Soil Erosion Management at The Watershed Level for Sustainable Agriculture and Forestry in Vietnam

T. D. Toan[1], T. Phien[1], L. Nguyen[1], D. D. Phai[1] and N. V. Ga[1]

INTRODUCTION

In Vietnam, sloping lands and mountainous areas account for two-thirds of the total territory. The influence of topography, geology, morphology, climate, etc., and of human activities has resulted in serious environmental degradation, particularly of soil and water. According to the Ministry of Plan and Investment, the total area having soil erosion problems in Vietnam is 13 million ha or 40% of the total area.

The cultivated land per capita in the country is decreasing annually. In 1989, it was 0.109 ha, but it decreased to only 0.089 ha in 1999. According to UNDP, with a projected population of 110 million in 2010, the cultivated land per capita will further decrease to 0.036 ha. These small landholdings coupled with inappropriate cultivation methods result in low productivity, famine, and poverty. In the hills and mountains, agricultural productivity is decreasing due to the erosion of the fertile soil every year.

Over the centuries, Vietnamese farmers have been adopting land use systems that are compatible with the environment, such as shifting cultivation. However, as populations increase, the need for more food, fuel, fodder, and shelter has led to forest encroachment, expansion of cultivated areas onto steeper, more fragile areas in the uplands, declining soil productivity, and environmental degradation (Garrity, 1998). Watershed degradation now poses a threat to the livelihood of the ever increasing Vietnamese population and the country's economy in general.

Soil erosion reduces on-site soil fertility in terms of chemical, physical, and biological attributes. These soil changes will, in time, reduce crop yields and hence income and household food security. The off-site effects of soil erosion often have broader economic and environmental implications including sedimentation, flooding, and reduced water quality resulting in poorer living conditions for the people. Land management research has provided a range of technologies, which can reduce soil loss to acceptable levels, but sustainable adoption of these technologies has been very limited, especially at the watershed level.

Watershed management is an important issue in Vietnam not only to protect the existing forest but also to conserve agricultural land for sustainable agriculture and biological diversity. It is the best way to minimize land surface runoff, soil loss (Tengberg and Stocking 2001,) and to prevent frequent and intense flash floods which cause much loss of human and animal life, damage to property and the environment (Cao Dang Du, 2000).

To address these concerns, the Management of Soil Erosion Consortium (MSEC) has decided to adopt a new research paradigm based on a participatory, interdisciplinary, catchment level approach. This new paradigm is now employed in the consortium's activities in Vietnam to develop sustainable and profitable natural resource development as short- and long-term benefits for farmers, who live and do cultivate in the watershed

OBJECTIVES

The general objective of the programme is to promote appropriate land management practices that minimize soil erosion and detrimental off-site effects, which are acceptable to present land users, reduce poverty in upland areas, and develop human resources. More specifically, the programme

[1] National Institute for Soils and Fertilizers (NISF) Hanoi, Vietnam

aims:

1. To develop sustainable and acceptable community-based land management systems by development of improved technologies for erosion control.
2. To quantify and evaluate the biophysical, environmental, and socioeconomic effects of soil erosion, both the on- and off-site impacts of soil erosion.
3. To generate reliable information and prepare scientifically-based guidelines for improvement of catchment management policies.
4. To enhance NARES capacity in research on integrated catchment management and soil erosion control.

Basically, the expected outcome is the enhanced adoption by land managers of practices that minimize soil erosion and its detrimental off-site effects. This will help the community develop the particular area in ways that are technically feasible, economically viable, socially acceptable, and environmentally friendly. The specific expected outputs are:

1. Better understanding of the on- and off-site impacts of erosion.
2. Soil erosion control technologies that are socially and institutionally acceptable to the community in the catchment areas.
3. Methodology for obtaining the participation of farmers and other stakeholders in the management of the catchment.
4. Appropriate policies that will improve the management of catchments by the local government and communities and will induce the farmers to adopt improved land management technologies.
5. Quality catchment research and effective dissemination of its results to farmers.
6. Enhanced capacity of the NARES in integrated catchment management

METHODOLOGY

Site selection

A multidisciplinary site selection team composed of experts from IBSRAM and national agencies visited and evaluated three pre-selected sites in Vietnam. These are the Ngoc Thanh Watershed in Vinh Phuc Province, Thung Dau Watershed in Hoa Binh, and Dong Cao Watershed, also in Hoah Binh Province. They were visited in November 1997, May 1998, and October 1998, respectively. The selection process conducted the following activities:

1. Field assessment and the examination of land use systems, cropping pattern, soil conservation practices of farmers, and the degree of on- and off-site effects.
2. Interviews and discussions with local farmers, key informants, and the local chiefs, mainly based on questionnaires and the examination of available reports/secondary data.
3. Summary discussion involving all team members.
4. Evaluation of the catchments in terms of representativeness, accessibility, availability of facilities, etc.

Biophysical and socioeconomic characterization

After the site was finally selected, a benchmark survey and preliminary characterization of the catchment was conducted. Primary data were collected using household surveys and rapid rural appraisal (RRA). Before conducting household survey, a reconnaissance visit was made to the site to get first hand knowledge about the selected site; it was followed by informal discussion with local farmers, and key informants of the village. A structured questionnaire was prepared to collect information from individual households on socioeconomic conditions and agriculture. The enumerators were hired from district extension services and were supervised by the NISF team. A complete enumeration of all the 38 households farming in the area was carried out. Data sets obtained through the household surveys were analyzed. This allowed the identification of problems, opportunities, and constraints within and outside the watershed. The data and information that were collected in the preliminary and comprehensive characterization of the selected sites are shown in Tables 1 and 2.

Table 1. Information needs for biophysical characterization.

Factors Location and area	Data/information needs	Relevance/importance Land use	Tools and techniques Field survey
Abiotic			
Geology and physiography/ landform	Parent material, rock formation, topography landform/shape, altitude, slope aspect	Soil classification, assessment of erosion potential suitability, selection design and evaluation of alternative land uses and practices	Secondary data, field observation, map analysis
Climate	Sunlight duration temperature, rainfall	Assessment of land suitability, erosion potential and land productivity; impact assessment of alternative land use and practices	Instrumentation, field measurement, records from Hoa Binh station
Soil	Soil morphology, texture, structure, erosion condition, soil fertility	Assessment of productivity, land suitability, erosion potential,	Soil survey/analysis and literature review evaluation of alternative land use and practices
Water resources	Hydrology, stream order, stream length	Appreciation of hydrologic behavior, assessment of land suitability, erosion potential and impacts alternative land use practices	Field measurement and map analysis
Biotic features			
Vegetation and land use	Farming systems, crops planted, species composition, plant density	Assessment of land erosion potential, land productivity, prediction of future hydrologic events; impact assessment of canopy and groundcover, existing land uses	Vegetation and land use assessment
Fauna and livestock	Species/kind/population/ distribution, management practices	Assessment of land suitability and impact on vegetation	Reconnaissance survey, key informant interview

Table 2. Information needs for socioeconomic characterization.

