	Location	Sources	Mapping	Printing
1970	1:100,000	104°20'-105°20' EL 4°40'- 5°40' SL	Land use map (Kantor Agraria)	May, 1970	September 1970
1978	1:25,000	104°19'-104°34' EL 4°55'- 5°10' SL	Land use map (Kantor Agraria)	January, May, July, 1978	November 1980; February, 1981; March, June,1983
1984	1:25,000	104°19'-104°34' EL 4°55'-5°10' SL	Revision of 1978 map (Kantor Agraria)	March, 1984	October,1984; March, December 1986
1990	1:25,000	104°19'-104°34' EL 4°55'- 5°10' SL	Revision of 1978 map and 1984 map (Kantor Agraria)	October, November, 1990	November,1991; August,1992

Table 3.3. Changes in percentage cover (%) of each land use measured by Syam et al. (1997) around Way Besai catchment

Land use form	1970	1978	1984	1990
1. Residence areas	0.00	1.03	1.70	2.20
2. Paddy-fields	0.36	2.92	5.02	5.35
3. Cultivated lands (crops and vegetable)	5.29	2.20	1.07	0.12
4. Cultivated area under shifting cultivation	9.38	4.81	0.33	0.00
5. Cultivated lands (mixed)	5.92	0.00	0.00	0.00
6.Plantationlands (monoculture)	0.00	20.83	41.77	41.11
7. Plantation lands (mixed)	0.00	0.93	0.95	19.26
8. Primary forest	57.38	32.60	21.39	12.72
9. Secondary forest	11.88	16.20	10.79	18.05
10. Ponds	0.00	0.03	0.01	0.07
11. Grasslands	8.96	18.44	16.98	1.12

Table 3.4. Land use composition in Way Besai subwatershed

No	Land use type	Area (ha)	% **
1	Shrubs	14,925	33.79
2	Paddy filed	2,375	5.38
3	Tegalan (cultivated land)	1,750	3.96
4	Coffee garden	5,000	11.32
5	Mixed-coffee garden	12,450	28.18
6	Grasslands	176	0.40
7	Private/community forest	2,500	5.66
8	Others	5,000	11.32
	Total	44,176	100

*) Source : Sub BRLKT Way Seputih (1998) based on the report in 1987 ;
**) percentage was calculated by the writer

The total area of Way Besai calculated by Sub BRLKT Way Seputih is larger than the area in Table 3.1. (38600 ha), probably some areas after Petai water gauge was included.

Table 3.5. Mean monthly river flows (m 3/s) of Way Besai river at Petai water gauge station

Year	Jan	Feb	Mar	Ap	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975	29	30.8	18.4	23.1	15.6	10.77	10.3	10.2	9.81	13.1	21.2	11.2
1976	15.4	17.5	18.9	23.8	14.2	7.75	6.61	7.58	5.6	7.07	18.4	14.7
1977	22.9	24.6	20.1	28.9	16.6	27.19	13.9	7.91	10.4	6	12.8	25.7
1978	24.8	21.7	37.8	23.6	2 7. 9	21.22	17.4	14.2	21.9	18.6	32.1	41.8
1979	34.3	42.7	22.2	29.1	29.3	18.81	18	12.2	12.5	13.9	19.8	
1980	29.7	21.8	22	22.9	17.6	13.17	10.3	10.3	12.3	19.8	33.4	35.1
1981	23.1	27.6	28.2	39.1	35.9	19.44	15.7	12.2	20.7	13	15.9	16.6
1982	37	38.8	19.8	31.2	17.7	8.96	8.16	5.46				
1983	40.4	17.3	27.7	27.1	28.6	15.21	11	6.95	5.18	6.73	17.9	16.9
1984	24.1	14.3	31.8	28.2	29.8	14.86	11.1	14.7	20.4	25.7	19.2	23.5
1985	31.4	23.8	24.4	30.6	17.1	18.99	23.1	17.7	14.9	18.6	18.5	25.2
1986	27	23.9	38.1	26.2	19,3	17.72	18.8	15.5	22.7	23.8	32.8	32.1
1987	45.4	27.4	34.9	33.3	28.1	18.84	143	10.3	8.11	9.54	14.9	31
1988	53.5	35.7	37.5	17.1	22.4	15.53	11.6	7.66	12.2	28.9	22.5	
1990	21.3	29	24.4	20.1	18.1	15.8	9.91	12.6	9.33	4.76	5.49	25.5
1991	33.7	27.3	34.5	40.7	28.4	13.2	7.75	5.85	5.32	3.84	16.7	33.3
1992			35.4	28.4	20.5	10.7		12.5	17.1			
1995	28.1	40.9	38.4	49.8	26	20.1	23	12	9.19	10.1	23.1	17.9
1996	22.1	39.2	29.9	36	13.4	13.9	14.4	13.9	17.9	32.5	32.3	18.7
1997	18.3	15.6	24.5	25.1	39.3	15.4	11.9	6.88	5.69	5.55	6.59	19.2
Nobs	19	19	20	20	20	20	19	20	19	18	18	16
Min	15.4	14.3	18.4	17.1	13.4	7.75	6.61	5.46	5.18	3.84	5.49	11.2
Max	53.5	42.7	38.4	49.8	39.3	27.19	23.1	17.7	22.7	32.5	33.4	41.8
Mean	29.7	27.4	28.4	29.2	23.3	15.87	13.5	10.8	12.7	14.5	20.2	24.3
SD	9.43	8.5	6.95	7.48	7.18	4.497	4.66	3.4	5.77	8.6	8.05	8.26
CV	31.6	31	24.4	25.5	30.8	28.32	34.3	31.3	45.3	59.1	39.8	34

Sources: 1974-1988: Proyek Pengumpulan Data Hidrologi dan Hidrometri Propinsi Lampung
1990-1997: Balai Penyelidikan Hidrologi Pusair, Bandung

Table 3.6. Mean monthly river flows (m 3/s) at Banjarmasin water gauge station

Year	Jan	Feb	Mar	Ap	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1972	101.8	86,2	44.5	41.3	84.8	23.5	11.2	9.94	6.3	6.18	7.25	27.2
1973	38.14	39.97	47	52.8	36.4	34.5	15.9	10.8	36.4	23.4	38.2	87.8
1974	24.8	34.32	21.2	53.3	44.5	21.3	17.5	20	30.2	32.4	33	35.8
1975	60.69	59.75	36.2	48.5	27.7	19.3	17.3	18.3	16	27.1	49.1	48.2
1976	37.88	37.35	48.7	52.4	24.9	12.6	10.9	13	9.54	16.7	42.9	43.7
1977	71.24	80.83	64.6	72.7	23.1	39	17	7.94	9.76	6.02	16.2	51.7
1978	47.13	43.52	80.4	40	50	39.8	32.7	24.7	35.5	28.3	49	62.4
1979	27.42	69.26	46	58.3	49.9	35.7	32.7	7.2	20.3	20.4	30.2	44.9
1980	73.76	39.69	42.2	57.9	33.6	25.5	21.3	22.1	21.8	31.6	70.6	89.1
1985	73.1	40.8	59.9	55.1	29.8	37.9	36.5	34.6	35.4	29.2	31.3	30.4
1986	51	46.9	78.5	51.3	42.5	26.8	25.4	21.4	33.3	41.7	49.9	55
1987	62.4	46.7	59.3	64.3	30.9	14.8	8.1	7.71	6.55	7.08	16.1	39
1988	40.3	26.9	15	31.9	33.7	21.1	18	21.1	13.5	19	36.8	35.8
1990	53.1	88.1	53.2	36.1	35.6	38.6	31.9	24.8	12.3	10.8	10.6	20.2
1991	36.4	28.6	33.9	50.6	45.9	19.6	12.8	8.63	8.21	7.18	24.4	52
1995	42.7	75.4	51.1	55.8	44.4	28.1	18.9	24	27.7	26.5	33.5	24.6
1996	32.7	49.8	52.1	44.9	25.1	19.1	18.9	17.3	20.8	23.6	35	37
NOBS	16	17	17	17	17	16	16	16	17	17	17	16
AVG	51.44	52.53	49.05	51.01	38.99	26.89	20.41	17.27	20.21	21.01	33.77	46.16
MIN	27.42	26.9	15	31.9	23.1	12.6	8.1	7.71	6.3	6.02	7.25	20.2
MAX	101.8	88.1	80.4	72.7	84.8	39.8	36.5	34.6	36.4	41.7	70.6	87.8
SD	19.02	19.5	16.7	9.84	14.2	8.75	7.91	7.42	10.6	10.3	15.6	16
CV	35.82	37.12	34	19.2	36.5	33.1	40.2	41.4	52.6	49.3	46.3	36.9

