Impact of Innovative Land Management Practices on Annual Runoff and Soil Loss from 27 Catchments in Southeast Asia

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Abstract

Rapid changes in Southeast Asian upland farming systems, resulting predominantly from increased population pressure and dependence on 'market forces', are leading to widespread land degradation and the clearance of native vegetation. Recent workshops on management strategies for these upland regions underlined the need for long term catchment-scale studies to provide the sound data that is still lacking. In particular, the links between agricultural activities in the uplands and downstream off-site effects are in question because of the difficulties in extrapolating findings from the plot scale to larger scales. The objectives of this paper are to summarise the main results obtained by the Management of Soil Erosion Consortium over the last six years and assess the impacts of i) rapid land-use changes and possible climatic changes on annual runoff and sediment yields, including bedload and suspended sediment loads, from 27 catchments and sub-catchments in the five Management of Soil Erosion Consortium countries (Indonesia, the Lao PDR, Philippines, Thailand, and Vietnam); and ii) selective innovative land-use practices aimed at improving soil conservation in these catchments. Topography, soil characteristics and initial land use were surveyed in each catchment. Monitoring included climatic, hydrological and erosion (bedload and suspended load) data, land use and crop yields, population density and farmers' income. The innovative practices tested were either spontaneous or set-up by the project and included: standard tree plantations, improved fallow with legumes, agroforestry practices (native grass strips and some agroforestry crops as hedgerows), direct sowing and mulch-based conservation, and fodder crops. Stepwise regression analyses were performed to identify the best predictors for runoff, bedload and suspended load. Our data clearly demonstrates that, without conservation practices, annual crops, especially maize and cassava, promote soil erosion at the catchment scale. Annual crops in upland catchments must therefore have off-site impacts on water quality. The team also clearly demonstrated the positive role of conservation technologies in reducing runoff and suspended load. However, despite their efficiency in combating soil erosion, few conservation techniques were adopted in the long term, especially by tenant farmers. Our findings suggest that soil erosion tends to increase with population density and more surprisingly with income per capita. If incentives are not put in place to reward upland communities that adopt appropriate land-use management systems, it is likely that land degradation will increase in the next few decades with off-site consequences for urban and industrialised lowland communities.

Keywords: land management practices, runoff, bedload, suspended load, annual crops, tree crops, off-site impact of soil loss, catchment.

1. Introduction

1.1 Factors contributing to land-use change

The current uncertainty about the exact extent of global change weakens the message of the scientific community, leads to controversy, and consequently delays political decision-making in spite of the necessity of adopting new socio-economic strategies. The need to make reliable predictions on the impacts of global change upon the environment (including estimates of their uncertainty) is particularly urgent in Southeast Asia, which is the most populated area of the world and is undergoing rapid economic growth. This entire region will undoubtedly be affected by the insatiable consumptive environmental footprint of the emerging economies of China and India.

The sustainability of the rapid changes in land-use practice taking place in Southeast Asia's tropical uplands is in question. Three main forces are currently recognised as driving these dramatic changes: population pressure, government policy and market demand. Two emerging driving forces appear to be climate change and land degradation. These five factors are interlinked and the relative importance of their role in influencing land-use changes depends on the region in question.

Continuing increases in population pressure result not only from natural growth but also from the migration of adjacent lowland farmers. Declining crop productivity in lowland areas is forcing the continued expansion of cultivation to increasingly steep slopes, often involving the clearance of native upland vegetation. In addition, government policies favouring the resettlement of remote and scattered villages, to provide improved access to education, health and market facilities, is leading to very high local population densities in some regions (Lestrelin and Giordano, 2007).

Very high rates of economic growth and escalating market demands for food and other agricultural products are encouraging farmers to replace food crops with non-food cash crops, which in turn may lead to their increased dependence on market forces (Burgers et al, 2005). Thus, even if market access conditions have greatly improved in recent decades, this has also meant that subsistence farmers increasingly need to generate additional sources of short-term income (Sidle et al, 2006b).

As the pace of economic and social change in this region accelerates, large tracts of rainforest may be converted to agricultural land with potentially critical environmental implications such as natural disasters (e.g. floods) and crop failure (e.g. due to drought), especially in the context of climatic change. For example, Bruijnzeel (2004) reported that in Thailand rainfall during the month of September (i.e. when the south-west monsoon current is weakening) has been decreasing remarkably since the 1950s. In July and August, when the monsoon is still strong however, no decrease has been noted (Yasunari, 2002), suggesting that the summer monsoon cycle is becoming shorter.

In east China the aridity index is also tending to increase (Fu, 2002) as a result of changes in soil surface roughness, leaf area index and reflection coefficients. Thus, observational evidence concurs with model predictions in suggesting that large-scale land-cover change in east Asia and Southeast Asia could indeed produce changes in the regional surface climate (Fu, 2002). Also of concern is the observation that even in places where annual rainfall is known to have decreased significantly over the last decades (e.g. the Sahel, Western Australia), concurrent decreases in the frequency of extreme events were not observed (see review in Valentin, 2004). Accordingly in Southeast Asia the frequency of flooding is not expected to decrease even though mean annual rainfall is reduced: the Intergovernmental Panel on Climate Change (IPCC, 2001) has predicted an increase in runoff of 50-150%. Present studies on the effect of climate change on erosion problems do not take into account the fact that farmers are often flexible in choosing crop rotations or planting dates, and that these could therefore be adjusted to achieve significant land-use change to compensate for the alterations in climate.

Being an open access resource, upland soils have been subjected to misuse and unsustainable farming practices that have resulted in land degradation: the uplands are being eroded and their nutrients depleted, resulting in lost soil stability and permanent damage. As the land resource base becomes less productive, food security is compromised and competition for dwindling resources increases. Thus a downward eco-social spiral is created. However, as mentioned by Scherr (2000) this situation is avoidable and in many circumstances reversible. Farmers often spontaneously seek innovations to stabilise or improve the resource base, or to depend less on degrading resources. Thus land degradation can lead to farmers giving up cultivation altogether or adopting new farming systems.