Factors	Information	Importance/relevance	Tools and techniques
Population	Total population, population density, growth rate, age class structure, gender and migration pattern	Population pressure, scarcity of land, pressure on resources, availability of labor, property rights regime	Key informants, head of commune interview
Settlement and land use history	Historical events, villagers' origin, reasons for settlement	Panning horizon, and decision making information flow	Literature review and key informant interview, PRA
Composition of village population	Ethnicity, cultural practices	Reaction to innovation presentation	Key informant interview

Predominant occupation	Predominant occupation, on-farm income, non-farm income, main crops produced, extent of commercialization, farming systems, hiring of farm labourers	Investment potential, adaptability of practices, land management technologies, opportunity cost of labor	Key informant survey, direct observation, structured survey
Access to market	Product flow, market for inputs, road system transportation, farm gate prices	Availability of inputs, product distribution, potential for agricultural development	Literature review (maps), direct observation, key informant interview
Access to information on agricultural innovation	Sources of information (extension workers, merchants, other farmers, radio, TV)), farmers' perceptions of soil erosion, level of education	Effectiveness of information dissemination	Formal (structured) survey, key informant interviews, group discussion with farmers
Credit constraints	Sources of credit, lending activities, interest rate	Availability of capital	Key information interview
Land tenure arrangement	Land classification tenurial arrangement, presence of long-term investments	Decision for long-term investments	Cadastral map, key informant interview, direct observation formal survey
Rural development	Previous and current intervention	Probably getting support from relevant institutions	Literature review and key informant interview
National, regional and local policies	Development thrusts, prices for inputs and marketed produce, price support, subsidies, taxes, credit, land rights, conservation/watershed conservation, upland agricultural development, afforestation, resource utilization	Relevance of project to national and local goals, policy formulation, planning	Literature review

Evaluation of the on-site effects of erosion

Identification and characterization of microcatchments

The selected catchment was further surveyed and characterized to identify several microcatchments that represent different land uses. The following activities were carried out:

1. Secondary data collection to complement the information generated during the initial inventory, formal survey, and PRA.
2. A field survey of the type of soil erosion.
3. Random soil sampling at 0–20 and 20–60 cm depth using a soil auger to assess soil fertility. Soil sampling on current field crops (cassava and natural grass fields) was also done for soil fertility and productivity monitoring.
4. Estimation of soil depth and soil structure.
5. Observation of crop health and percentage of soil cover by crop and native vegetation.
6. Assessment of crop yield by discussion with farmers on average crop yields every year.
7. Survey and evaluation of farmers' income.
8. Data analysis and evaluation.

Instrumentation of microcatchments

The IBSRAM hydrologist and members of the local project team conducted the visit in October 1998 to identify the specific places for hydrological stations. Construction of five weirs started in April 1999, and was completed by the end of August of the same year.

Five water-level recorders and six rain gauges were installed in the places identified by the project team. Installation of all equipment and devices was completed in August 1999. The coordinates of the location of the structures and measuring devices were determined using a GPS GARMIN III. The exact locations are shown in Table 3 and Figure 1

Table 3. The location of weirs and rain gauges in the catchment.

	Location		
	Latitude (N)	Longitude (E)	Altitude (m)
Main weir	20°57'23.7	105°29'29.0	157
Weir No. 1	20°57'19.4"	105°29'10.0"	173
Weir No. 2	20°57'14.2"	105°29'07.3"	180
Weir No. 3	20°57'13.1"	125°29'03.2"	181
Weir No. 4	20°57'07.7"	105°29'03.7"	233
Rain gauge 1	20°57'20.1"	105°29'13.4"	187
Rain gauge 2	20°57'21.1"	105°29'05.0"	186
Rain gauge 3	20°57'12.0"	105°29'09.9"	206
Rain gauge 4	20°57'07.9"	105°29'06.1"	277
Rain gauge 5	20°57'08.1"	105°29'06.5"	266
Weather station	20°57'12.5"	105°29'04.0"	195

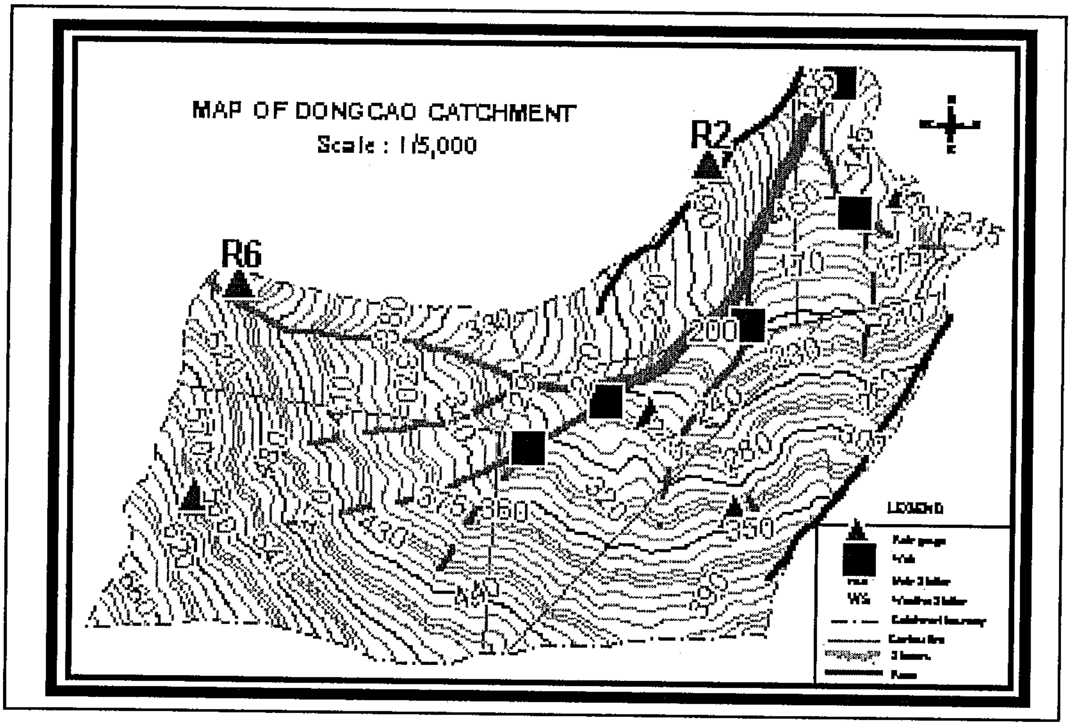


Figure 1. Map of Dongcao Catchment.

Data collection and monitoring

The water level in each stream was recorded both manually using staff gauges and automatically using the automatic water level recorders. Water discharge and sedimentation calibration was also done. Runoff (using staff gauges) and suspended and bedload sediment from each sediment trap and channel were measured at every rainfall event. Water samples from traps and outlets were taken to develop rating curves of suspended sediment. Soil chemical and physical analyses were done in the NISF laboratory. Monitoring of rainfall from the manual rain gauge was done every day at 08.00. Monitoring of water levels was conducted using the automatic and manual devices. The automatic water level recorders were set to read every five minutes.

Evaluation of the off-site effects of soil erosion

The potential off-site impacts of soil erosion in the Dong Cao Catchment were identified by evaluating the possible consequences in the downstream areas. As described elsewhere, the discharge from the catchment is used for irrigating a small area of paddy below and also drains to a reservoir. Initial assessment was done by visual inspection of the downstream farming activity and conducting interviews with the farmers.

Initial assessment of the sediment discharged from the main outlet feeding into the paddy area was also done by collecting and analyzing water samples draining into the reservoir. Nutrient contents in the water and sediment were analyzed to identify nutrient loss and water pollution. In the paddy fields, soil samples were collected randomly using a soil auger at 0–20 cm and 20–60cm depths, to describe not only the soil profile but also to identify the soil's physical and chemical characteristics. Changes in rice yields were evaluated from data from literature and discussion with the farmers.

RESULTS AND DISCUSSION

Site selection

Dong Cao Catchment was finally selected as the model site for the project. It is located in the bow-shaped range of Vietnam's mountainous area that connects the north and the south. Basically, it represents the typical cultivated mountainous uplands with slopes of more than 25%. The altitude varies from 125 to 700 m asl and the slope ranges from 15–60% (Figure 2). All the water discharged from the catchment is used directly for 10 ha of paddy rice irrigation downstream. This provides a good opportunity for scientists to also evaluate the off-site effects of soil erosion from the upper catchments.