Sources: 1972-1980:Team Studi Universitas Lampung (1982)
1985-1996: Balai Penyelidikan Hidrologi Pusair, Bandung

Table 3.7. Mean monthly river flows (m 3/s) at Sukajaya water gauge station

Year	Jan	Feb	Mar	Ap	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	15.3	25	21.5	15.9	14.8	12	7.39	7.48	6.17	5.27	5.14	15.5
1991	23.4	18	27.4	30.8	20.2	7.13	6.22	4.87	5.07	4.33	15.3	22.7
1992	14.75	17	30.7	18.6	16.4	7.8						
1995	20.38	23	33.2	28.6	8.39	11.9	14.1	4.32	7.8	8.65	21.2	10.3
1996	20.59	30	20.6	23.3	12	9.43	8.44	10.7	18.1	13.5	15.1	15.2
1997	14.26	12	11	10	26.9	7.12	3.3	3.05	2.88	2.4	2.57	.5.37
NOBS	6	6	6	6	6	6	5	5	5	5	5	5
AVG	18.11	20.83	24.07	21.2	16.45	9.23	7.89	6.08	8	6.83	11.86	13.81
MIN	23.4	30	33.2	30.8	26.9	12	14.1	10.7	18.1	13.5	21.2	22.7
MAX	14.26	12	11	10	8.38	7.12	3.3	3.05	2.88	2.4	2.57	5.37
SD	3.494	5.9	7.38	7.2	5.94	2.08	3.54	2.72	5.31	3.93	6.95	5.79
CV	24.5	49	66.7	71.4	70.8	29.3	107	89.1	184	163	269	107

Sources: Balai Penyelidikan Hidrologi Pusair, Bandung

Table 3.8. Monthly rainfall data at Pajar Bulan

Year	Jan	Feb	Mar	Ap	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	SUM
1974	229.7	218.1	61.6	319.1	308.5	30.7	162.3	171.8	309.2		119.9	193.6	2124
1975	397.5	294.3	128.1	261.7	208.3	168.3	133.3	113.8	117.2	172.3	313.8	159.7	2468
1976	226.6	150.9	299.5	259.6	127.7	8.6	76.7	114.6	66.2	208	336.8	307.4	2183
1977	356.5	174	171	273.5	281	209	67	53	137.5	91.5	258.5	560.5	2633
1978	254	290	537.5	134	315	213.5	155	95	332	256.5	336.5	620.5	3540
1979	480.8	324.5	213.1	291.4	422.8	116.2	195.8	149.3	156.9	111.5	144	182.5	2789
1980	334	241.5	246.5	295	91.5	76	112	65.6	241.1	341.5	329.6	277	2651
1981	30.5	186	113	309.5	242	211	218	280	187	94	170.5	166	2208
1982	270	136	101.5	176	149	37.5		30	1.5	12	7	541.2	1462
1983	386.3	75	307	164	447	139	80	61.6	44.8	279	205.9	564.8	2754
1984	290.4	182	439	396.1	319.3	108.6	192.6	181.8	286.4	344.8	299.9		3030
1985	319.9	93.8	413.8	222	111.2	307.4	264.3	61.7	138.5	382.8	168.7	283	2767
1986	304.7	182.1	271.4	180.8	235.4	233.8	84.62	14.2	204.8	252	215	391.5	2570
1987	283.9	307.5	334.1	368.1	139	126.6	115.8	64	45.2	118.4	128.4	218.8	2250
1988	423	225	281	157	220	116	84	73.4	60	223	316.4	169	2348
1989	401.6	122.2	180.5	156.5	148.4	80.8	128	209.4	42.2	138.8	309.1	356	2274
1990	131	264	161	263	168	80	200	108	99	47	167	167	1855
1991	436.8	128,8	304	269.3	154.4	73.8	14.2	0	171.4	22	424.4	33	2032
1992	158	321.3	387.6	291.4	159.2	63.4	84.4	176.5	272.2	203.6	445.2	371	2934
1993	384	186	244	382	207	99	98	135	15.4	157	507	369	2783
1994	562	318	337	236	80	69	0		55.2	9.7	56.1	363	2086
1995	444	480	507	250.9	147.6	364.4		5.1					2199
1996	389.5	397	377.1	359.5	150.5	22.3	93	140	208	270.5	243		2650
1997	199	71	124.6	172.5	373	27.5		15			19	363.5	1365
1998	411.5	334.8	333	274	260	157	137.5	104.5	131	283	146.5	129	2702
Average	324.2	228.1	274.9	258.1	218.6	125.6	122.6	101	144.5	182.7	236.2	308.5	2426
Sum	8104	5704	6873	6453	5466	3139	2697	2423	3323	4019	5668	6787	60655
Max	562	480	537.5	386.1	447	364.4	264.3	280	332	382.8	507	620.5	3540
Min	30.5	71	61.6	134	80	8.6	0	0	1.5	9.7	7	33	1365

Source: Proyek Hidrologi Lampung

Table 3.9. Monthly rainfall data at Air Hitam

Year	Jan	Feb	Mar	Ap	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	SUM
1974									81.3	203.5	182	154.6	621.4
1975	533.6	208.6	125	309.6	192.4	109	124.6	179	142.6	234.6	263.8	131.4	2554
1976	894	218.4	245.6	210	123.6	24.4	110.6	126	27.4	28.6	317.4	260.8	2587
1977	389.2	196.4	243.8	190.4	206	207.4	124	61.4	189.2	81	246.2	426	2564
1978	283.8	219.4	611.8	158.8	277.8	177.6	182.2	103.8	328.1	252.8	374.2	438	3342
1979	323.4	265.6	306	368.2	270.4	63	80.8	98.4	218	190.8	169.8	255.8	2610
1980	336.8	296.8	208.4	252.8	117.8	215	169.2	92.6	195.6	331.1	388	408.4	3013
1981	221.8	294.6	311.2	280	362.2	255.2	206.2	55	248	131.8	269.9	236.4	2872
1982	425	216.4	213.4	290.6	152	47.4	26.8	24	41.6	45.8	67.4	48.7	1599
1983	256.8	131.2	432.4	269.2	40	103.4	96.4	33	318.8	152	312.8	251.8	2398
1984	242	5	349.4	301	234.6	50.2	84.4	165.6	340.5	196.7	277.4	258.6	2505
1985	254.2	142.2	322	236.4	91.8	247.8	353.4	100	214.4	381.6	235.3	300	2879
1986	227.6	198.4	373.2	129.2	134.4	251.6	126.6	142	393	251.4	275.6	328.8	2832
1987	233.4	458.8	256.7	267.8	116	181.3	86.4	124.2	101.4	98.4	205.4	242.2	2372
1988	534.2	218.4	420	119.2	161.4	56.2	50.6	149.6	50.2	337	339.8	169.8	2606
1989	386.2	334.6	235.6	214.8	210.6	137	36.2	273.6	97.8	384.6	333.2	450	3094
1990	142	349	483.4	117.5	159.8	126.8	155.8	149.6	89.4	27	161.6	186.6	2149
1991	378.4	296.2	300.8	447.6	224.8	58.2	1.2		34.6	57.6	370.2	371.6	2541
1992	181	299	399.4	332.8	255	24.4	90.4	143.6	218	256.4	411.8		2612
1993	333	267	237	353	305	149	184.4	117.2	59.8	80.4	382.4	442.6	2911
1994	386	213.4	253.4	188.6	161.6	54.6	0	9	28.8	83	106	231.3	1716
1995	336	387	256	269.9	299.8	148.8	155.6	16	123.7	177	203	81	2454
1996	274.2	200.8	160.2	207	164.6	28.8	152	101	76	213.2	42.8	51.3	1672
1997	68	83.8	140	147.4	481.6	260	260	35.8	26	162	311	408.4	2384
1998	412	212	336	296	239	271	104	147	147	347	157	393	25257
Avg	335.5	238	3009	248.2	204.8	135.3	123.4	106.4	151.6	188.2	256.1	272	3366
Max	894	458.8	611.8	447.6	481.6	271	353.4	273.6	393	384.6	411.8	450	25257
Min	68	5	123	117.5	40	24.4	0	9	26	27	42.8	48.7	621.4