1.2 The on-site and off-site effects of land-use changes

Land-use changes have several on-site (i.e. at the scale of the cultivated fields) and well documented impacts such as the clearance and fragmentation of native vegetation, losses in biodiversity, changes to water regimes, and soil degradation (Gardner and Gerrard, 2003; Sidle et al, 2006b). These problems may be paramount to individual land owners/users but may not represent the broader off-site and downstream impacts. Runoff and soil erosion are often not only the primary consequences and symptoms of land mismanagement but are also involved in negative off-site impacts such as flooding, pollution, and siltation of water bodies and reservoirs. In headwater catchment areas it is hypothesized that increased exploitation of land resources with associated fragmentation of native forest vegetation, even on areas as small as <1 km^2, can result in increased sediment discharge and elevated nutrient loads which reduce the quality and availability of water to downstream users (e.g. Bruijnzeel, 2004). Thus runoff and soil erosion resulting from changes in land use and/or climatic conditions concerns not only upland farmers but also the downstream users of water resources. Indeed, although land degradation is often associated with poverty (e.g. Pender et al, 2001; Penning de Vries et al, 2002) especially in mountainous regions dominated by people who may be politically disempowered and economically marginalized, public interest in management of uplands emerges mainly from a realisation that environmental degradation of these lands affects richer communities (e.g. Lian, 1993).

1.3 Creation of the Management of Soil Erosion Consortium

Although their effects are likely to have impacts at the global level, the interactions between climatic and anthropic changes have been studied less in Southeast Asia than in the areas of mean latitude. Integrated and cross-scale knowledge is therefore essential to understanding current processes and predicting future trends. A key element in achieving these goals is the ability to operate at many levels within catchments where the integration of biophysical and land-use characteristics enables integrated approaches. Recent workshops on management strategies in the uplands of Southeast Asia underlined the need for long-term catchment studies (Tomich et al, 2004; Sidle et al, 2006ab). Because land degradation results from a web of spatially and temporally dependent processes, the problem arises of whether researchers are able to provide useful scientific inputs for developing and testing promising new environmental policy interventions (Tomich et al, 2004). For example, several scientists have questioned the impact of deforestation on large-scale flooding, suggesting that these effects have been overestimated (Kiersch and Tognetti, 2002; Bruijnzeel et al, 2004) and that major sources of sediments can be roads, poorly constructed and maintained terraces, coffee plantations or bank erosion (Sidle et al, 2006b). The successful adaptation of upland Southeast Asian catchments to climate and land-use changes depends on their present and future adaptive capacity. In developing countries especially, investment priority should be switched from the common focus on disaster recovery to assessment of the vulnerability of these catchments to such changes and to improvement of their capacity to adapt (Mirza, 2003). From all these discussions and findings, central questions for environmental policy have been raised: is there firm evidence for causal links between agricultural activities and off-site impacts? Is it thus relevant to envisage some form of payment for watershed services? Can we expect that continued population growth and improved market access will result in positive adaptive responses in terms of sustainable land management?

In order to address these issues and provide sound data on the extent of accelerated soil erosion resulting from rapid land-use change, a regional network called 'the Management of Soil Erosion Consortium' (MSEC) was established towards the end of the 1990s. Five countries (Indonesia, the Lao PDR, the Philippines, Thailand and Vietnam), the International Water Management Institute (IWMI) and the French Institut de Recherche pour le Développement (IRD) have been implementing a long-term research programme aimed at monitoring changes in farming practices and the resulting runoff and sediment yields, at the catchment scale. This consortium also aims to assess various innovative land-use practices to reduce soil losses and enhance the livelihood of affected communities (Maglinao et al, 2004).

1.4 Aims of this paper

This paper summarises the main results obtained by this consortium over the past six years with the aim of assessing the impacts of (i) rapid land-use changes and possible climatic changes on annual runoff coefficients and sediment yield (including bedload and suspended sediments loads) from 27 catchments and sub-catchments in the five MSEC countries and (ii) selective innovative land-use practices aimed at improving soil conservation in these catchments. These objectives meet the two technology transfer needs related to catchment processes recently identified for the tropics of Southeast Asia (Sidle et al, 2006a), namely the incorporation of an appropriate level of "good science" with socio-economic issues and constraints; and the development of appropriate management perspectives.

2. Materials and methods

2.1 Identification of reference catchments

Selecting the benchmark catchments for this study involved the participation of local stakeholders and thus depended on the farming situation and the willingness of farmers in the area to participate. It was also important to assess how well the catchment represented the overall characteristics of catchments in the region, and its accessibility for monitoring throughout the project activities. Additional considerations included the existence of other related projects that would complement the project (for the Philippines) and whether institutional links associated with the selected site were established (for Indonesia). 27 catchments and sub-catchments were thus selected and have been monitored since 2000. Table 1 shows the basic biophysical information for each benchmark site. Briefly, their size varies from 0.6-285 ha, the mean slope steepness is 8-48%, and annual rainfall reaches 1,028-3,840 mm.

2.2 Surveys and monitoring

Topography, soils and initial land use were surveyed in each catchment at the onset of experiments using the global positioning system and a theodolite. This geo-referenced data was used for geographical information system analysis of each catchment.