The watershed is located in Dong Cao village (thus its name Dong Cao Watershed), Tien Xuan commune, Luong Son District, Hoa Binh Province (Figure 3). Tien Xuan commune consists of 18 villages: Co Dung (1), Co Dung (2), Xom Chua (1), Xom Chua (2), Que Vai, Dong Dau, Dong Cao, Go Choi (1), Go Choi (2), Binh Son, Trai Moi (1), Trai Moi (2), Xom Nhom, Xom Mieu (1), Xom Mieu (2), Go Me, Bai Dai, and Go Che. There are 1,100 households in the commune.

Dong Cao village has 38 households. It is located at 20° 57' 40" N and 105° 29' 10"E. The main crops are cassava, taro, peanut, rice, maize, forest plantation such as eucalyptus, *Acacia mangium*, etc. Water from streams in the catchment is used for irrigation of 10 ha of paddy in Dong Cao village. Tien Xuan commune has 250 ha of paddy fields.

Current road access to the site requires a 4WD vehicle. It is muddy on rainy days. Electricity supply is good. Accommodation is at the farmers' houses. A working house/office is now constructed at the site.

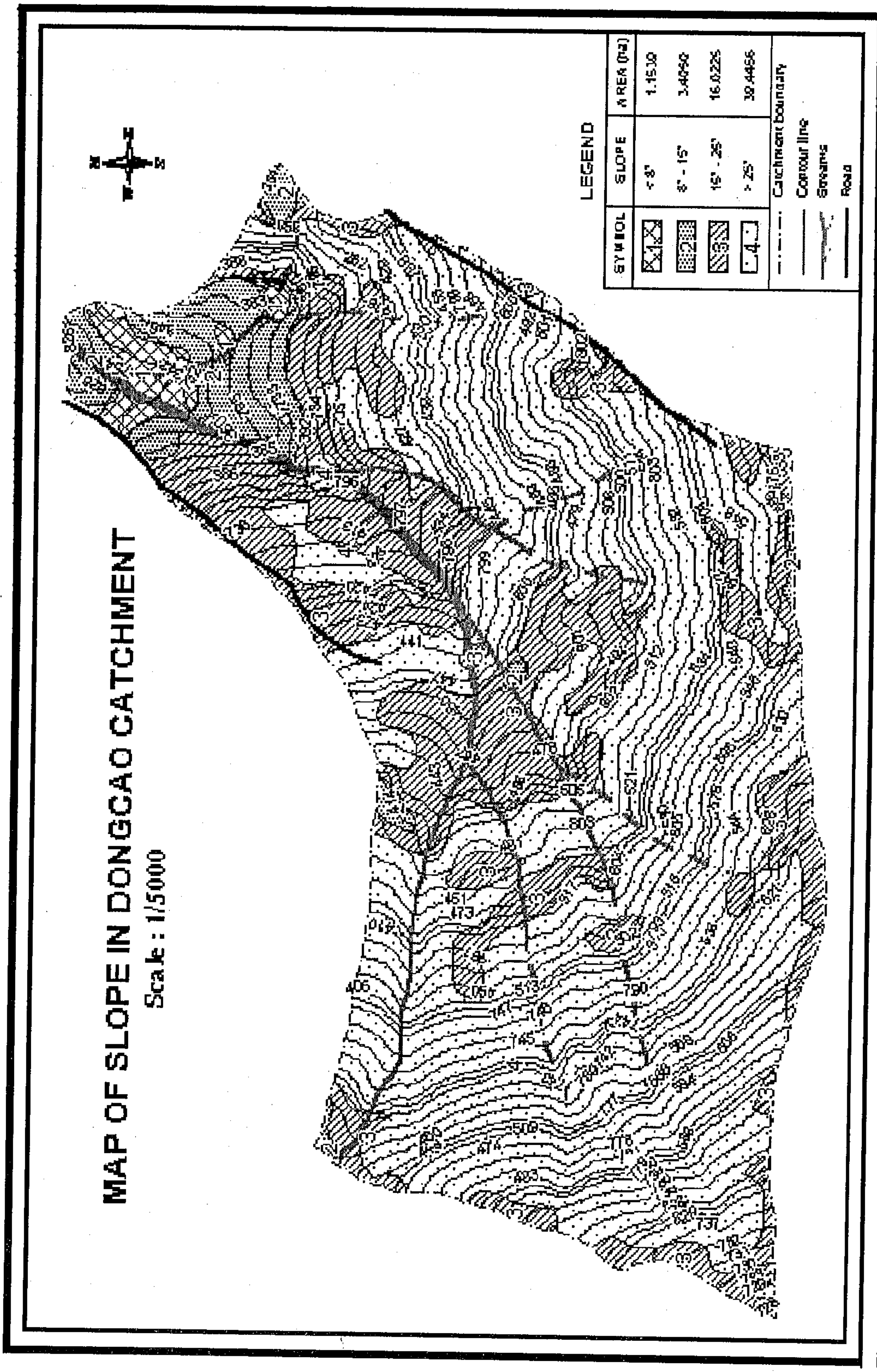


Figure 2. Slope map of Dong Cao Catchment.