Source: Proyek Hidrologi Lampung

Table 3.10. Monthly rainfall data at Sumber Jaya

Year	Jan	Feb	Mar	Ap	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	SUM
1972	512	320	235	195	439	56	34	91	8	27	237	452	2,632.0
1973	254	316	416	366	304	278	17	138	421	248	287	409	3,454.0
1974	131	239	91	511	368	85	237	196	230	338	295	249	2,970.0
1975	339	197	208	226	1.48	54	144	78	218	333	308	96	2,349.0
1976	159	105	443	209	15	10	15.6	121	98	58	204	143	1,580.6
1977	222	326	429	103	255	269	83	35	89			375	2,186.0
1978	184	164	416	213	372	279	298	171.1	335.8	162	307.9	411.8	3,314.6
1979	442.2	294.1	242.7	317.4	328	119.9	207.8	134.9	176.7	106.3	294.5	286.8	2,951.3
1980	250.2	248.5	253.2	181.2	186.4	103.2	131.4	122.1	114.4	193.5	361.9	493.1	2,639.1
1981	684.7	219.6	506.9	403.8	320	173.9	320.5	64	357.1	141.8	205.8	158.4	3,556.4
1982	313.2	319.3	132.3	246.2	133.4	66.7	68.2	32.1	43.1	58.6	29.4	512	1,954.5
1983	619.7	259.3	284.6	317.5	437.8	36.5	58.2	24.2	14.4	79	416.9	282.4	2,830.5
1984	275.5	208.8	315.5	270.4	320.1	133.3	214.3	301.7	160.5	275.3	160.8	237.1	2,873.3
1985	426.5	160.6	270.4	321.2	86.3	185.9	197.1	95.9	159.7	249.3	216.9	648.6	3,018.4
1986	174.4	220.7	437.5	164.6	135.5	59	108.1	80.3	201.4	308.7	102.8	282.9	2,275.9
1987	129.1	160.5	311.8	72.7	177.3	130.1	47.3	44.9	28.5	27.9	340.7	347.7	1,818.5
1988	375.5	177.3	196.7	79.5	112.4	105.9	66.5	222	57.5	581	100.3	164.5	2,239.1
1989	304.9	274.4	144.6	179.7	905	528	102.7	54.1	111.6	206.3	212.6	315.3	339.2
1990	284.4	595.6	226.4	83.1	118.7	182.4	117	142.5	81.6	74.3	138		2,042.0
1991	435.4	233.6	327.9	406.9	191.3	136.7		20.5	47.1	1.5	411	350.1	2,562.0
1992	299	345	449.9	202.1	206.6	97.6	193.4	203	61	641.5	303	365	3,367.1
1993	266.7	151.3	243.1	239.2	132.8	118	117.5	102.7	32	54.5	289	270	2,016.8
1994	413	185.5	28.3	279	99	38	155.5	2.5	25	54	50	208.1	1,537.9
1995	373.7	398	243	422.2						262	760	279.6	2,738.5
1996	548	701	544	519.9	235.5	65	344	166.7	131.2	288	278.8	71	3,892.1
1997	128.8	90	298.5	306.5	270		10.9	21		13.6	56	249	1,444.3
1998	493.4	406.5	353.5	299.2	263.3	93.5	163.5	123	158.5	195.5	159	217.5	2,926.4
Avg	334.8	271	298.1	264.2	252.3	136.2	138.1	107.2	134.3	191.4	251	302.9	2,644.0
Max	684.7	701	544	518.9	905	528	344	301.7	421	641.5	760	648.6	3,892.0
Min	493.4	406.5	353.5	299.2	263.3	93.5	163.5	123	158.5	195.5	159	217.5	2,926.0

Source: Proyek Hidrologi Lampung

Table 3.11. Climatic condition at Sumber Jaya (1996-1998)

Month	Average	Max	Min	Relative Humidity	Evapo ration	Wind velocity	Rainfall
	----------	^{o}C	----------	%	mm/day	km/day	mm
Jan	22.56	26.4	17.4	85.12	3.47	2.49	496.1
Feb	22.86	25.84	18.63	81.57	3.3	2.18	243.1
Mar	22.76	26.92	18.45	80.79	3.69	1.71	342.4
Ap	23.47	27.19	18.61	80.65	4.19	1.71	277.6
May	23.07	26.59	18.54	81.65	3.54	1.39	245.8
Jun	22.16	26.77	15.75	80.95	3.9	1.53	114.8
Jul	21.73	27.5	15.4	78.86	4.61	1.62	119.9
Aug	21.34	27.4	14.72	78.04	3.4	1.71	82.6
Sep	21.59	28.2	14.1	75.6	4.87	1.86	88.91
Oct	22.05	27.9	15.26	76.68	4.56	1.73	199.7
Nov	22.88	27.28	18.37	77.12	4.52	1.93	174.3
Dec	22.54	26.69	17.56	79.53	3.47	2.15	195.6

Source: PLN Way Besai-Sumber Jaya

Table 3.12. Temperature and humidity data at Pajar Bulan

Month	Temperature (^{0}C)			Relative humidity (%)
	Max	Min	Avg	
Jan	26.2	17.9	22.1	85.2
Feb	27	17.1	22.1	81.4
Mar	27.3	17.2	22.3	88.5
Ap	28.5	16.9	22.7	88.2
May	29.1	16.2	22.6	88.7
Jun	27.4	15.7	21.6	87.7
Jul	27	15.4	21.2	88.8
Aug	28.1	14.2	21.1	87.8
Sep	31.4	15.9	23.6	86.4
Oct	27.7	15.3	21.5	88
Nov	27.2	16.9	22	86.7
Dec	26.8	17.5	22.1	89.2

*) Source: Proyek Hidrologi Lampung

**) calculation was based on 1975-198 5 data for temperature; and 1975-1995 data for relative humidity

Table 3.13. Some soil properties from various elevation and land use types at Way Besai subwatershed (Salam et al., 1998)

Site	Depth (cm)	Altit (m)	Distance (m)	pH (H2O) 1:2.5	oraganic-C (g/kg)	total-N (mg/kg)	Available-P (mg/kg)	CEC (cmol/kg)
Bukit Rigis:								
PF	0-20	1550	0	4.4	60.4	5.5	4	43.2
	20-40			4.8	25	2.3	1.5	18.2
SF	0-20	1400	628	5.4	41.4	3.4	2.1	18.5
	20-40			4.9	21.7	2	1.5	13.7
CP	0-20	1120	1660	4.9	28.5	2.3	1.5	11.4
	20-40			4.9	10.1	1.2	1	12.5
CL	0-20	1100	2160	4.4	15.8	1.7	1.5	12.4
	20-40			4.3	7.5	0.8	0.7	12.2
Sekincau:								
PF	0-20	1620	0	4	73.1	6.1	5.6	41
	20-40			4.1	32.7	2.5	3.3	22.4
SF	0-20	1440	530	4.8	42.9	3.5	2.1	15
	20-40			4.6	24.5	2.4	1.5	16.1
CP	0-20	1240	1550	4.6	30.9	3.3	1.5	13.5
	20-40			4.4	11.2	1.2	1	16
CL	0-20	1170	2300	5.2	19.3	1.8	1.8	13.9
	20-40			4.1	7	0.9	1	13.9
Tri Mulya:								
PF	0-20	890	0	5.4	58	5.1	3.5	37.6
	20-40			4.9	18.2	2	1.3	21.9
SF	0-20	740	335	5.5	38.7	3.2	2.3	24.8
	20-40			5	12.5	2.1	2.1	14.8
CP	0-20	490	765	5.4	26.7	2.5	2.8	14.7
	20-40			4.8	7	1.3	1.5	11.8
CL	0-20	465	1220	5.2	14.2	1.3	2.1	13.8
	20-40			5	5.5	0.7	1	12.7
Tri Budi Syukur								
PF	0-20	1240	0	4.9	30.5	1.8	7.3	18.4
	20-40			5.2	3.8	1.1	5.4	15.3
SF	0-20	985	354	5.9	27.5	3.2	7.3	23.9
	20-40			5.7	10.2	1.4	6.1	20.2
CP	0-20	735	826	5.1	22.6	2.6	7.3	14.4
	20-40			5.4	11.1	1.4	6.9	13.2
CL	0-20	710	1427	4.8	13.3	1.8	6.9	11.7
	20-40			5.6	6.5	0.6	6.5	9.2
Puri Mekar								
PF	0-20	940	0	5.5	23.3	2	8.9	8.2
	20-40			5.3	13.6	1.2	7.3	4.9
SF	0-20	790	381	5.2	30	2.9	10.1	8.4
	20-40			5.7	10.7	1.2	6.9	5.9
CP	0-20	540	940	5.6	23.4	2.5	7.3	11.2
	20-40			5.4	11.4	1.4	6	9.3
CL	0-20	525	522	5.3	23.2	2.1	11.1	8.3
	20-40			4.9	8.7	0.9	3.8	6.5

Note: PF: primary forest; SF: secondary forest; CP: coffee plantation; CL:cultivated land

IV. SOIL EROSION FROM A MICROCATCHMENT
Testing ANSWERS Model

4.1 Introduction

Since 1970, the Universal Soil Loss Equation (USLE) has been the most widely applied erosion model. However, the equation suffers from the conceptual defect that rainfall and soil factors (among others) cannot simply be multiplied together because of subtractive effect of soil infiltration capacity in generating runoff from a given rainfall (Kirkby,1980).