Table 1: Main attributes of the catchments

Country	Indonesia	Lao PDR	Philippines	Thailand	Vietnam
No. of equipped catchments	4	8	5	5	5
Catchment size (ha)	1.1-285	0.6-60.2	0.9-84.5	3-93	2.6-49.7
Catchment area name	Kalisidi	Huay Pano	Mapawa	Huai Ma Nai	Dong Cao
Province	Semarang	Luang Prabang	Bukidnon	Phrae	Hoa Binh
Latitude	07020'S	19051'10''N	08002'50''N	18013'20''N	20057'40''N
Longitude	1100E	102010'45''E	125056'35''E	100023'40''E	105029'10''E
Elevation (m)	390-510	400-700	1,080-1,505	400-480	125-700
Mean slope (%)	30-46	18-61	18-26	8-15	28-38
Geology and land form	Basaltic lava	Shale; schist	Basalt, pyroclastics	Siltstone, sandstone	Schist
Rainfall* (mm)	1,208-3,840	1,305-1,414	347-548	1,028-1,493	1,048-2,368
Number of years[§]	3 (2001-2004)	5 (2001-2005)	3 (2000-2002)	5 (2001-2005)	5 (2001-2005)
Soils	Inceptisol	Ultisol; Entisol	Ultisol, Inceptisol	Alfisol; Ultisol	Ultisol
Vegetation and land use	Rice, maize, rambutan	Forest, bush fallow; upland rice, maize, Job's tears	Forestry, open grassland, maize, potato	Soybean, mung bean, maize, tamarind	Cassava, tree plantations
Trialled practices	Fodder	Improved fallow	Natural vegetation strips	None	Fodder
Hydrology	Permanent flow	Permanent flow	Intermittent flow	Intermittent flow	Permanent flow

*over the period of hydrological measurements only a few months per year were recorded at some sites.
[§]data not yet available for 2006.

Monitoring included:

- ✓ Climatic data: automatic weather stations and several manual rainfall gauges in each catchment;
- ✓ Hydrological data: four to eight hydrological stations equipped with automatic water level recorders;
- ✓ Erosion data: suspended load was assessed using automatic water samplers at time intervals from two minutes to one hour depending on water discharge peaks; bedload sediments, i.e. sediments trapped in weirs, were collected and weighed after each main rainfall event, or in some countries, only once at the end of the rainy season. In Thailand sediment cores were collected from the reservoir downstream of the benchmark catchment;

- ✓ Land use: a map based on field surveys was prepared every year;
- ✓ Production: in most cases, crop yields were measured in the field;
- ✓ Farmers' income and population density: socio-economic surveys were conducted at least at the beginning and end of the experiments. In Laos, surveys included a historical study over the last decade (Lestrelin and Giordano, 2007).

2.3 Trial of innovative land-use practices

One way to tackle the negative impacts of soil erosion is to identify innovative land-use practices that address natural resource conservation while providing opportunities for an adequate livelihood to farmers in the catchment. In the MSEC catchments an interdisciplinary participatory approach was used to try and identify and trial several innovative practices. Prior to meeting with the farmers, the research team assessed the biophysical, social and economic conditions of the catchment in order to identify interventions highly suited to each site. Lists of previous trials that had proved successful were also compiled by the team to facilitate discussion with the farmers. Land management options were then identified and introduced through consultation. Experience has shown that if farmers are included in the selection process they are more likely to continue practising the system, which in the long-term provides them with enhanced incomes and leads to less resource degradation. The introduced land management options were evaluated for their acceptability and sustainability, and wider uptake at the community level was promoted to produce greater impact. The main innovative practices included:

- ✓ Tree plantations (*Acacia mangium, Styrax*) in Vietnam;
- ✓ Improved fallow with legumes (*Cajanus cajan* and *Crotalaria micans*) in the Lao PDR;
- ✓ Agroforestry practices: strips of native grasses and some agroforestry crops as hedgerows in the Philippines;
- ✓ Direct sowing and mulch-based conservation agriculture (with *Brachiaria ruziziensis*) in Laos;
- ✓ Fodder crop: ruzi grass (*Brachiaria ruziziensis*) in Vietnam and Benggala grass (*Panicum maximum*) in Indonesia.

2.4 Statistical analyses

Statistics for erosion variables were computed from the available yearly data from the 27 catchments: 102 figures for runoff coefficient (Rc), 110 for bedload (BLD), 95 for suspended load (SUL), and 90 for total sediment yield (TSY=BLD+SUL). Linear regression analyses were performed with a personal computer version of the SPSS® package using stepwise linear regression. With this analysis procedure, independent variables can be added individually from the model at each step of the regression, and therefore changes in the R-squared value can be evaluated. In the linear regressions, only parameters statistically significant at the 0.01 level were retained. These stepwise regressions were used to identify the best predictors for runoff coefficient and sediment yield.

3. Main findings

3.1 The impact of land-use changes or innovative practices on soil erosion

3.1.1 Lao PDR

In Laos, the prevailing cropping system until the 1990s was swidden (slash-and-burn) cultivation of upland rice with one year of cultivation and eight years of fallow. Rice cultivation years resulted in 5.7 tonnes $ha^{-1} yr^{-1}$ of sediment being generated while fallow years generated 0.4 tonnes $ha^{-1} yr^{-1}$. Under that system the mean annual sediment yield was therefore 0.9 tonnes $ha^{-1} yr^{-1}$. At the end of the 1990s, this system was replaced with longer cultivation and shorter fallow periods (two years of cultivation followed by two fallow years) and the mean annual sediment yield increased to 3.1 tonnes $ha^{-1} yr^{-1}$. During this period farmers experienced difficulties in controlling weed competition within their rice fields. Consequently they gradually replaced upland rice with maize, which led to the production of nearly double the amount of sediment (11.3 tonnes $ha^{-1} yr^{-1}$). Thus overall, this change of system and replacement of crop led to an approximate increase in mean annual sediment yield (5.9 tonnes $ha^{-1} yr^{-1}$) of 600%. In contrast, the improved fallow trial produced only 0.1 tonnes $ha^{-1} yr^{-1}$ of sediments, and continuous direct sowing and mulch-based conservation agriculture produced 0.7 tonnes $ha^{-1} yr^{-1}$. Economic and technical constraints (the need for herbicide usage to remove grass) are currently limiting the adoption of the direct sowing system, but the improved fallow system seems to have a higher chance of being adopted by farmers.