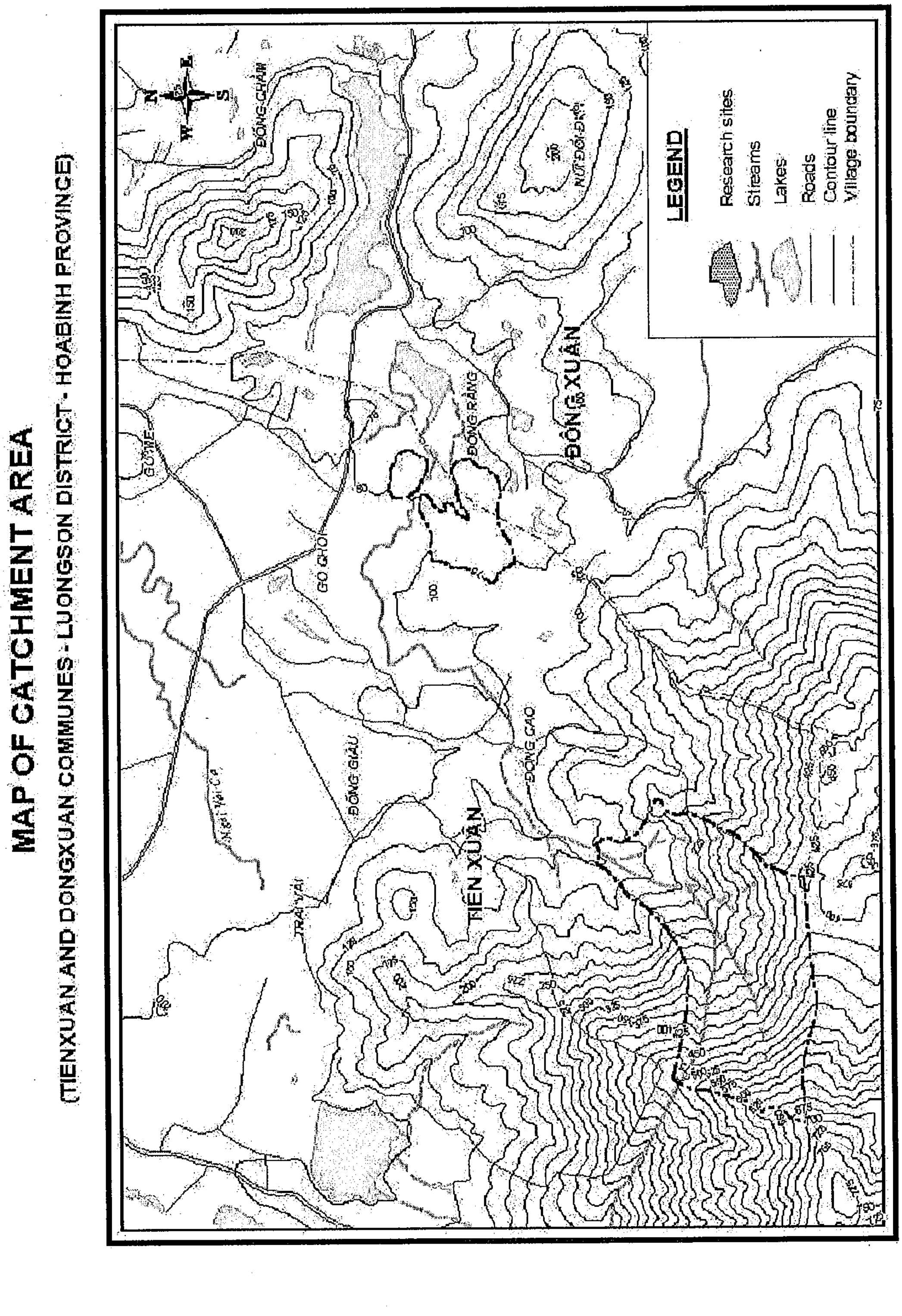


Figure 3. Map of catchment area.

Biophysical and socioeconomic characterization

Climate

Based on the meteorological data recorded at two nearby stations, the average annual rainfall in the area is 1,500 mm. About 80–85% of the rainfall occurs from April to October (Figures 4 and 5). The mean temperature ranges from 15–27°C with the lowest occurring in February.

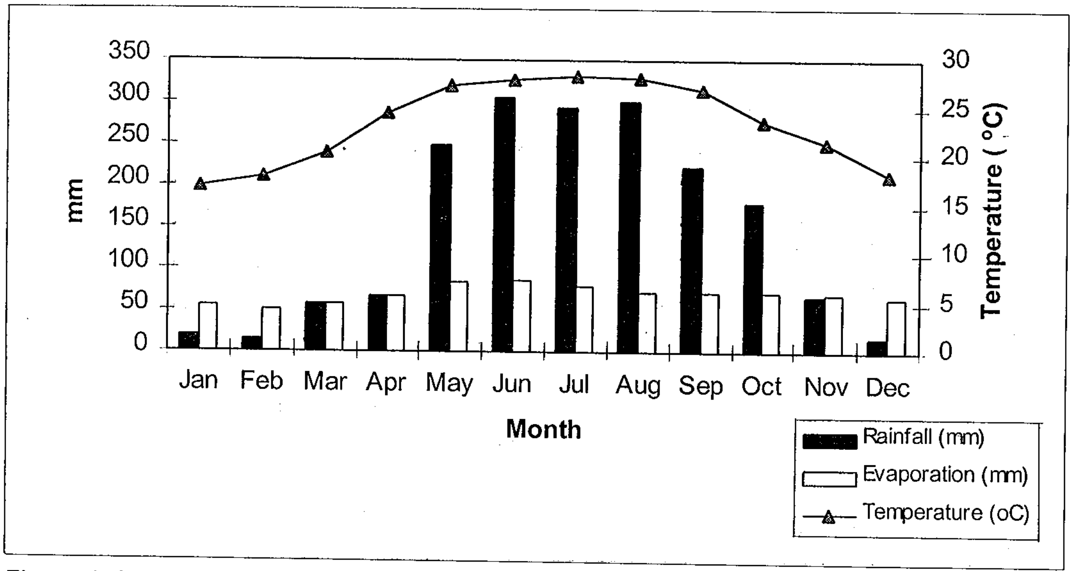


Figure 4. Sixteen-year monthly average rainfall, evaporation and temperature recorded at Hoa Binh station from 1994–1999.

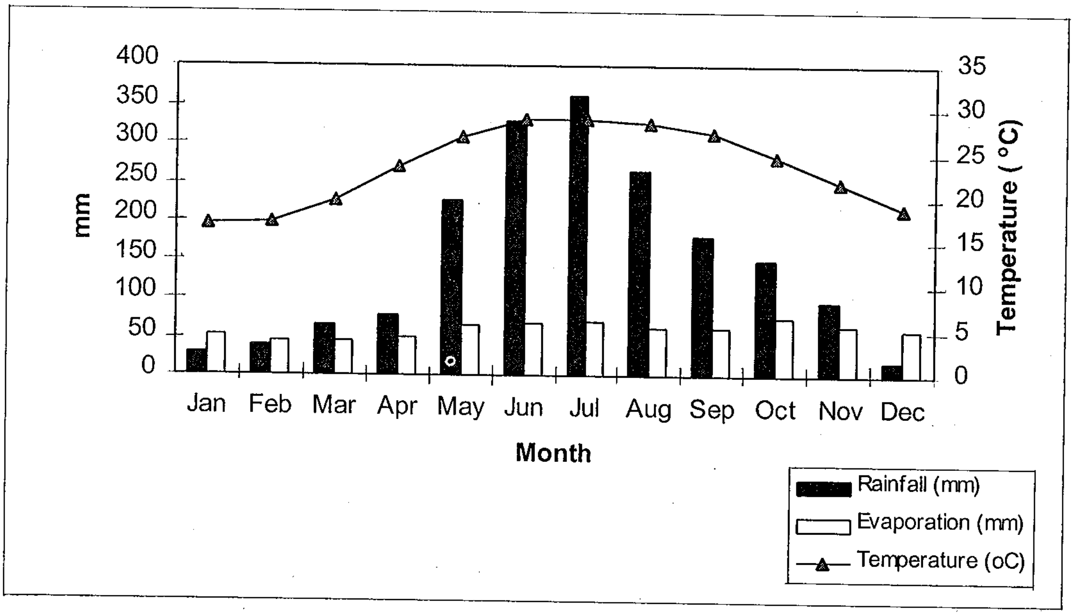


Figure 5. Sixteen-year monthly average rainfall, evaporation, and temperature recorded at the Son Tay station from 1984–1999.

Soils

The soils of the area are derived from parent materials primarily consisting of shale. They are classified as Ferralsols and Acrisols or Ultisols in the USDA Soil Taxonomy system. They have shallow to medium depth and medium stone content with very low nutrient content. The texture is clay loam to clay. A sample profile description is shown in Table 4.

Table 4. Soil profile description of sample pit.

Soil horizon designation	Soil depth, cm	Profile description
Ap	0–20	Dark brown (7.5YR 3/4 moist; 7.5YR 4/4 dry); loam; moist; granular structure; porous; many fine and medium roots throughout and some small gravels; clear smooth boundary.
Bt	20–40	Brown (7.5YR 4/6 moist; 7.5YR 5/6 dry); clay; moist; granular structure; less porous than upper horizon; some small plant roots and animal channels; some small gravels; presence of weathered rock fragments; clear smooth boundary.
BC1	40–90	Bright brown (7.5YR 4.5/6 moist; 7.5YR 5/7 dry); clay; moist; granular structure; slightly porous; very few plant roots; many weathered rock fragments (30–40%); diffuse smooth boundary.
BC2	90–140	Yellowish brown (10YR 5/7 moist; 7.5YR 6/6 dry); clay; moist; many weathered rock fragments; granular structure.

Vegetation and land use

Thirty years ago the catchment was covered with forest. Because of a need for more food, massive deforestation occurred after 1978. Annual crops, maily upland rice, was grown, soil erosion was accelerated and after 3–5 years, the soil fertility declined.