In recent years, the development of soil erosion prediction models are intended to describe processes of soil detachment, deposition, and sediment transport both spatially and temporary. Several erosion-transport-sediment models are emphasized process-based erosion are fundamentally different from Universal Soil Loss Equation (USLE). Process-based erosion equations can be validated by evaluating the functional dependency of the mathematical solution for various independent variables with experiment data.

Ideally, a predictive techniques should satisfy the conflicting requirements of reliability, universal applicability, easy usage with a minimum data, comprehensiveness in terms of the factors included, and the ability to take account of changes in landuse and conservation practice (Morgan, 1979).

ANSWERS is a model intended to simulate the behavior of watersheds having agriculture as their primary land use. ANSWERS is a short for Areal Nonpoint Source Watershed Environment Response Simulation.. ANSWERS is a deterministic model based upon the fundamental hypothesis that : " At every point within a watershed, functional relationships exist between water flow rate and those hydrologic parameters govern them, e.g.: rainfall intensity, infiltration, topography, soil type, etc. Furthermore, these flow rates can be utilized in conjunction with appropriate component relationships as the basis for modelling other transport related phenomenon such as soil erosion and chemical movement within that watershed."(Beasly and Huggins, 1991).

4.2 Purpose of the study

The purpose of this study was to measure water flow and sediment loads on a micro catchment, and to test the validity of ANSWERS model in describing erosion and sedimentation processes in the catchment.

The UNILA team was responsible for (a) setting up a flume on one micro catchment at UNILA-JAPANESE experiment site, (b) setting up an automatic raingauge, (c) making a topographic map with maximum contour interval 0. 5 m.

The IPB team was responsible for collecting basic data for ANSWERS model and applied the model ; including in soil survey, analysis of the data, and transfer the model to UNILA team.

This report contained some basic informations of the experiment, and the results were written by the IPB team in a separate report.

4.3 Methodology

4.3.1 Location of the experiment

The catchment was located at UNILA-JAPANESE experiment site at Bodong Jaya subvillage. The altitude was from 760-820 m above sea level with the mean slope gradient around 30%. The area was around 1,6 ha and mostly covered by coffee trees.

Administratively it was belong to Dusun Bodong Jaya, Sukajaya Village, Pajar Bulan subdistrict, Sumber Jaya District, West Lampung Regency. The distance from Bandar Lampung is around 180 km . The situation map of the catchment is shown in Figure 4.1.

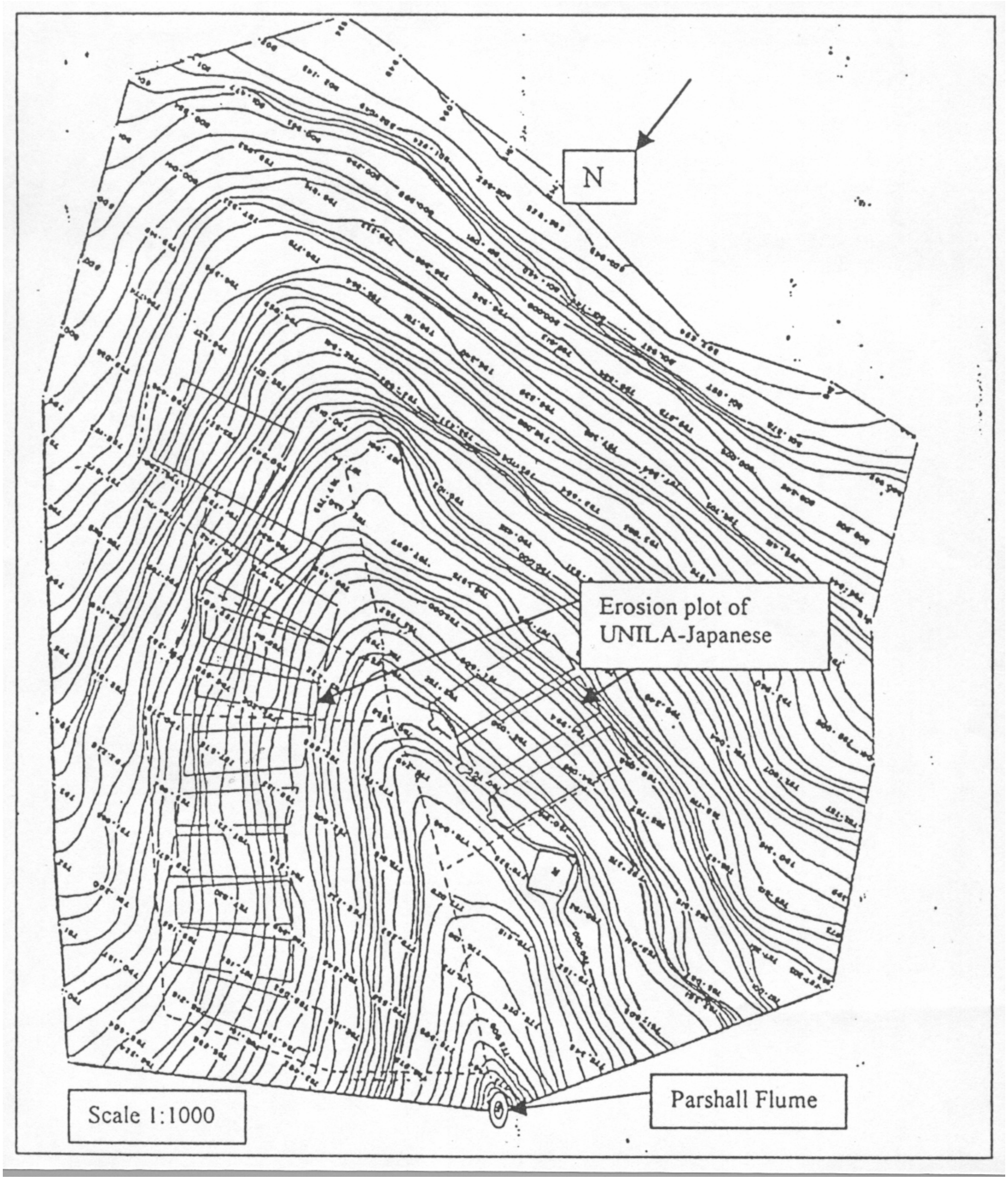


Figure 4.1. Contour map of micro catchment experiment

4.3.2 *Flume*

A parshal flume was installed at the end of the catchment. An automatic water level recorder was set up near the flume to measure the water level which flows on the flume. The water gauge was daily type, and the chart was change every morning. The design of the flume and automatic water level are shown in figure 4.3. The discharge through the flume was calculated using based on the work of Israelsen and Hansen (1976) as shown in Table 4.1.

4.3.3 *Rain gauge*

There are three rain gauge at the cathmnet, two of them was existing since 1995, and one was installed after this research started. All the rain gauge was belong to UNILA-JAPANESE experiment site, also the latest rain gauge was given by Prof. Masateru Senge (Gifu University) for supporting this research.

The rain gauges have different type; the first rain gauge was manual; the second was attached to automatic weather station which record every ten minutes, and the last was using chart and change daily. he two automatic raingauge was a tipping bucket type.

4.3.4. Water sample

Water sample was taken if the there was a flow within the flume. A 500-ml water samples was taken at least twice during a runoff event. If the runoff was still flowing after recession time, one sample was taken. The sample was oven-dry and weight.