3.1.2 Vietnam

In the Vietnamese MSEC catchment, from 2000 onwards the predominant land-use practice has gradually changed from cassava to tree plantations. Some farmers had the opportunity to sell their land, whilst others, under a policy directive, planted trees or trialled an improved fallow system. Thus there has been a dramatic decrease in the extent of cassava production in the catchment, with the total area declining from 40% of the watershed area in 2001 to less than 0.5% in 2004. With this decline in area under cropping, the opportunity arose to introduce livestock into the catchment. The effects of a fodder species (*Brachiaria ruziziensis*), established under a no-tillage regime, and of tree plantations were evaluated with respect to their impact on slope erosion reduction. The annual soil loss recorded as bedload measurements decreased from 7.3 tonnes $ha^{-1} yr^{-1}$ with cassava to 1.0 tonnes $ha^{-1} yr^{-1}$ with the establishment of fodder, and 0.7 tonnes $ha^{-1} yr^{-1}$ with tree plantation.

3.1.3 Philippines

In the Philippines, the traditional method for cultivating maize parallel to the hillslope is highly erosive (36.2 tonnes $ha^{-1} yr^{-1}$ of bedload). When maize was cultivated following the slope contour and with grass strips, the crop produced only 0.7 tonnes $ha^{-1} yr^{-1}$, similar to the bedload from grass alone.

3.1.4 Indonesia

In Indonesia, 25% of land originally under rambutan plantation was converted to cassava because farmers needed to devote more land to seasonal or annual crop farming to increase income. This led to an increase in total sediment yield from 2.9 to 13.1 tonnes $ha^{-1} yr^{-1}$, consisting predominantly of suspended sediment load. Lower bedload was observed under cassava, probably due to the tillage method of making dikes for the cassava along contour lines in the lower slope. The introduction of fodder grass as an option to reduce erosion and improve income through livestock integration resulted in a significant reduction in the sediment yield (from 10.8 to 2.7 tonnes $ha^{-1} yr^{-1}$). By 2002 this system was being used on more than 60% of the area.

3.1.5 Thailand

Since 2004 maize has been replacing soybean and mungbean in Thailand due to a fungus that infected mungbean and to higher prices for maize. Abandoned land, secondary forest patches and even sweet tamarind orchards have been cultivated with the maize. Sediment yields, already high with soybean/mungbean at 4.9 tonnes $ha^{-1} yr^{-1}$, even under fruit trees (3.0 tonnes $ha^{-1} yr^{-1}$), more than doubled following these land-use changes to 11.7 tonnes $ha^{-1} yr^{-1}$.

3.2 The impact of exceptional rainfall events

In Thailand on the 16^{th} and 17^{th} of June 2004, 218.2 mm of rain fell in six hours with a maximum intensity of 70 mm h^{-1}, an event that occurs every one in a hundred years. Suspended sediment concentrations of 35 g l^{-1} were measured in the main weir. The annual sediment yields in the main weir (17 tonnes $ha^{-1} yr^{-1}$) were nearly 20 times higher than for the three previous years (mean: 0.9 tonnes $ha^{-1} yr^{-1}$). At the gauges in the four sub-catchments the sediment measurements were lower (from two to ten times), suggesting that stream bank erosion was the major contributor. Sediment cores sampled from the reservoir downstream of the catchment (121 km^2), which is mainly under forest, showed that the 2004 sediments were as thick as the total sediments of the four previous years (S. Huon, personal communication). In Vietnam, a single event associated with typhoon Koni (117.5 mm in 210 minutes, on July 23, 2003) caused a sediment yield of 149.6 tonnes at the main weir. This is equivalent to an average soil loss of 3 tonnes ha^{-1} over 49.7 hectares, mainly in the form of suspended load. Sedimentation concentrations reached 26 g l^{-1} in the main weir. This single event accounted for 42% of the total sediment yield for 2003.

3.3 Main predictors of runoff and sediment yield

Among the numerous factors evaluated, only a few had significant correlations (table 2) with Runoff coefficient (Rc), the ratio (in %) between runoff and rainfall, bedload (BLD; tonnes $ha^{-1} yr^{-1}$), suspended sediment load (SUL; tonnes $ha^{-1} yr^{-1}$) and total sediment yield (TSY, tonnes $ha^{-1} yr^{-1}$ with TSY=BLD+SUL). Sediment yield and its components (BDL and SUL) were weakly correlated with runoff coefficient. The runoff coefficient decreases when annual rainfall increases because ground cover is generally higher under wetter than drier climates. Similar results have been obtained along a climatic gradient in West Africa (Valentin, 2004).

Table 2: Pearson correlation coefficients (r) between (1) runoff and sediment yield and (2) environmental and land-use factors