Cassava, corn, and arrowroot are now cultivated on the sloping/steeplands. In some areas, there are secondary forests and plantation forests with eucalyptus, *Acacia mangium*, cinamomum, and some fruit trees (Figure 6). Legume-based cropping systems are observed on gentle slopes and foothills. There are 10 ha of paddy rice along the outlet of the Dong Cao Catchment. Water from the catchment is enough to grow two rice crops and one winter crop (corn, bean, vegetable).

Livestock and fauna

Livestock is also an important source of income to support farmers' livelihoods. Livestock provides draft power, manure, and meat. In Dong Cao village, the households have on average 1 buffalo, 1 cow, 3 pigs and 32 chickens. Pig and chicken raising provide additional sources of income for the farmers.

Population and settlement history

Dong Cao village is one of the three villages near the catchment. There are 38 families now living in the village which has a population 196 persons, mainly coming from other villages since the 1960s. Sixty percent are the native Muong and 40% belongs to the Kinh ethnic group who migrated from Ha Tay Province in the 1960s through a government programme. The households have an average size of 5–7 members.

A recent survey showed that about 45% are males and about half are economically active at ages from 15– 60 years. They are engaged in different types of production activities like field crop cultivation and livestock raising. About 28% of the total population are below 15 years old.

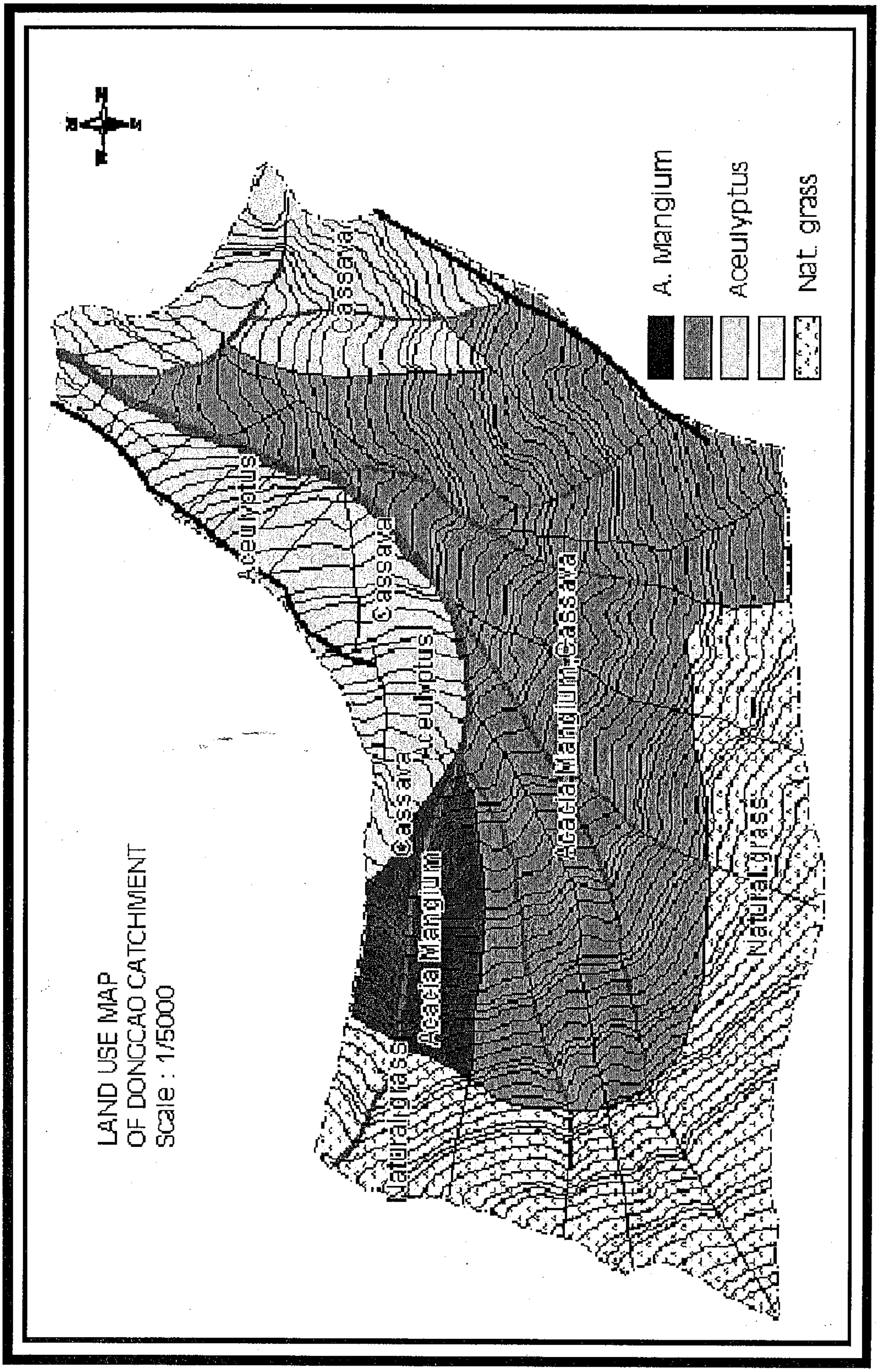


Figure 6. Land use map of Dong Cao Catchment.

During peak activities on the farm like planting, weeding, and harvesting, all members of the family work. In 80% of the families, men are mostly responsible for land preparation, such as ploughing, harrowing, pest and disease control while women do the weeding, fertilization, and purchase of materials. The children help in the field after school.

Animal husbandry and daily household activities like cooking, washing are done by women. They also gather firewood, buy and sell products. In general, family labour is not fully utilized for agricultural activities.

Decision-making on household needs depends on the kind of activities and the things to be purchased. In general, daily household needs, such as food and clothing are decided by women. Most agricultural activities are decided by women.

Almost all of the children go to primary school as it is situated within the village. Only a few children, particularly the females continue to secondary school. One reason is that it is far from the village.

Land use history

Before 1970, all of the area of 120 ha of land in Dong Cao Catchment was covered by primary forest. The local farmers conducted agricultural activities only on the foothills and along the main stream for paddy rice and arrowroot.

After 1970, because of population growth, more food was needed. The forest was cut for new agricultural land. Since 1980, all of the forest has been cut for cultivation. Corn and cassava have been planted as the major crop. Cassava has been considered the main crop since 1986.

Predominant occupation and income

Agriculture is still the major source of household income. The average total income is 8 million Vietnamese dong per household, 57% of which comes from farm produce and 39% from livestock. The average net income is however very low with only 58% of the households achieving a net annual income of 2.8 million VN dong.

All farmers in the village reported as full time farmers and fully relied on agricultural activities for their livelihoods. About 24% of the Muong households reported that their produce was enough for less than 7 –9 months of their annual food requirement, 24% are self-sufficient and 53% have food surplus. About 76% of the Kinh people are self-sufficient or have food surplus. All those with food shortages are the Muong people.

