LAND USE AND SOIL EROSION IN TIKOLOD, SABAH, MALAYSIA

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ABSTRACT

Soil erosion and the deterioration of water quality in many river systems of Malaysia is a major concern and can among other things be attributed to deforestation associated with land conversion for agricultural purposes. This study looks at the relationship between land use and soil erosion in Tikolod, Sabah. The village has gone through a major transformation because of an increase in population partly caused by migration from Kionop village located within the boundaries of what is today Crocker Range National Park (CRNP). With the use of rapid rural appraisal, an erosion risk assessment using the Universal Soil Loss Equation (USLE) and monitoring of river discharge and turbidity, it was possible to investigate the relationship between land use practices and soil erosion in relation to water quality. The study found that farmers did not relate soil erosion to land management but to the rainfall and no explicit soil conservation measures were used. Risk of erosion was high on ginger and hill rice fields mainly due to the steep slopes and because no conservation measures were used. It was questionable whether the USLE was valid for plots of 40 degrees slope. Finally, the lack of buffer zones along the river may be the major cause of high turbidity and sediment concentration in the watershed combined with a reduction of the fallow period. It is therefore important that conservation practices are incorporated in future land management to prevent deterioration of water quality.

INTRODUCTION

In recent years there has been an increasing concern over soil erosion and the deterioration of water quality in many river systems in Malaysia. Accelerated soil erosion is either seen as the result of logging activities, the introduction of rubber plantations, tin mining activities or deforestation associated with land conversion for agricultural, industrial or urbanisation purposes (Brooks et al. 1993; Department of Environment 1996; Wan Ruslan Ismail 1997). Not only may soil erosion cause a reduction in soil productivity (NSE-SPRPC 1981; Oyedele 1996), but the off-site effects in tenrts of siltation problems, disruption of water supply and the damage of freshwater resources etc. may be significant (Murtedza and Chuan 1993). Sediment yields seem to be considerably greater in Sabah when compared with major rivers in Peninsular Malaysia (Department of Environment 1996). There has been some discussion about the extent to which shifting cultivation poses a threat in terms of soil erosion arid hence whether it has an impact on water quality.

The watershed of Tikolod in the Tambunan district of Sabah has gone through a dramatic increase in population from around 100 people in the late 1970s to approximately 470 people in 1999. This increase in population has partly been caused by migration from Kionop village located within the boundaries of what is today Crocker Range National Park. In the early 1980s the Tikolod area went through a transformation from consisting of scattered households to being centred around the four hamlets of today. The largest hamlet (Tikolod village) consists of around 40 households with three other hamlets having around 10 households each. The watershed is dominated by two major rivers, the Tikolod river and the Bolotikon river. The geology mainly consists of sedimentary rocks of Tertiary age and the soils are sandy clay loams and sandy loams. Shifting cultivation using slash and burn techniques is the predominant farming system with ginger and hill rice as the main crops supplemented by fruit trees, oil palm and coffee. There is hardly any primary forest while secondary forest is prevalent.

There is evidence to suggest that traditional shifting cultivation has little long term effect on soil loss since abandoned plots quickly are recolonized by vegetation. However, where fallow periods are reduced or where the ground is left bare between row crops, sheet erosion is high (Department of Environment 1996). It is therefore important to look at the specific land management practices used by farmers and to assess the risk of erosion associated with particular types of land use with erosion risk assessment methods such as the empirically based Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978).

In the USLE, annual soil loss A (t/ha) is a product of the rainfall erosivity *(R)*, the soil erodibility *(K)*, an index of slope length and slope steepness *(LS)*, the cover and crop management factor *(C)* and the conservation practice factor *(P)* (Wischmeier and Smith 1978). Although the model initially was developed based on 10,000 years of plot studies east of Rocky mountains in the US, the model has become one of the most widely used in the world with several applications in the tropics (see for example Morgan 1986; Balamurugan 1991; Folly 1997; Mati 1999). Several attempts have been made to modify and further develop the USLE (e.g. Cooley and Williams 1983; Renard et al. 1994), but the original USLE still remains the most widely used due to its simplicity.

Because soil erosion is a very complex problem influenced by a wide range of both bio-physical and socio-economic parameters (Napier et al. 1991; Folly 1997), the mechanisms determining land use patterns and land management should be investigated alongside the physical parameters such as soil characteristics and vegetation. To fully understand the problem, the dynamics in the system have to be unveiled so that key issues can be targeted as a step towards solving or preventing the problem.

The overall objective of this study is to investigate the relationship between land use practices and soil erosion in Tikolod. By looking at the local knowledge about soil erosion, the way in which social and institutional factors influence land use and by estimating erosion risk and discussing the potential off-site effects of erosion, the extent of the problem will be assessed and future strategies identified.