Factors	Unit		Rc	BDL	SUL	TSY
Number		n	102	110	95	90
Runoff coefficient	%	Rc	1	.242*	.214*	.266*
Bedload	t ha^{-1} yr^{1}	BDL	.242*	1	.350**	.890**
Suspended load	t ha^{-1} yr^{1}	SUL	.214*	.350**	1	.735**
Sediment yield = SUL+BDL	t ha^{-1} yr^{1}	TSY	.266*	.890**	.735**	1
Annual rainfall	mm	R	-.388***	NS	NS	NS
Maximum monthly rainfall	mm	MxP	-.262**	NS	.260*	NS
Minimum monthly rainfall	mm	MnP	-.336***	NS	NS	NS
Surface of the catchment	ha	Sf	.210*	-.190*	NS	NS
Catchment perimeter	m	Pm	.225*	NS	.296**	0.01
Max elevation - Min elevation	m	Δz	.224*	-.239*	NS	-.218*
Mean slope of the catchment	%	Ms	NS	-.266**	-.311**	-.378***
Standart deviation of slope	%	Sd	-.416***	.207*	NS	NS
Mean slope of the stream path	%	Ssp	-.464***	-.191*	NS	-.279**
Clay content of the topsoil	%	Cl	-.360***	NS	NS	NS
Sand content of the topsoil	%	Sa	.223*	NS	NS	.225*
Mean soil depth	m	Md	-.464***	NS	-.216*	-.311**
Bamboo	%	Bo	NS	NS	.286**	.265*
Maize (one cycle/year)	%	Mz1	.399***	.203*	.339**	.524***
Maize (two cycles/year)	%	Mz2	-.303**	.705***	NS	NS
Maize= Mz1+ Mz2	%	Mz	.313**	.587***	.365***	.547***
Cassava	%	Ca	NS	NS	.260*	.229*
MZ+CV	%	MzCa	.255**	.568***	.433***	.595***
Total annual crops	%	Tac	.380***	.391***	.318**	.464**
Total trees	%	Tre	NS	-.208*	NS	NS
Fallow	%	Fw	NS	-.234*	NS	-.270*
Improved fallow	%	IFw	-.333***	NS	NS	NS
Grass strips	%	Gs	-.332***	NS	NS	NS
Conservation practices	%	Cp	-.594***	NS	NS	NS
Conservation practices & Fallow	%	CpFw	-.414***	NS	-.305**	-.390***

*Correlation is significant at the 0.05 level
**Correlation is significant at the 0.01 level
*** Correlation is significant at the 0.001 level
NS = not significant.

Surprising results were i) the increase of runoff coefficient with sand content, which can be explained by the high susceptibility of sandy soils to crusting (Valentin and Bresson, 1992) and ii) the decrease in sediments exported from the catchments with increasing slope, which is due to a slower development of surface crusts on steep slopes (Janeau et al, 2003). No relationship was observed between forest cover and runoff or sediment yield. Tree cover (Tre), including forest, plantation and fruit trees, had no effect on runoff coefficient and only a slight influence on bedload (r= -0.21). Bamboo appears to favour suspended load (r= 0.29), most likely because the soil surface is not sufficiently protected against the direct impact of the rain by a litter layer or understorey (Wiersum, 1985). The very low understorey cover under bamboo is not only due to shading but also allelopathy inhibiting seedling germination and establishment (Eyini et al, 1989). Fallow tends to limit sediment yield (r=-0.27) and improved fallow reduced runoff coefficient (r= -0.33). Conservation practices (Cp), which include improved fallow, direct sowing, grass strips and natural vegetation strips as well as terraces with grass risers, greatly reduce runoff coefficient (r= -0.59) but have no significant effect on sediment yields, except when combined with fallow (r= -0.39). No significant correlation was found between the proportion of the catchment cultivated with upland rice and runoff and erosion. By contrast maize, and to a lesser extent, cassava, had a major impact on sediment yields. Runoff coefficient (Rc), bedload (BLD), suspended load (SUL) and sediment yield (TSY) can be statistically predicted by the equations presented in table 3.

Table 3: Predictive equations of runoff and sediment yield

Variable	Equation	Eq. #	n	R^2
Rc	Rc = [4.77 – (0.32xCp)] + (0.25xMz) - (0.09xΔz) + (0.37xSa)	1	102	0.55
BLD	BLD = [1.38 + (0.51xMz_2)] - (0.06xCp) + (0.10xMz_1)	2	110	0.64
SUL	SUL = [-1.24 + (0.05xMzCa)] + (0.0005xPm) + (0.005xM_xP)	3	95	0.30
TSY	TSY = [3.157 + (0.12xMzCa)] - (0.03xCpFw)	4	90	0.39

Stepwise regressions determined that only three physical catchment characteristics: Δz (Max elevation - Min elevation), Pm (Catchment perimeter) and Sa, and one climatic factor, M_xP (Maximum monthly rainfall), were statistically selected to predict runoff coefficient and suspended load. By contrast, conservative practices (CP), conservation practices and fallow (CpFw), maize (Mz1, Mz2), and maize plus cassava (MzCa) are major predicting factors for runoff, bedload, suspended load and sediment yield.

3.4 Impacts of socio-economic factors

Socio-economic factors were also evaluated for each catchment. Changes in two main factors over time were instrumental in leading to land-use change: market access, as reflected by the annual income per capita, and population density (figure 1). The Lao, Vietnamese and Filipino sites are located in areas with similar and balanced demographic and economic 'trajectories', which suggests that increases in population density do not invariably lead to a decrease in annual income. Cramb (2005) recently hypothesised that fertility management techniques for acid upland soils were influenced by these same two factors. Figure 1 tends to confirm this hypothesis. For example, when population densities and income were low in the Lao PDR, farmers relied on shifting cultivation to extract a subsistence income from upland soils. Recently, however, the fallow period has been reduced from eight to two years (de Rouw et al, 2005) as a consequence of rapidly increasing population pressure resulting from natural growth but also from national resettlement and conservation policies (Lestrelin and Giordano, in press). This has led to an increase in soil tillage and hence an increase in tillage erosion on steep slopes (Dupin et al, 2002). In Vietnam, the Philippines and Laos, where farmers remain poor, the use of both organic and inorganic fertilisers is low. By contrast, the improved socio-economic conditions in Thailand favour the intensive use of industrial agricultural inputs. In Indonesia, where population densities are highest, organic inputs are relied upon heavily.