Farmers use fertilizers only for paddy rice at the rate of 72kg N as urea, 25kg P_2O_5 as superphosphate, 53 kg K_2O as potassium chloride, and about 7–8 t FYM ha^{-1}. The application of FYM depends upon the number of livestock in the households. It was reported that farmers never use fertilizer for upland crops as they find difficulty in transporting it to the upslope. Rice varieties commonly used are CR 203, Khang Dan, Tap Giao, and Q5 (from China)

Land tenure arrangement and policy

To overcome food shortages and to alleviate poverty, the Vietnamese government has put much effort to manage natural resources, particularly the sloping lands for sustainable agricultural and forestry production. The first orientation is to reduce deforestation, and to encourage permanent cultivation and human settlement. To achieve these purposes, the government allocates a large part of forest and barren lands (or unused land according to the Land Law) to people, with the aim to plant new forests and to protect existing natural forests. Program 327 with an annual budget of US$50 million has been carried out since 1992 to rehabilitate, protect, and make special use of forests. In 1993, a legal status was also provided for the allocation of these lands to organizations, households, and

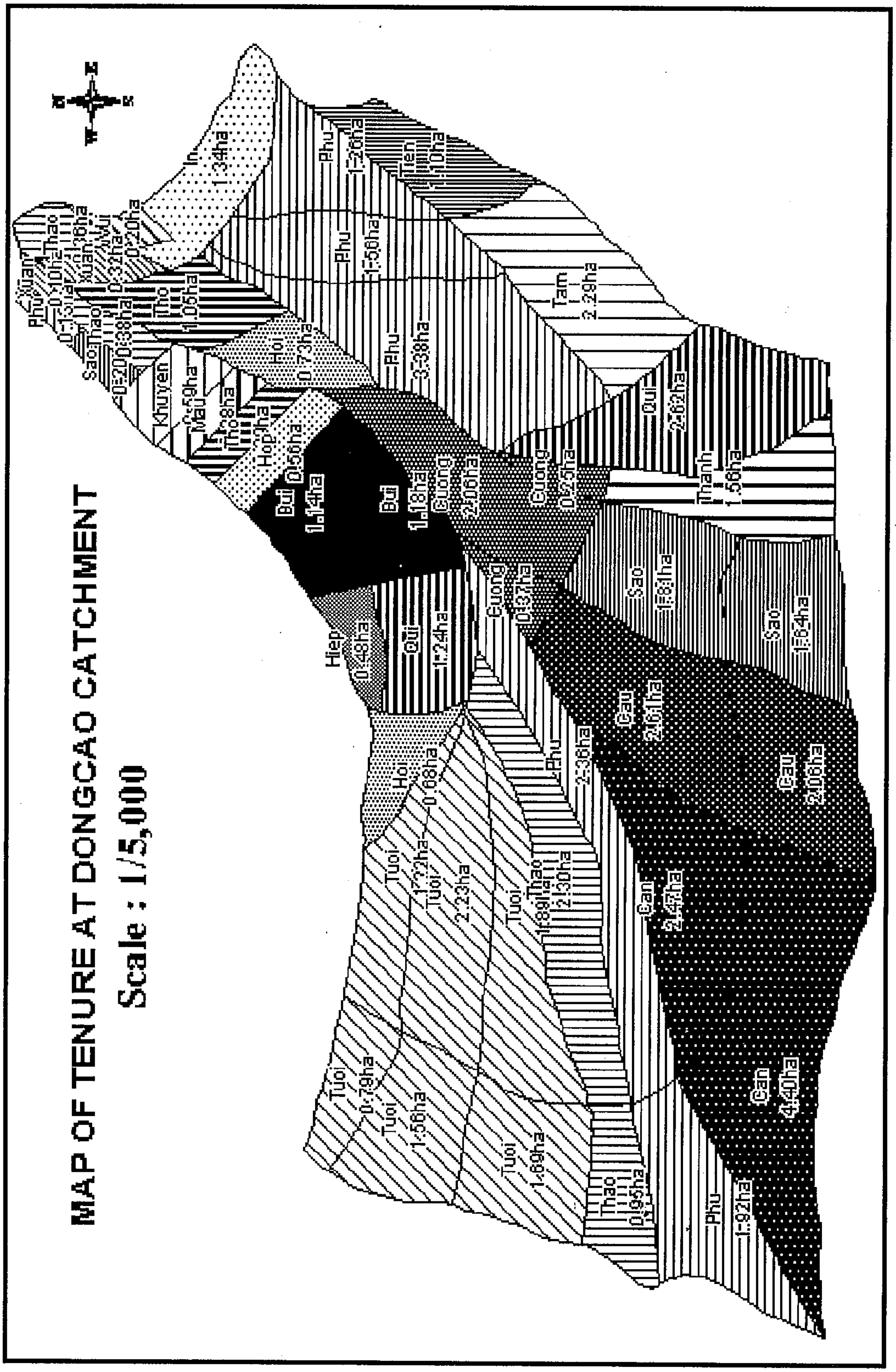


Figure 7. Land tenure map at Dong Cao Catchment.

individuals. Decree 02/CP of the government on 15 January 1994 clarified how forestland can be allocated and used sustainably. The purpose of this programme is: to speed up forest planting on barren land, to protect the existing forest, to increase the forest cover to 40% by 2010, to establish raw material (wood) for processing industries, and to create more jobs and income for farmers (Doan Diem, 1999).

According to government land use policy, the land and forest are allocated to farmers with land use rights for 30 years for annual crops and 50 years for perennial crops and forest trees. All the area of Dong Cao Catchment is allocated to farmers (Figure.7)

Conventional approaches to natural resource management had little effect, because they were dominated by top-down solutions to problems perceived by external stakeholders, not by the people who live there. In addition, forestry conservation policies have sometimes been defined inadequately. Programme 327, for instance, lacks clarity on how to manage the potentially conflicting objective of reforestation, environmental protection, poverty alleviation, and social integration. Moreover short-term income issues for highlanders have not been mentioned in the policy, which they face every day.

Forests, therefore, have been cut down not only as sources of fodder and other products for sale, but also for new agricultural land. Meanwhile long-term income has not been gained yet. This explains why the forest cover is receding and land degradation resulting from soil erosion has become wider and more severe.

Evaluation of the on-site effects of erosion

The model catchment covers an area of 120 ha. Four microcatchments were delineated and characterized measuring 4.77, 9.45, 5.19 and 12.36 ha. Figure 8 and Table 5 shows the area and production of different crops in each microcatchment.

Table 5. Crops and area planted in the different microcatchments (ha).

Weir	Total area	Other purposes	Cassava+ *Acacia mangium*	Cassava	Secondary Forest	Natural grass
W 1	4.77			3.21	-	1.56
W 2	9.45		2.25	5.56	-	1.64
W 3	5.19	-	5.19	-	-	-
W 4	12.36	-	3.18	-		9.18
MW	96.00	15.70	21.73	38.54	5.02	15.01

Source: Field Survey, 1999

The data in Table 5 show that the catchment has a large cultivated area, occupying about 61% of the total (22 ha of *Acacia mangium* intercropped with cassava and 39 ha of cassava monoculture). The secondary forest and natural grass occupy 5 and 15 ha, respectively. Microcatchment 4 (W4 has the largest area among the four microcatchments) has about 3 ha of *Acacia mangium* intercropped with cassava and 9 ha of natural grass. Microcatchment 2 (W2) has the largest cultivated area of about 8 ha while microcatchment 1 (W1) has the least with only about 3 ha. Microcatchment 3 (W3) has all its area under cultivation (*Acacia mangium* intercropped with cassava).