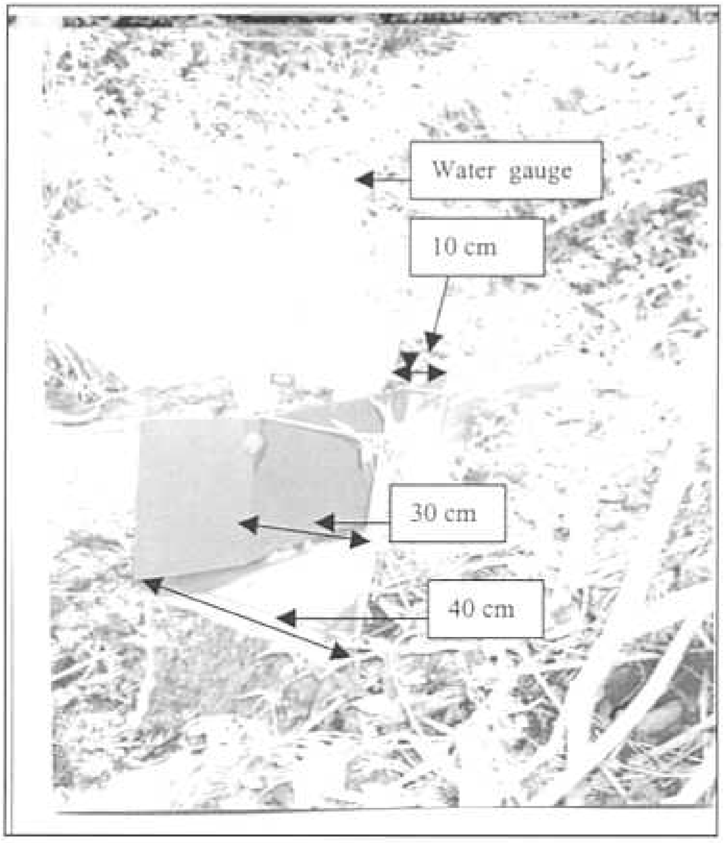


Figure 4.2. Parshall flume and water gauge used in the experiment

Table 4.1. Free flow through Parshall flume (Israelsen and Hansen, 1976)

Upper Head, H_a		Throat Widths												
Feet	Inches (Approx.)	1 in.	2 in.	3 in.	6 in.	9 in.	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	8 ft	10 ft
		Flow in Cubic Feet per Second												
0.10	1 3/16	0.009	0.019	0.03	0.05	0.09								
0.12	1 7/16	0.013	0.025	0.04	0.07	0.12								
0.14	11/16	0.016	0.032	0.05	0.09	0.15								
0.16	15/16	0.020	0.039	0.06	0.11	0.19								
0.18	2 3/16	0.024	0.047	0.07	0.14	0.22								
0.20	3/8	0.028	0.055	0.08	0.16	0.26	0.35	0.66	0.97	1.26				
0.22	5/8	0.032	0.065	0.10	0.19	0.30	0.40	0.77	1.12	1.47				
0.24	7/8	0.037	0.074	0.11	0.22	0.35	0.46	0.88	1.28	1.69				
0.26	3 1/8	0.042	0.084	0.12	0.25	0.39	0.51	0.99	1.46	1.91	2.36	2.80		
0.28	3/8	0.047	0.094	0.14	0.28	0.44	0.58	1.11	1.64	2.15	2.65	3.15		
0.30	5/8	0.052	0.105	0.15	0.31	0.49	0.64	1.24	1.82	2.39	2.96	3.52	4.62	
0.32	13/16	0.058	0.116	0.17	0.34	0.54	0.71	1.37	2.02	2.65	3.28	3.90	5.13	
0.34	4 1/16	0.064	0.127	0.19	0.38	0.59	0.77	1.50	2.22	2.92	3.61	4.30	5.66	
0.36	5/16	0.069	0.139	0.21	0.41	0.64	0.84	1.64	2.42	3.19	3.95	4.71	6.20	
0.38	9/16	0.075	0.151	0.22	0.45	0.70	0.92	1.79	2.64	3.48	4.31	5.13	6.76	
0.40	13/16	0.082	0.163	0.24	0.48	0.76	0.99	1.93	2.86	3.77	4.68	5.57	7.34	9.1
0.42	5 1/16	0.088	0.176	0.26	0.52	0.81	1.07	2.09	3.08	4.07	5.05	6.02	7.94	9.8
0.44	1/4	0.095	0.189	0.28	0.56	0.87	1.15	2.24	3.32	4.38	5.43	6.48	8.55	10.6
0.46	1/2	0.101	0.203	0.30	0.61	0.94	1.23	2.40	3.56	4.70	5.83	6.96	9.19	11.4
0.48	3/4	0.108	0.217	0.32	0.65	1.00	1.31	2.57	3.80	5.03	6.24	7.44	9.8	12.2
0.50	6	0.115	0.230	0.34	0.69	1.06	1.39	2.73	4.05	5.36	6.66	7.94	10.5	13.1
0.52	1/4	0.123	0.245	0.36	0.73	1.13	1.48	2.90	4.31	5.70	7.09	8.46	11.2	13.9
0.54	1/2	0.130	0.260	0.38	0.78	1.20	1.57	3.08	4.57	6.05	7.52	8.98	11.9	14.8
0.56	3/4	0.138	0.275	0.40	0.82	1.26	1.66	3.26	4.84	6.41	7.97	9.52	12.6	15.7
0.58	15/16	0.145	0.290	0.43	0.87	1.33	1.75	3.44	5.11	6.77	8.43	10.1	13.3	16.6
0.60	7 3/16	0.153	0.306	0.45	0.92	1.40	1.84	3.62	5.39	7.15	8.89	10.6	14.1	17.5
0.62	7/16	0.161	0.322	0.47	0.97	1.48	1.93	3.81	5.68	7.53	9.37	11.2	14.8	18.5
0.64	11/16	0.169	0.338	0.50	1.02	1.55	2.03	4.01	5.97	7.91	9.85	11.8	15.6	19.5
0.66	15/16	0.177	0.355	0.52	1.07	1.63	2.13	4.20	6.26	8.31	10.3	12.4	16.4	20.4
0.68	8 3/16	0.186	0.372	0.55	1.12	1.70	2.23	4.40	6.56	8.71	10.9	13.0	17.2	21.5
0.70	3/8	...	0.389	0.57	1.17	1.78	2.33	4.60	6.86	9.11	11.4	13.6	18.0	22.5
0.72	5/8	...	0.406	0.60	1.23	1.86	2.43	4.81	7.17	9.53	11.9	14.2	18.9	23.5
0.74	7/8	...	0.424	0.62	1.28	1.94	2.53	5.02	7.49	9.95	12.4	14.9	19.7	24.6
0.76	9 1/8	...	0.442	0.65	1.34	2.02	2.63	5.23	7.81	10.1	12.9	15.5	20.6	25.7
0.78	3/8	...	0.459	0.68	1.39	2.10	2.74	5.44	8.13	10.8	13.5	16.2	21.5	26.8
0.80	5/8	...	...	0.70	1.45	2.18	2.85	5.66	8.46	11.3	14.0	16.8	22.4	27.9
0.82	13/16	...	...	0.73	1.50	2.27	2.96	5.88	8.79	11.7	14.6	17.5	23.3	29.0
0.84	10 1/16	...	...	0.76	1.56	2.35	3.07	6.11	9.13	12.2	15.2	18.2	24.2	30.2
0.86	5/16	...	...	0.79	1.62	2.44	3.18	6.33	9.48	12.6	15.8	18.9	25.1	31.4
0.88	9/16	...	...	0.81	1.68	2.52	3.29	6.56	9.82	13.1	16.3	19.6	26.1	32.5
0.90	13/16	...	...	0.84	1.74	2.61	3.41	6.80	10.2	13.6	16.9	20.3	27.0	33.7
0.92	11 1/16	...	...	0.87	1.81	2.70	3.52	7.03	10.5	14.0	17.5	21.0	28.0	35.0
0.94	1/4	...	...	0.90	1.87	2.79	3.64	7.27	10.9	14.5	18.1	21.8	29.0	36.2
0.96	1/2	...	...	0.93	1.93	2.88	3.76	7.51	11.3	15.0	18.8	22.5	30.0	37.5
0.98	3/4	...	...	0.96	2.00	2.98	3.88	7.75	11.6	15.5	19.4	23.2	31.0	38.7
1.00	12	...	...	0.99	2.06	3.07	4.00	8.00	12.0	16.0	20.0	24.0	32.0	40.0
1.02	1/4	...	...	1.02	2.12	3.17	4.12	8.25	12.4	16.5	20.6	24.8	33.0	41.3
1.04	1/2	...	...	1.05	2.19	3.26	4.25	8.50	12.8	17.0	21.3	25.6	34.1	42.6
1.06	3/4	...	...	1.09	2.26	3.36	4.37	8.76	13.2	17.5	21.9	26.3	35.1	44.0
1.08	15/16	...	...	1.12	2.32	3.45	4.50	9.01	13.5	18.1	22.6	27.1	36.2	45.3
1.10	13 3/16	...	...	..	2.40	3.55	4.62	9.27	13.9	18.6	23.3	27.9	37.3	46.7
1.12	7/16	...	...	..	2.46	3.65	4.75	9.54	14.3	19.1	23.9	28.8	38.4	48.0
1.14	11/16	...	...	..	2.53	3.75	4.88	9.80	14.7	19.7	24.6	29.6	39.5	49.4

4.4. Results

4.4.1 *Soil condition*

A representative profile for this location was reported by Afandi et al. (1998) as shown in Table 4.2. According to Soil Taxonomy (USDA, 1990) , the soil was belong to Typic Tropohumults, which characterized by high organic matter at upper layer. The soil texture was dominated by clay fraction in all depth. The low bulk density of this soil indicated that the soil was friable and porous.