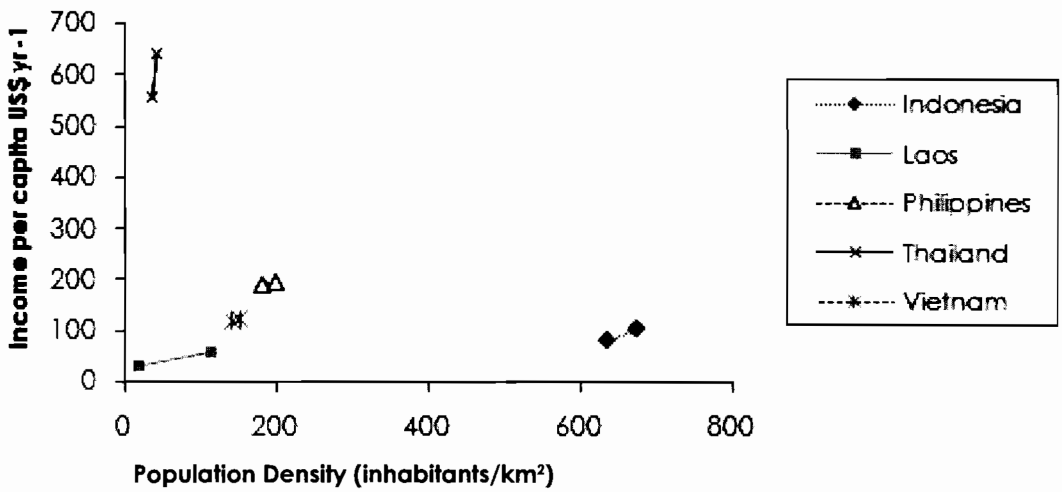

Figure 1: Density and income per capita in the five country sites

The two points per country correspond to the recent past and current situations: Indonesia: 2000-2002; Laos: 1990-2003; Philippines: 2000-2002; Thailand: 2000-2005; Vietnam: 2000-2002.

As shown in figure 2, soil erosion tends to increase with population density. Yet, the Indonesian catchment clearly illustrates that very dense populations can generate a positive response to control soil erosion, based on terraces and organic amendment.

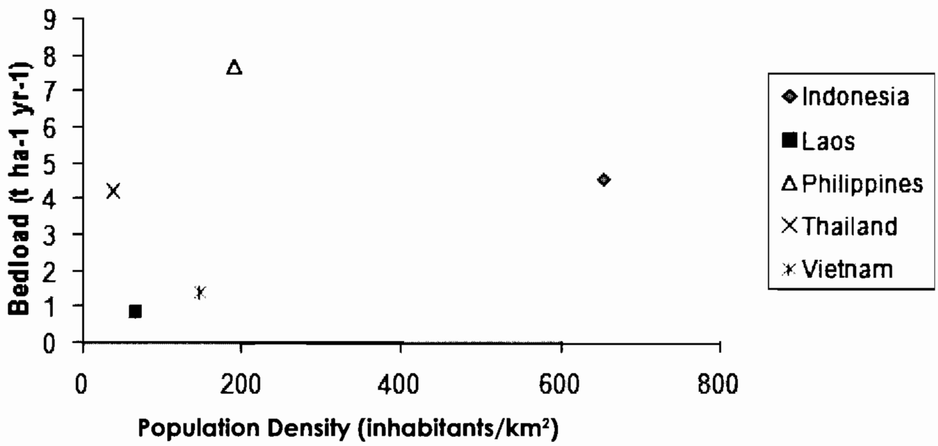

Figure 2: Mean bedload measurements for each catchment compared to population density

These five cases also suggest that soil degradation is not always associated with poverty since soil erosion tended to increase with the mean income per capita (figure 3). Similar results were obtained in Ethiopia (Tefera, 2006; Tefera and Sterk, in press). The relatively low soil erosion rate in Thailand is not due to investment by farmers in soil conservation technologies but rather to the fact that the soils are already so eroded by farming practices that a surface gravel layer now protects the soil from further erosion.

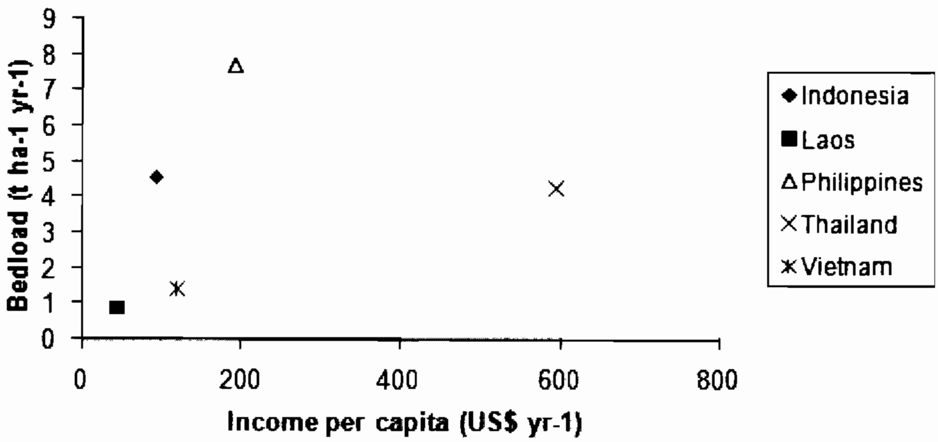

Figure 3: Mean bedload measurements for each catchment compared to income per capita

4. Discussion

Using the large data set collected in the five MSEC study sites, the team was able to determine highly significant statistical correlations, and hence predictors, for runoff coefficient and bedload with catchment characteristics (both physical and land use). Bedload is easier to collect and assess than suspended load (and hence the total sediment yield) so it was possible to generate a larger bedload data set and this probably improved the results of the statistical analyses. The data clearly demonstrates that without conservation practices, annual crops, especially maize and cassava, promote soil erosion at the catchment scale. This data is consistent with that obtained on field plots (e.g. Siddle et al, 2006b). Our results confirm and highlight the role of upland agricultural activities in generating runoff and sediments at the catchment level. Annual crops in upland catchments must therefore have off-site impacts on water quality. Similarly, this study clearly demonstrates the positive role of innovative land-use practices in reducing runoff and suspended load. In other words, its results contradict the emerging 'revisionist' mood mentioned by Tomich et al. (2004), which questions the effective role of conservation practices at the catchment scale.