Cassava is the predominant crop occupying about 80% of the catchment. The local variety, Xanh Vinh Phu as well as improved varieties (KM953, SM 17-17-12) are planted in the area. The cropping calendar of the major crops grown in the catchments is shown in Figure 9

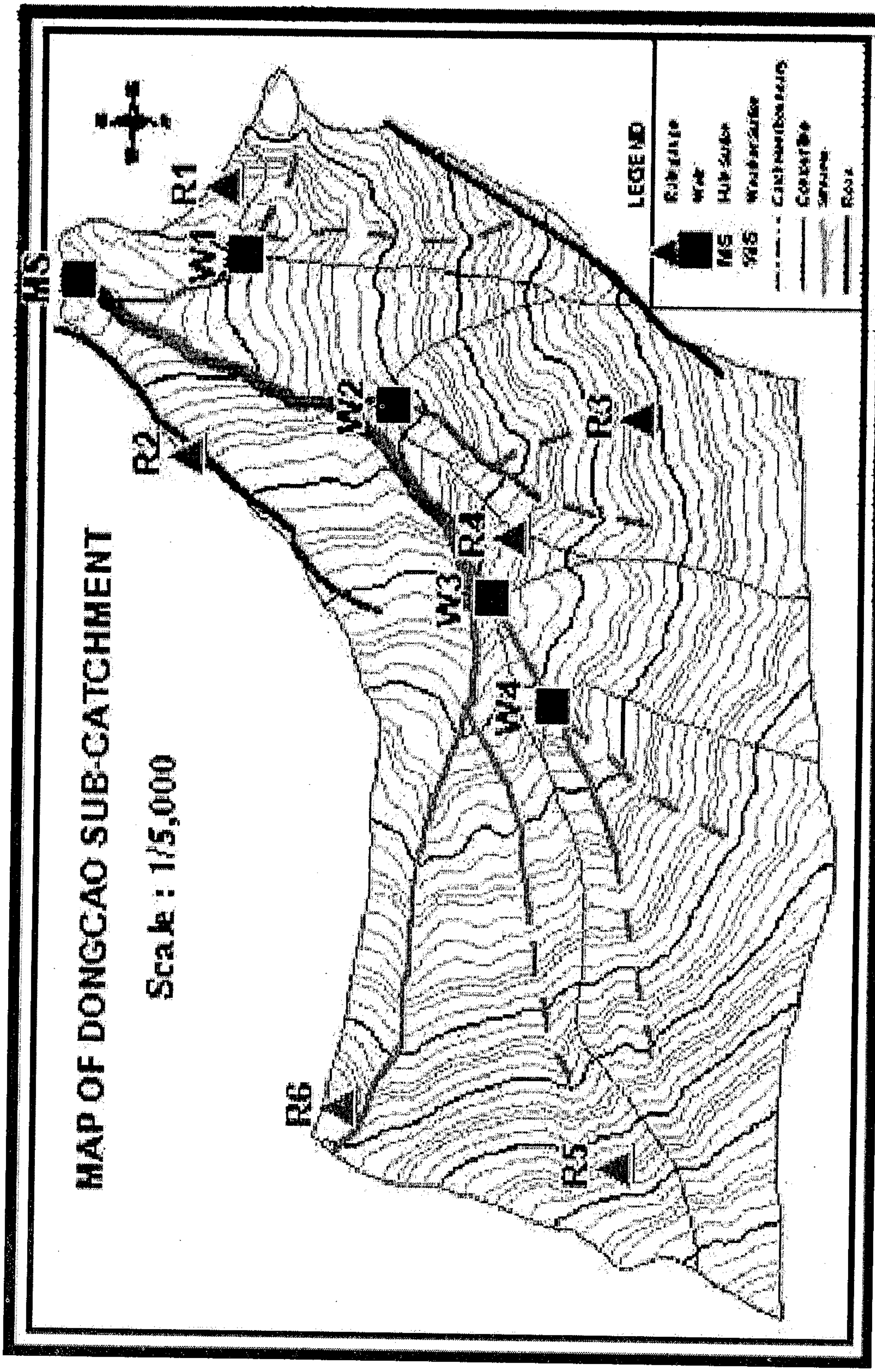
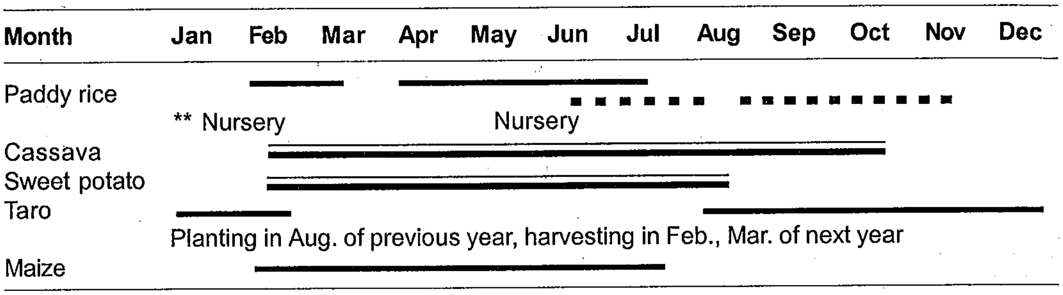


Figure 8. Map of Dong Cao subcatchment.

Figure 9. Cropping calendar of the major crops in Dong Cao Catchment.



**Paddy rice: Two crops per year
Source: Field Survey, 2000

Hydrological monitoring

Rainfall from January to September 2000 amounted to close to 1,399 mm. This represents 93% of the average annual rainfall of the area. Water continued to flow out of the main outlet even when there was no rain, as in January (Table 6 and Figure 10). This is because the main stream at Dong Cao Catchment has a permanent flow. Water is partly stored as groundwater after each rain event and then gradually flows out. This explained why after each rain event, even after big storms, the discharge did not change significantly. Table 7 shows the total rainfall and discharge from the catchment.

Table 6. Monthly rainfall and discharge from January to September 2000.

Month	Rainfall (mm)	Discharge (l s^{-1})
Jan	0.0	1.4
Feb	9.5	1.0
Mar	27.5	1.0
Apr	156.5	1.4
May	263.0	1.3
Jun	205.0	7.3
Jul	313.0	6.9
Aug	137.9	2.6
Sep	287.1	4.2

Table 7. Rainfall and discharge from the catchment.

Month	Total rainfall holding in watershed (m^3)	Total discharge from watershed (m^3)	Surplus water (infiltration, plant uptake, evaporation)
Jan	0	3,629	-3,629
Feb	9,120	2,506	6,614
Mar	26,400	2,678	23,722
Apr	150,240	3,629	14,6611
May	252,480	3,482	248,998
Jun	196,800	18,922	177,878
Jul	300,480	17,885	282,595
Aug	132,384	6,964	125,420
Sep	275,616	10,886	264,730
Total	**1,343,520**	**70,580**	**1,272,940**

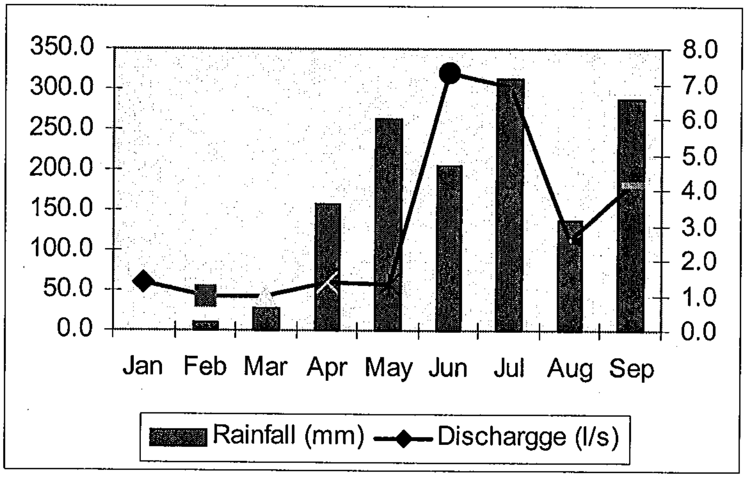


Figure 10. Rainfall and discharge at Dong Cao Catchment (Jan. to Sep. 2000).