Table 4.2. Selected soil properties at test site

Depth	pH	N-total	C-organic	CEC	texture (%)			bulk density
cm		(%)	(%)	(me/100g)	sand	silt	clay	g/cm
0-10	4.92	0.26	3.48	13.3	25.2	13	51.8	0.96
10-20	4.89	0.16	1.86	9.9	25.1	16	58.9	0.93
20-35	4.91	0.09	0.89	9.3	26.1	13	60.9	0.99
35-60	4.87	0.07	0.82	8.7	26.3	13	60.7	0.93
60-100	4.85	0.06	0.82	8.7	28	15	57	

Source : Afandi et al. (1998)

4.4.2 . *Rainfall condition*

The rainfall condition from 1995-1998 at UNILA-Japanese experiment site was summarized below :

(a) total rainfall in 1996/1997 was 1341.8 mm and in 1997/1998 was 1865.9 mm,
(b) the maximum daily rainfall was 82 mm/d which almost concentrated in two hours
(c) the maximum rainfall intensity was 17 mm/10 min

(Afandi et al., 1999).

The amount of daily rainfall during the experiment time is shown in Table 4.3

Table 4.3. Daily rainfall data at the experiment site in 1999

	Jan	Feb	March	Apr	May	June	Jul
1	0	0	2	0	0	0	0
2	3.5	0	0	0	0	0	0
3	8.5	0	0	0	0	0	30.5
4	5	0	7.5	0	0	0	15.5
5	3	1	0	0	7	0.5	1
6	3	0	46.5	0	25	0	0.5
7	0.5	0	0.5	1	1	0	7.5
8	5.5	0.5	10.5	0.5	2.5	0	4
9	9	1.5	20.5	0	0	0	0
10	19.5	9	36	0	26.5	0	0
11	0.5	0	10.5	0	34.5	36	0
12	15.5	3	61	0	7.5	1.5	0
13	21	1	1.5	15	29.5	8.5	0
14	15.5	28	0	0	9.5	0	0
15	14.5	10	2.5	1	2	3.5	0
16	11.5	21	0	0	0	0	1.5
17	48.5	17.5	13.5	0	0	0	0
18	23.5	28.5	8	0	0	0	16
19	0.5	9.5	1.5	0	0	0	9
20	3	10	0	0	0	0	0
21	3.5	15.5	0	0	0	0	0
22	17	6.5	0	0	0	9	0
23	25	3.5	13	0	60	0	0
24	4	25	1	0	4.5	0	0
25	6.5	7	0	0	3	36	0
26	2	53	0	9	2	0.5	
27	0	0	0	25	18.5	0	
28	0.5	15	0	17	5.5	9	
29	0.5	266	0	0	16.5	23	
30	0		7	13.5	0	40.5	
31	0		0	82	0		
Sum	270.5	532	243	164	255	168	85.5

Source: Automatic weather station of UNILA-JAPANESE experiment site

4.4.2 *Land use*

Most of the test site (about 95%) was occupied by coffee tree. About 1656 m^2 or 10% of the whole areas were used by the erosion plot of UNILA-Japanese . A base camp was also existed in this area. This situation would effect the sediment transfer, because the soil erosion was trapped by the plot.

4.4.3 *Water flow*

The pattern of hydrograph on several rainfall events are shown in Figure 4.3-4.5. Due to the small area of the catchment, the peak flow was reached very fast, around seven minutes after the water have started to enter the Parshall flume.