Among annual crops, maize, especially when double cropped and cultivated parallel to the slope (rather than on the contour), and cassava are the most erosive. This is due to the rather low vegetative cover these crops provide and the need for repeated weeding. Cassava is often used to replace the main staple crop (usually upland rice) because it is less demanding. The recent development of maize in Southeast Asia is associated with rising prices and improved market access (Cramb, 2005). Cassava is also being increasingly produced as a source of bio-ethanol (e.g. Hu et al, 2004) and the detrimental effect of cropping both cassava and maize is likely to be exacerbated by the increasing demand for biofuel (e.g. Pretty et al, 2002; ICRISAT, 2007). Increased maize cropping may also be a response by farmers to a consistently shorter summer monsoon. In addition, current observations (de Rouw et al, 2005) suggest that the conversion of upland rice (C3-plant) to maize (C4-plant) is associated with similar changes in weed communities, as the native forest vegetation is gradually replaced by a savannah-type vegetation.

In Vietnam, sediment yields were greatly reduced when cassava was replaced by tree plantations and a fodder crop. Conversely, soil erosion has increased in Laos due to the shortening of the fallow period and the recent cultivation of maize. In such circumstances farmers tend to encroach on tree plantations or to destroy them to extend annual crops, as seen in Indonesia and the Philippines.

Despite their efficiency in combating soil erosion, only a few innovative land-use practices are being adopted in the long term by farmers. In Indonesia, however, grass planting on the bench terrace risers and in the lower areas of the catchments has been adopted by a majority of farmers. Although sections of forest or tree plantations were present in most catchments, the proportion of these forests or tree plantations did not appear as a key factor in soil conservation. The advantages of mostly spontaneously adopted agroforestry systems are best illustrated in Indonesia. These systems are not well accepted by farmers in other countries. In Vietnam for example, tree plantations on hillslopes, which greatly limit soil erosion, are blamed by farmers for depleting the water available for downstream paddy rice. Despite their effectiveness in combating erosion, at the Philippines site, the practice of planting strips of natural vegetation was only adopted by landowners, but not tenant farmers, due to the cost of establishment. Fodder crops appear to be an interesting alternative only for farmers who have sufficient land for growing both fodder and arable crops. It is significant that conversion from field crops to fodder/livestock often occurs only when the quality of the land has degraded so far that cropping is no longer a viable proposition.

5. Conclusion and recommendations

Based on data from 27 Southeast Asian catchments monitored for three to five years, this study has shown that:

- ✓ It is essential to conduct long-term studies at the catchment scale i) to observe/record land-use changes under prevailing conditions and determine their impacts on runoff and erosion, ii) to test new practices and their effects in mitigating possible off-site impacts, iii) to increase the chance of recording exceptional rainfall/runoff events, and iv) to analyse various hydrological and erosion processes, their possible time lag responses to land-use change and their cumulative effects. In this respect, an international network of long-term monitoring sites can be considered as an invaluable tool not only for scientists but also for policy makers;
- ✓ Runoff and soil erosion are predominantly influenced by land use not only at the plot scale but also at the catchment scale;
- ✓ The conversion of upland rice or orchards to maize and cassava greatly increases runoff and sediment yields at the catchment scale. Maize and cassava are major predictors for suspended load and sediment yield. These two crops are responsible for higher sediment contents in streams within the studied catchments. These environmental impacts must not be overlooked when governments in Asia move to promote their cultivation for bio-ethanol production;
- ✓ Innovative conservation land-use practices (improved fallow, direct sowing, grass strips and natural vegetation strips, terraces with grass risers) are efficient in preventing erosion not only at the plot scale but also at the catchment scale;
- ✓ For successful adoption by farmers, conservation strategies need to be tailored to the local demographic, economic and cultural conditions. There is a need for greater recognition of this diversity by international agencies and donors, some of whom are too specialised in a single strategy;

- ✓ Land degradation is not invariably associated with poverty and high population density. In this study, under high density conditions, the communities were more inclined to adopt and maintain more sustainable practices. The communities with the highest incomes were not necessarily the most willing to invest in conservation practices;
- ✓ If incentives are not put in place to reward upland communities that adopt appropriate land-use management systems, it is likely that land degradation will increase in the next few decades with off-site consequences for more urban and industrialised lowland communities.

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References

Burgers, P., Ketterings, Q.M. and Garrity, D.P. 2005. "Fallow management strategies and issues in Southeast Asia." *Agriculture, Ecosystems and Environment*. 110: 1-13.

Bruijnzeel, L.A. 2004. "Hydrological functions of tropical forests: not seeing the soil for the trees?" *Agriculture, Ecosystems and Environment*. 104: 185–228.

Cramb, R.A. 2005. "Farmers' strategies for managing acid upland soils in Southeast Asia: an evolutionary perspective." Agriculture, Ecosystems and Environment. 106, 69–87.

de Rouw, A., Soulilad, B., Phanthavong, K. and Dupin, B. 2005. The adaptation of upland rice cropping to ever-shorter fallow periods and its limit. In Bouahom, B., Glendinning, A., Nilsson, S., and Victor, M. (eds.). *Poverty reduction and shifting cultivation stabilisation in the uplands of Lao PDR: Technologies, approaches and methods for improving upland Livelihoods*. Proceedings of a workshop held in Luang Prabang, Lao PDR, January 27 - 30, 2004. Vientiane, Lao PDR: National Agriculture and Forestry Research Institute. 139-148.

Eyini, M., Jayakumar, M. and Pannirselvam, S. 1989. "Allelopathic effect of bamboo leaf extract on the seedling of groundnut." *Tropical Ecology*. 30(1): 138-141.

Dupin, B., Phantahvong, K. B, Chanthavongsa, A. and Valentin, C. 2002. "Assessment of tillage erosion rates on steep slopes in the northern Lao PDR". *The Lao Journal of Agriculture and Forestry*. 4: 52-59.