METHODOLOGY

Rapid rural appraisal methods such as semi-structured interviews, group interview, land use mapping and cropping calendar sessions, and matrix scoring and ranking were used to investigate land use and management practices, to identify parameters influencing farmers' use of land and to find out how soil erosion is perceived locally. To eliminate possible biases and cross-check information, triangulation was used which means that the same information is gathered in different ways (Aalbæk 1994; Mikkelsen 1995). An anthropologist took part in all interviews and sessions to ensure continuity and comparability of results together with at least one person with a natural scientific background who could ask specific questions relating to land use, soils, farming practices and hydrology. The informants were selected with the aid of a young man in Tikolod village and represented a range of age, farm size and land use and came both from the Bolotikon River and the Tikolod River watersheds.

As information on land use in the area is scant and because of time constraint, it was decided to produce a land use map through a mapping session with 5 key informants identified to have comprehensive knowledge about the watersheds. The informants were asked to include information on rivers, roads, fields, ridges marking the boundaries of the watersheds, owners of fields, size of the fields (if possible), crops at the fields, whether there was a grant on the fields and locations of recent landslides (i.e. within the last year). To gather information about land management and cropping cycles, a cropping calendar was established with the help of 5 informants. This was supplemented by a matrix scoring exercise that identified the extent to which crops are used for food in the household, the extent to which they serve as a source of income, labour requirements for cultivation and palatability.

An assessment of annual soil loss rates was carried out using the USLE. The erosivity factor *R* was calculated using an equation proposed by Foster et al. (1981) based on annual rainfall and the maximum 30-minute rainfall intensity. The Foster et al. equation was chosen because it had proven successful in previous studies in Malaysia (Dr. Tie, personnal communication). In order to determine the *K*, *LS* and *C* factors, 12 fields with either dry rice *(Oryza sativa)* or ginger *(Zingiber officinale)* and with typical slope gradients ranging from 20 to 40 degrees were investigated. In each field, two surface soil samples were collected up- and downslope and analysed for organic matter content and soil texture. This enabled the erodibility factor to be estimated using the USLE nomograph (Wischmeier and Smith 1978). The *LS* factor was calculated using an equation given by Morgan (1986) using slope and length of slope as measured in the twelve fields. A *C* factor value was calculated for ginger according to the procedure outlined by Wischmeier and Smith (1978) using table values for potatoes. For the remaining land use types such as forest and rice, guide values from the literature were used. As conservation practices virtually are absent in the watersheds, the *P* factor was set to a maximum value of one.

In order to explore the relationship between land use and soil erosion and its off-site effect, two hydrological gauging stations were established to monitor river discharge from the Bolotikon River and Tikolod River watersheds according to Gunston (1998). As a current meter was not available, flow velocity was determined by timing the movement of a float (in this case a half-filled water bottle) over a known distance and river discharge was then calculated by multiplying velocity with the cross section and the time period (Gunston 1998). Flow velocity was measured regularly in the period 20-28 October 1999 supplemented by turbidity measurements using a back scanner turbidity meter. Two tipping-bucket rain gauges (type Rain-O-Matic 100.051) connected to HOBO 2000 Event Loggers were installed upstreams in the two water-sheds for continuous monitoring of rainfall characteristics and sediment concentration was determined on a number of selected water samples.

RESULTS AND DISCUSSION

Farming practices and perception of soil erosion

The majority of the farmers claimed that typical fallow periods in the Tikolod area are 2-4 years and that the length of the fallow period has not changed much over the last 20 years. Plant indicators are used to assess whether a piece of land has regained its fertility. The most fertile land will typically be allocated for the growth of ginger having great importance as a cash crop. The matrix scoring and ranking workshop showed farmers' motivations for growing different crops (Table 1). Whereas ginger is a cash crop and provides the main source of income, rice is grown for home consumption. The labour requirement for ginger was indicated to be higher as compared to rice and differed from findings by Dirir et al. (1999) in Patau village of the Tambunan district. This may be attributed to the fact that wet rice is the most important cash crop in Patau as opposed to ginger in Tikolod and that the scores given express the actual labour requirement of a particular crop rather than the relative labour requirement. The second most important food crop is banana followed by the remaining food crops and obtained a medium score both in terms of food and income. Coffee and rubber both have high labour requirements but do not have much importance as cash crops.

Farmers initially stated that soil erosion was not a problem although it was observed several places within the two watersheds. Soil erosion was not linked to land use by the farmers but exclusively with heavy rainfall considered to be the main problem in relation to farming activities, and erosion a mere symptom. A similar situation was observed by Lindskog and Tenberg (1994) in Burkina Faso where many farmers did not perceive land degradation to be influenced by human actions. On the other hand, soil erosion is a well defined concept in dusun (the local language) with (1) 'Norulun' meaning "wash away"- sheet erosion; (2) 'Notuhan' for landslides and (3) 'Noung Kudan' to describe erosion of river banks and gully erosion. Farmers reported of exposed ginger roots as soil is washed away and during heavy rains plants are washed away and gullies formed.