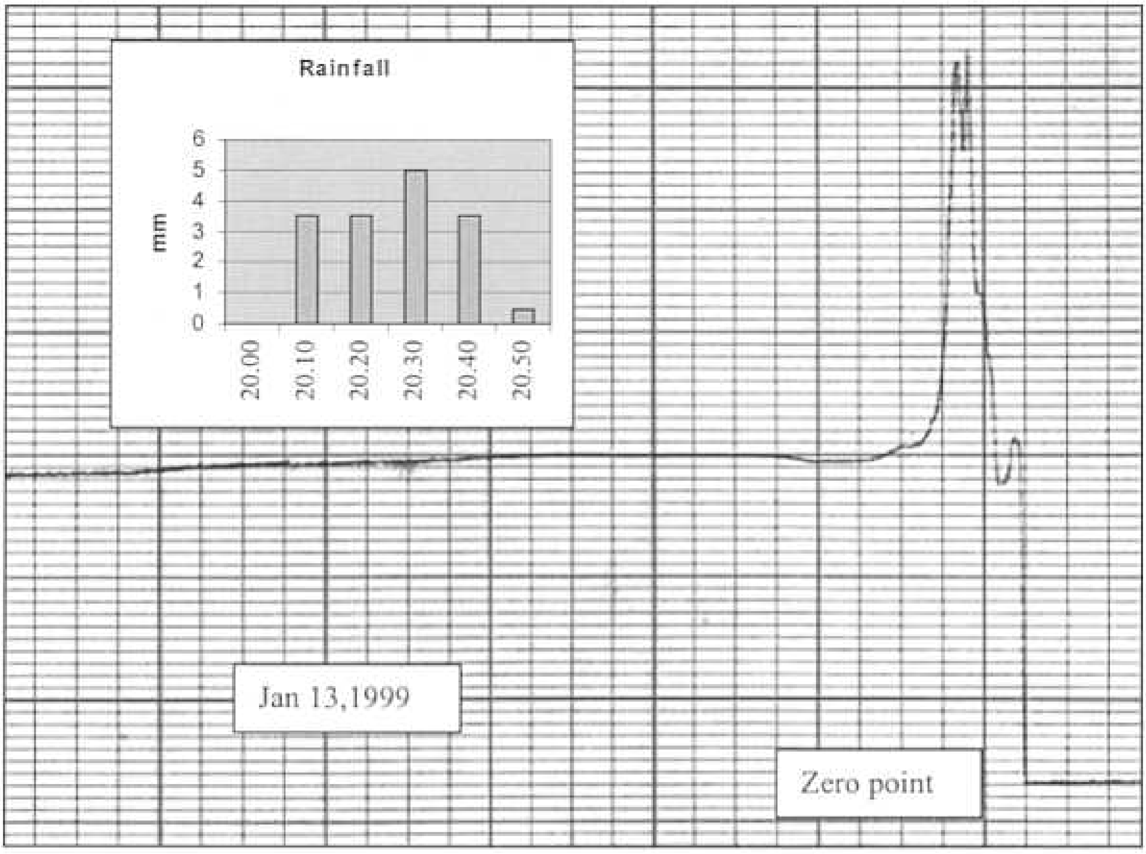


Figure 4.3. Pattern of hydrographs due to a rainfall event at January 13,1999

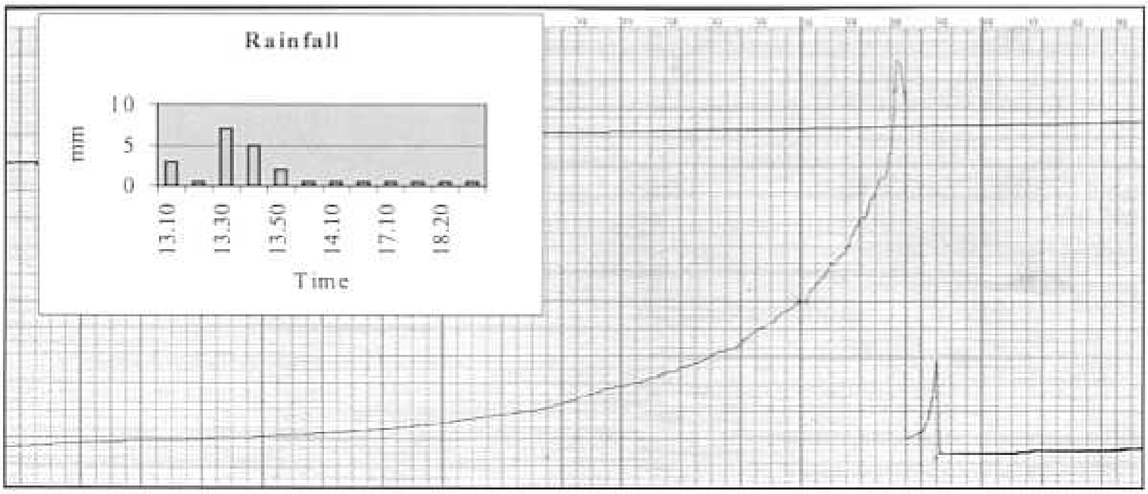


Figure 4.4. Pattern of hydrographs due to a rainfall event at January 18,1999

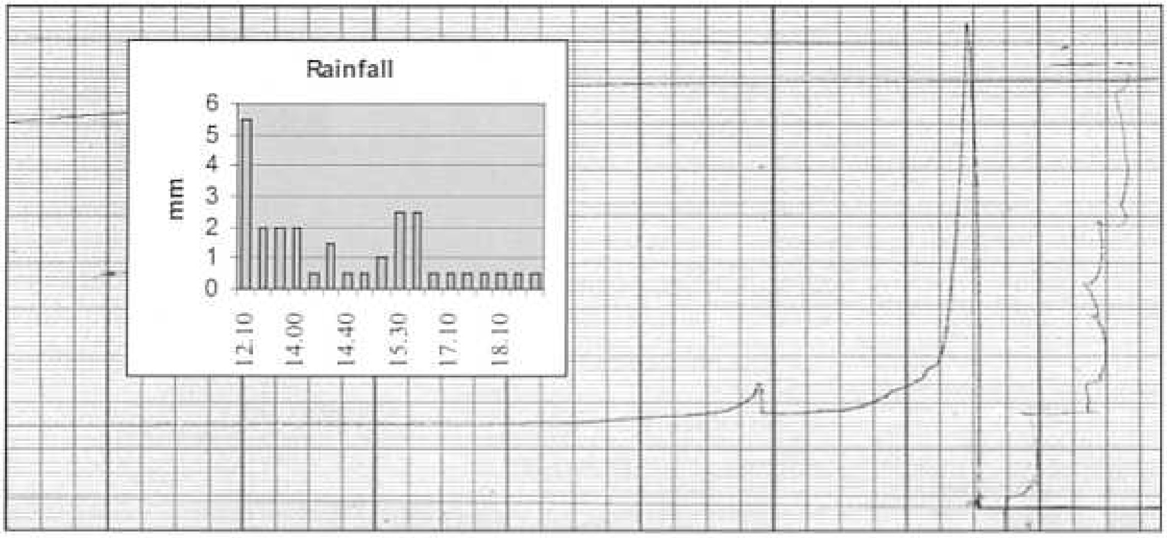


Figure 4.5. Pattern of hydrograph due to a rainfall event at January 23, 1999

V. CONCLUSION

5.1 Sediment Transfer

The sediment trap designed by UNILA team was very simple and very easy to operate. The data could be collected on a daily or monthly basis , and expressed in gram per unit slope length (g/m). However, because the measurement have been done in the natural condition, the coefficient of variation among the replications was very high due to some reasons, such as : the different in sediment transfer process among the replication (rill or sheet erosion or land slide) , the activity of the farmer (weeding, tillage) and the existence of litter at the soil surface. The minimum value of coefficient of variation was found on tegalan (21.95%) and the maximum value was shrubs filter (211.33 %).

The sediment transfer from five different land use were as follow: clean weeded coffee garden at lower slope have the biggest sediment yield (111.03 g/m), followed by mixed-coffee garden (83.77 g/m), tegalan with horticultural crops (69.40 g/m), clean weeded coffee (30.23 g/m), and clean weeded coffee at upper slope (10.12 g/m). On the other the sediment yield from the forest areas was almost zero (0.01 g/m), and the no sediment yield was found at Calliandra forest. The multistrata system also produced a very low sediment yield (0.24 g/m) compare to opened forest (0.6 g/m).

It is very surprising that the sediment transfer on the dry month (June and July) were bigger than that of the wet month (January – April). The surface cover condition of the land use system and farmer activities (weeding, tillage, fertilizer application) gave a high contribution on sediment transfer other than soil erosion factors.
This study showed that short filter cover with small grass or shrubs was very effective to entrap the sediment than a very long one. Runoff will have a chance to accumulate in the longer slope, and a rill will be created if there is a concentrated flow.

5.2 Characteristic of Way Besai subwatershed

The area of Way Besai subwatershed measured above the outlet of Petai water gauge (Sumber Jaya) was 389 km2. The minimum water flow measured from 1975-1997 was 3.84 m3/s occurred on October 1991, and the maximum was 53.5 m3/s occurred on January 1988. Analysis of the data from 1974-1998 showed that the average annual rainfall ranged from 2426 mm to 3366 mm. The wet month (monthly rainfall > 200 mm) were usually occurred from November until May, however during the dry month (June-October) the monthly rainfall was still exceed 100 mm.
Syam et al. (1997) reported that in 1970 the forest occupied 57.38% of that areas which become 21.39% in 1990; on the other hand the monoculture plantations (coffee plantation) increased from 0% in 1970 to 41.77% in 1990. Based on 1985 data, Sub Balai Rehabilitasi Lahan dan Konservasi Tanah Way Seputih (1998) reported that the coffee garden occupied 11.32% of the Way Besai subwatershed, and the area of mixed-coffee garden (coffee tree under forest area ?) was 28.18%.

5.3 Micro Catchment Experiment

The micro catchment was located at Bodong Jaya subvillage, Sumber Jaya, Western Lampung. The altitude ranged from 760 to 820 m above sea level with the mean slope gradient 30%. The area was around 1,6 ha and mostly covered by coffee trees. The water flow was measured using a Parshal flume with 10-cm throat widths completed with an automatic water level recorder. The soil was characterized by high organic matter at upper layer and dominated by clay fraction in all depth with low bulk density. Due to the small area of the catchment, the peak flow was reached very fast, around seven minutes after the water have started to enter the Parshall flume.

REFERENCES

Afandi, B. Rosadl, K.T. Manik, M. Senge, Y. Oki, and T. Adachi. 1999. Soil Conservation in Coffee Plantation with Weed Management. In: Can Biological Production Harmonize with Environment ? Reports from Research Sites in Asia. *Proc. of the International Symposium of the United Nations University, Tokyo, October 19-20,1999. Asian Natural Environ. Sci. Centre, the Univ. of Tokyo,* Inst. of Advanced Studies the United Nations Univ, and Creative Basic Research Group for "The development of Sustainable Biological production Technologies Harmonized with Regional Environmental Conditions in East Asia". p.251-254.

Afandi, R.A.B. Rosadi, T.K. Manik, M. Senge, T. Adachi, and Y. Oki. 1998. Pengaruh gulma di bawah tanaman kopi terhadap beberapa sifat fisika tanah. *Jurnal Tanah Tropika* IV(7): 7-11.

Beasly, D.B. and L.F. Huggins. 1991. *ANSWERS User's Manual.* Agricultural Engeneering Department Publication No.5. .

Binnie and Partners. 1994. *Southern Sumatra Water Resources Project Tulang Bawang Irrigarion FeasibilityStudies Vol. 9 Annex D (Hydrology) and E (Flood Drainage Model).* Final Report. Ministry of Public Works Directorate General of Water Resources Development and . Commision of the European Communities.

Daniels, R.B. and J.W. Gilliam. 1996. Sediment and chemical load reduction by grass and riparian filter. *Soil Sci. Soc. Am. J.* 60:246-25 1.

Inoue, J and Danaluddin. 1980. *Survei Penjajagan Way Besai.* Dinas Pekerjaan Umum Daerah Tingkat I Lampung.

Israelsen, O.W. and V.E. Hansen. 1976. *Irrigation Principles and Practice.* Third ed. John Wiley & Sons, Inc. New York.

Kelly, S.D.E. and A.A. Gomez. 1998. Measuring erosion as a component of sustainability, p.1333-148. In: P.W.T. Penning de Vries, F. Agus, and J. Kerr (eds). *Soil Erosion at Multiple Scales: principles and methods for assessing causes and impacts.* IBSRAM. CABI Publishing.