Fu, C.F. 2002. Can human-induced land-cover change modify the monsoon system? In Steffen, W., Jäger, J., Carson, D.J. and Bradshaw, C. (eds.). *Challenges of a Changing Earth*. Berlin: Springer-Verlag. 133-136.

Gardner, R.A.M, and Gerrard, A.J. 2003. "Runoff and soil erosion on cultivated rainfed terraces in the Middle Hills of Nepal". *Applied Geography*. 23: 23-45.

Hu, Z., Pu, G., Fang, F. and Wang, C. 2004. "Economics, environment, and energy life cycle assessment of automobiles fuelled by bio-ethanol blends in China." *Renewable Energy*. 29: 2183-2192.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), 2007. *Pro-Poor biofuels: outlook for Asia and Africa: ICRISAT's Perspective*. A working paper. URL: http://www.icrisat.org/Investors/Biofuel.pdf

Intergovernmental Panel on Climate Change (IPCC), Working Group II, 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the IPPC. Cambridge University Press.

Janeau, J.L., Bricquet, J.P., Planchon, O. and Valentin, C. 2003. "Soil crusting and infiltration on steep slopes in northern Thailand". *European Journal of Soil Science*. 54(3):543-554.

Kiersch, B. and Tognetti, S. 2002. "Land-water linkages in rural watersheds: results from the FAO electronic workshop". *Land Use and Water Resources Research*. 2: 1.1-1.6.

Lestrelin, G. and Giordano, M. 2007. "Upland development policy, livelihood change and land degradation: Interactions from a Laotian village". *Land Degradation & Development*. 18: 55-76.

Lian, F.J. 1993. On threatened people. In Brookfield, H. and Byron Y. (eds.). *South-East Asia's Environmental Future the Search for Sustainability*. Kuala Lumpur:United Nations University Press; Singapore: Oxford University Press.

Maglinao, A.R., Valentin, C, and Penning de Vries, F. (eds.). 2004. *From soil research to land and water management: Harmonizing people and nature*. Bangkok: International Water Management Institute, Asian Development Bank.

Mirza, M.M.Q. 2003. "Climate change and extreme weather events: can developing countries adapt?" *Climate Policy*. 3: 233-248.

Penning de Vries, F.W.T., Acquay, H., Molden D., Scherr, S.J., Valentin, C. and Cofie, O. 2002. I*ntegrated land and water management for food and environmental security*. Comprehensive assessment research paper No 1. Colombo: International Water Management Institute.

Pender, J., Gebremedhin, B., Benin, S. and Ehui, S. 2001. "Strategies for sustainable agricultural development in the Ethiopian highlands." *American Journal of Agricultural Economics*. 83(5):1231-40.

Pretty, J.N., Ball A.S., Xiaoyun, L. and Ravindranath, N.H. 2002. "The role of sustainable agriculture and renewable-resource management in reducing greenhouse-gas emissions and increasing sinks in China and India." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences.* 360(1797): 1741-1761.

Scherr, S.J. 2000. "Downward spiral? Research evidence on the relationship between poverty and natural resource degradation." *Food Policy.* 25: 479-498.

Sidle, R.C., Makoto, T. and Ziegler A.D. 2006a. "Catchment processes in Southeast Asia: Atmospheric, hydrologic, erosion, nutrient cycling, and management effects." *Forest Ecology and Management.* 224: 1-4.

Sidle, R.C., Ziegler, A.D., Negishi, J.N., Rahim Nik, A., Siew, R. and Turkelboom, F. 2006b. "Erosion processes in steep terrain-Truths, myths, and uncertainties related to forest management in Southeast Asia." *Forest Ecology and Management.* 224: 199–225.

Tefera B. 2006. *People and dams: environmental and socio-economic changes induced by a reservoir in Fincha'a watershed, western Ethiopia.* Doctoral Thesis. Wageningen University.

Tefera, B. and Sterk, G. in press. Environmental impact of a hydropower dam in Fincha'a watershed, Ethiopia: Land use changes, erosion problems, and soil and water conservation adoption. Proceedings of the 2nd International Workshop on Sustainable Sloping Lands and Watershed Management: Linking research to strengthen upland policies and practices.12-15 December 2006, Luang Prabang, Lao PDR.

Tomich, T.P., Thomas, D.E. and van Noordwijk, M. 2004. "Environmental services and land use change in Southeast Asia: from recognition to regulation or reward?" *Agriculture, Ecosystems and Environment.* 104: 229-244.

Valentin, C. and Bresson, L.M. 1992. "Morphology, genesis and classification of soil crusts in loamy and sandy soils." *Geoderma.* 55:225-245.

Valentin, C. 2004. Overland flow, erosion and associated sediment and biogechemical transports. In Kabat, P., Claussen, M., Dirmeyer, P.A., Gash, J.H.C., Bravo de Guenni, L., Meybeck, M., Pielke, R.A., Vörösmarty, Sr.C.J.R., Hutjes, W.A. and Lütkemeier, S. (eds.).*Vegetation, Water, Humans and the Climate. A New Perspective on an Interactive System.* Global Change - The IGBP Series. Berlin: Springer verlag. 317-322.

Wiersum, K.F. 1985. Effects of various vegetation layers in an Acacia auriculiformis forest plantation on surface erosion in Java, Indonesia. In: El-Swaify, S.A., Moldenhauer, W.C., and Lo, A. (eds.). *Soil Erosion and Conservation.* Ankeny, IA: Soil Conservation Society of America. 79–89.

Yasunari, T. 2002. The role of large-scale vegetation and land use in the water cycle and climate in monsoon Asia? In Steffen, W., Jäger, J., Carson, D.J. and Bradshaw, C. (eds.). *Challenges of a Changing Earth.* Berlin: Springer-Verlag. 129–132.

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