The calculated soil loss from the different microcatchments measured from January to September 2000 is shown in Table 8 and Figure 11. The data showed that more than 45 tons of sediment were measured for the total area of the catchment or a soil loss of 0.47 t ha^{-1}. Among the microcatchments, W1 has the largest soil loss of about 0.9 t ha^{-1} and the least is W4 with about 0.2 t ha^{-1} soil loss. As already mentioned, W1 is the smallest microcatchment, while W4 is the largest. While they have almost the same area under farming, the cultivation in W4 is *Acacia mangium* intercropped with cassava compared to a monoculture cassava in W1. Moreover, W4 has a large area under natural grass. Comparing the soil loss from W1 and W3 which have relatively similar area shows the effect of the cassava intercropping systems as against a cassava monoculture. W1 had 3a larger soil loss per hectare than W3. The effect of the presence of natural grass in the microcatchments was also manifested in the results. Natural grass could enhance infiltration, reduce runoff and runoff velocity and consequently reduce soil loss.

Table 8. Soil loss (kg) measured from the different microcatchments in Dong Cao, January–September 2000.

Weir	Area (ha)	Total soil loss (kg)	Soil loss ha^{-1} (kg)
W1	4.8	4,488	941
W2	9.4	5,244	555
W3	5.39	4,367	841
W4	12.4	2,583	209
MW	96.0	45,509	474

Analysis of the sediments showed the large amounts of nutrients that have been lost through erosion. A total of 740 kg OM, 39 kg N,31 kg P_2O_5 and 80 kg K_2O have been lost from the catchment (Table 9, and Figure 12). The data clearly show that farming without soil conservation results in soil and nutrient losses which could further result in lower crop yields and productivity. It is anticipated that with proper soil management and applying the appropriate land use, soil and nutrient losses could be minimized.

Discussion with farmers showed that they indeed notice the occurrence of erosion by the muddy colour of the water that comes from the catchment. They said that crop yields in the uplands decrease year by year. After cutting down the forest, upland rice yielded 3–4 t ha^{-1}, but after three years, this decreased to just 0.8–1.2 t ha^{-1}. Similar decrease in yield was also observed for maize and cassava.

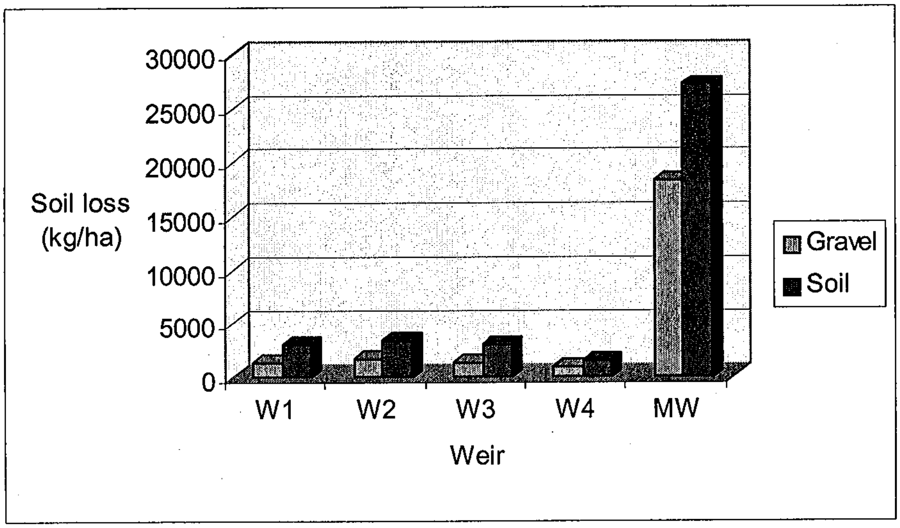


Figure 11. Soil loss (kg) from the different microcatchments in Dong Cao.

Table 9. Calculated amount of nutrients lost from the catchment through erosion (kg ha^{-1}).

Weir	Soil loss (kg ha^{-1})	Nutrient loss (kg ha-^{1})			
		OM	N	P_2O_5	K_2O
W1	941	133	4.9	3.8	7.6
W2	555	188	7.0	4.6	5.1
W3	841	150	7.9	4.2	8.0
W4	209	116	5.0	2.2	4.9
MS	474	740	39.1	30.5	80.4

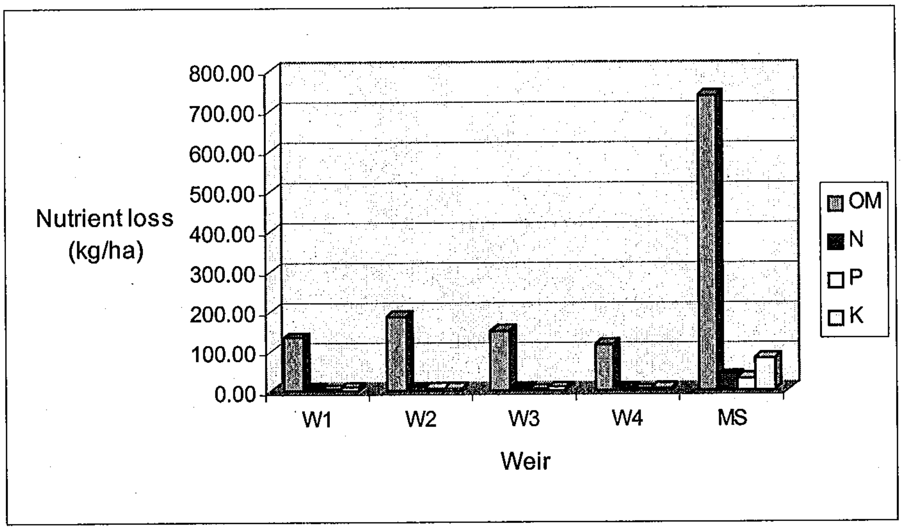


Figure 12. Amount of nutrients lost by erosion (kg ha^{-1}), Jan to Sep 2000.

Evaluation of the off-site effects of soil erosion

Fields survey/farmers discussion.

As mentioned above, water from the catchment is used for irrigation of 10 ha of paddy rice downstream. Farmers stated that before forest cutting, water discharge flowed continuously, but since the cutting down of the forest, there has been seasonal fluctuation in the flow. Scarcity of water in the dry season and flashfloods in the rainy season occur, resulting in damage to irrigation canals and the paddy fields themselves. While the floods carry away some fertile topsoil, even coarse pebbles and stones are transported. This results in land preparation difficulties, reduced area of the fields cultivated, and yield decrease. For fields farther away, the yield increase because of the nutrients that have been carried down.

Paddy field evaluation

Results of the analysis of the soil samples collected randomly in the paddy fields showed a relatively high content of organic matter, N, and P_20_5% and did not vary much relative to the distance from the catchment. Potassium, calcium, and magnesium content, however, were low.

The nutrient content in the water discharge showed that nitrogen did not vary with distance, but the amount of P_20_5, K_20 and Ca ++ varied considerably. The amount of Ca^{++} in water increased with distance, but P_20_5, and K_20 decreased.

CONCLUSION AND RECOMMENDATIONS

1. Watershed management is an important issue in Vietnam, not only to protect the forestland but also to conserve agricultural lands for sustainable production and alleviate the conditions of the farmers on the uplands. This research addresses these concerns and local farmers are deeply involved.
2. Dong Cao Catchment was selected for studying the on-site effects of erosion on soil degradation and crop yields, and to evaluate its off-site impact.
3. Based on the first results of the study, soil erosion can be affected considerably by the nature of land use in the area. Preliminary evaluation showed that cassava intercropping reduces erosion compared to plain cassava monoculture. The presence of natural grass also helps to reduce the amount of soil lost from the slopes. The size of the catchment seems to also affect the amount of erosion measured at the outlet. The amount of nutrients carried away with the eroded soil points to the fact that erosion will reduce the on-site fertility of the sloping lands.

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