Kirkby, M.J. 1980. Modelling water erosion process. p.183-216. In: M.J. Kirkby and R.P.C. Morgan (eds). *Soil Erosion.* John Wiley & Sons. Chichester.

Lumbanraja, J., T. Syam, Fl. Nishide, A.K. Mahi, M. Utomo, Sarno, and M. Kimura. 1998. Deterioration of soil fertility by land use changes in South Sumatra, Indonesia: from 1970 to 1990. *Hydrological Process.* 12: 2003-2013.

Lumbanraja, J. T. Syam, Sarno, and S.Wada. 1999. Soil mineralogy consideration for sutainability of the catchment of Way Besai river in Sumatera. *Proc. Seminar Toward Sustainable Agriculture in Humid Tropics Facing 21" Century:* 218-225. Bandar Lampung, Indonesia, September 27-28,1999.

Morgan, R.P.C. 1979. *Soil Erosion.* Longman. London.

Noordwijk, M. van, M. van Roode, E.L. McCallie, and B. Lusiana. 1998. Soil Erosion and sedimentation as multiscale, fractal process: Implication for models experiments and the real world. p.223-253. In: P.W.T. Penning de Vries, F. Agus, and J. Kerr (eds). Soil *Erosion at*

Multiple Scales - principles and methods for assessing causes and impacts. IBSRAM. CABI Publishing.

Salam, A.K, A. Katayama, and M. Kimura. 1998. Activities of some soil enzymes in different land use systems after deforestation in hilly areas of West Lampung, South Sumatra, Indonesia. *Soil ScL Plant Nutr.*, 44(1): 93-103.

Syam,T.,H. Nishide, A.K. Salam, M. Utomo, A.K. Mahi, J. Lumbanraja,S.G. Nugroho,and M. Kimura. 1997. Land Use and Cover Changes in a Hilly Area of South Sumatra, Indonesia (from 1970 to 1990). Soil Sci. *Plant* Nutr.,43 (3):587-599.

Sub Balai Rehabilitasi Lahan dan Konservasi Tanah Way Seputih. 1998. *Rencana* Proyek *(Project Plan) Kabupaten Dati II Lampung* Barat 1997-2001 Buku I *(Naskah).* Departemen Kehutanan Kanwil Lampung.

Team Studi Universitas Lampung. 1982. Studi *Identifikasi Perencanaan Sumber-Sumber Air* Untuk *Menunjang Resetlement Penduduk Pada Calon Waduk Way Besai, Lampung Utara.* Kerjasama Proyek Penelitian dan Pengembangan Sumber-Sumber Air (P3SA) PU dengan Universitas Lampung.

Wiryawan, B., B. Marsden, H.A. Susanto, A.K. Mahi, M. Ahmad, H. Poespitasari (Editors). 1999. *Lampung Coastal Resources Atlas.* Government of Lampung Province and Coastal Resources Management Project (Coastal Resources Center, University of Rhode Island and Centre for Coastal and Marine Resources Studies, Bogor Agricultural University). Bandar Lampung.

Zachar,D. 1982. *Soil Erosion.* Elsevier Publishing Company. Amsterdam.

APPENDIX

Table A.1. Monthly sediment flow from various land use types and filter (g/m)

Land use	Slope Length (m)	Replication	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
Multistrata system	10.5	1	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
	10.5	2	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.27
	10.5	3	0.00	0.23	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43
	9	4	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Tegalan/ Horticultural crop	17.5	1	0.57	1.34	0.92	6.13	26.47	21.87	18.5	0.00	0.00	4.67	0.00	80.46
	19	2	0.60	1.78	0.28	10.12	8.02	0.08	18.73	0.00	0.00	16.28	3.47	59.36
	20	3	0.42	0.60	0.49	4.89	5.73	13.49	16.77	0.00	0.00	21.06	15.53	78.97
	22.5	4	1.28	0.98	0.74	2.12	37.92	2.58	0.84	0.00	0.00	0.83	0.11	47.41
	23	5	0.68	0.10	0.00	23.03	2.47	18.67	7.95	0.00	0.00	27.9	0.00	80.79
Filter Grass Filter	3	1	0.09	2.24	5.33	3.45	0.00	0.00	23.75	0.00	0.00	3.65	28.86	67.38
	1.5	2	0.00	2.08	11	0.00	0.00	0.00	29.57	0.00	0.00	0.00	0.00	42.65
	1.5	3	0.00	1.78	0.00	0.00	0.00	0.00	8.57	0.00	0.00	0.00	0.00	10.35
Mixed coffee garden	9.5	1	2.47	1.11	0.00	0.89	3.98	17.46	0.64	0.00	0.00	90.78	39.22	156.56
	9.5	2	0.44	1.03	0.94	0.95	25.55	4.10	0.41	0.00	0.00	91.48	15.10	140.01
	9.5	3	0.35	0.83	0.58	0.77	0.98	0.23	6.02	0.00	0.00	1.43	17.48	28.66
	10	4	0.38	0.00	1.28	0.15	3.25	0.22	0.00	0.00	0.00	1.54	3.02	9.84
Shrubs Filter	4.5	1	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	3	2	0.10	1.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.34	2.48
	3	3	0.02	1.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.39
	3	4	0.00	1.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.51
	3	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clean weeded coffee	18.5	1	1.00	0.63	2.36	0.47	0.47	21.08	0.27	0.00	0.00	23.10	20.80	70.18
	18	2	0.00	0.90	0.34	0.00	2.15	0.00	0.00	0.00	0.00	1.67	24.88	29.95
	18	3	0.11	0.31	1.10	1.19	0.42	0.00	0.46	0.00	0.00	13.16	0.00	16.74
	18	4	0.30	0.44	0.68	0.33	1.40	0.12	0.00	0.00	0.00	2.64	2.11	8.02
	18.5	5	0.93	0.00	1.15	0.68	3.49	0.00	6.37	0.00	0.00	13.65	0.00	26.27
Filter	12	1	0.11	1.30	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.21	1.77	3.79
	11.5	2	0.56	1.19	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.83
	11	3	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60
	11.5	4	0.83	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	177.68	178.92
	12	5	0.00	0.00	0.60	0.72	0.00	0.00	0.70	0.00	0.00	0.00	0.00	2.02
Clean weeded coffee- Upper slope	33	1	0.12	0.67	1.15	0.00	0.80	0.05	0.40	0.00	0.00	10.92	0.87	14.98
	33	2	0.35	0.25	1.18	0.00	0.75	0.68	3.16	0.00	0.00	0.21	1.71	8.41
	34	3	0.14	0.18	1.21	0.00	0.00	5.55	3.78	0.00	0.00	0.41	3.37	14.63
	34	4	0.20	0.51	0.56	0.00	0.51	0.05	0.34	0.00	0.00	0.27	0.00	2.44

Table A.1. (continued)

Land use	Slope Length (m)	Repli cation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
Clean weeded coffee-Lower slope	14	1	0.48	0.00	2.82	0.00	2.30	15.95	15.55	0.00	0.00	4.11	75.50	116.70
	13	2	0.70	0.00	1.61	0.00	0.69	5.91	5.91	0.00	0.00	4.44	0.00	51.74
	13	3	1.07	0.88	1.85	0.00	0.77	39.46	39.46	0.00	0.00	7.32	91.34	177.85
	14	4	0.03	0.75	1.69	0.00	0.29	27.69	27.69	0.00	0.00	17.39	25.14	97.81
Forest	300	1	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	300	2	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	300	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	300	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	300	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Opened forest	40	1	0.00	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
	40	2	0.03	0.05	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.25
	40	3	0.03	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
	40	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.47	2.47
	40	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.14
Calliandra	15	1-5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-	0.00
Calliandra	5	1-5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-	0.00

- : the sediment trap was destroyed

Table A.2. Composition of soil fraction at the experiment site (0-10 cm)*

No	Land use	Clay %	Silt %	Sand %	Texture Class
1	Multistrata system	55.4	12.5	32.1	Clay
2	Tegalan (horticultural crop)	48.6	18.4	33	Clay
3	Mixed coffee garden	58.2	15.4	26.4	Clay
4	Clean weeded coffee with filter	48.5	20.1	31.4	Clay
5	Clean weeded coffee-upper slope	60.3	14.4	25.3	Clay
6	Clean weeded coffee-lower slope	50.2	18.4	33.4	Clay
7	Forest (Bukit Rigis) **	38	24	38	Clay loam

WORLD AGROFORESTRY CENTRE (ICRAF)

SOUTHEAST ASIA REGIONAL OFFICE WORKING PAPERS

Funded by the
Asian Development Bank
RETA 5711