Table 1. Matrix scoring and ranking for crops

	HR	WR	GI	FI	CO	OP	MA	BA	DU	LA	RU
Food	5	5	1	3	3	3	3	4	3	3	0
Income	1	1	5	2	2	2	2	2	3	3	3
Labour req.	4	3	5	2	5	4	2	2	3	3	5
Palatability	5	5	2	3	3	2	4	3	5	4	0

Number in boxes refer to overall rank, minimum score is 0 and maximum score is 5. (HR = hill rice, WR = wet rice, GI ginger, El = fish, CO = coffee, OP = oil palm, MA = maniok, BA = banana, DU = durian, LA = langsat, RU rubber).

Table 2. Average annual soil loss for ginger

Ginger Field no.	Slope	*K*	*LS*	*A* (t/ha/year)
1	30º	0.19	7.06	283.9
2	40º	0.14	22.60	669.5
6	20º	0.16	5.03	170.3
R3	40º	0.14	19.57	579.8
R4	30º	0.15	7.48	237.4

R5	20º	0.12	3.15	79.9
Average soil loss				336.8

Fields marked with R are located in the Tikolod river watershed and fields without in the Bolotikon river watershed.

Some farming practices used in Tikolod play an important role in reducing soil erosion. Weeds, for instance, are left to grow on ginger fields three months after the ginger has been planted thereby protecting the soil from raindrop impact. The use of herbicides rather than weeding is widspread among younger farmers and prevents disturbance of the soil surface when the weeds are pulled out of the ground. In a study by Hashim et al. (1995) clean weeding was shown to substantially increase soil loss. A few farmers also put the felled stems of smaller trees along the contours of steep slopes as this makes it easier to walk in the field or they leave stems in the gullies. However, explicit soil conservation practices were rarely practised and this corresponds with observations by Voon and Teh (1992) in the region. When conservation measures were used this was driven by other motivations/rationales such as saving time, easing the work and improving the yield. This indicates that if soil conservation is actually imbedded in the local way of farming it cannot be detected as an articulated local knowledge as many scientists following a traditional northern scientific tradition have a tendency to conclude (Richards 1993).

Erosion risk assessment

The erosivity factor *R* was calculated to be 214.6 using the Foster et al. (1981) equation. This is considered low by Morgan (1986) who used the average of two other methods (Morgan 1974; Roose 1975) for determining erosivity in an area close to Kuala Lumpur. Values of erodibility *K* ranged from 0.12 to 0.19 (Table 1 and 2) and the soils can be classified as having medium erodibility according to Morgan (1986). *K* factor values are relatively high when compared to values found by Stephen (1995) using the USLE nomograph and rainfall simulator experiments, but relatively low when compared with studies carried out by Ambar and Wiersum (1980). Both Ambar and Wiersum (1980) and Vanelslande et al. (1987) pointed to the lack of correlation between various erodibility indices and the USLE *K* factor and stressed the importance of not applying the USLE nomograph on soils significantly different to the ones from which the nomograph was developed. Organic matter content varied from 1.7 to 3.9 % except for two locations which had around 6 % organic matter content, again indicating a low to medium erodibility.

High values were calculated for the *LS* factor (Table 1 and 2), particularly when slopes were above 30 degrees and the question is whether values are realistic since the equation originally was developed for slopes where cultivation is permissible, i.e. below 7 degrees (Morgan 1986). McCool et al. (1987) found two linear relationships for the *LS* factor with a breakpoint at around 9 per cent slope which showed that the original USLE equation overpredicts the *LS* factor at higher slopes. Furthermore, *LS* factor estimations are greatly influenced by the length of slope (Folly 1997) which varied considerably within the study area and *LS* factor values may therefore be lower in some parts of the area.

Table 3. Average annual soil loss for dry rice

Dry rice field no.	Slope	*K*	*LS*	*A* (t/ha/year)
3	40º	0.14	20.21	489.9
4	30º	0.18	7.89	245.9
5	20º	0.19	2.39	78.6
R1	30º	0.15	9.98	259.2
R2	20º	0.13	3.05	68.6
R6	40º	0.14	19.57	474.4
Average soil loss				269.4

Fields marked with R are located in the Tikolod river watershed and fields without in the Bolotikon river watershed.

Table 4. Land use distribution in the Bolotikon and Tikolod watersheds, October 1999

	Bolotikon		Tikolod	
Crop	No. of plots	%	No. of plots	%
Ginger	30	50.0	17	41.4
Hillrice	11	18.3	7	17.1
Fruit trees (mainly durian)	11	18.3	7	17.1
Wetrice	5	8.3	3	7.3
Maniok	1	1.7	2	4.9
Coffee	1	1.7	2	4.9
Oil palm	1	1.7	1	4.9
Rubber			2	2.4
Total	60	100.0	41	100.0

Coffee and oil palm fields are intercropped.

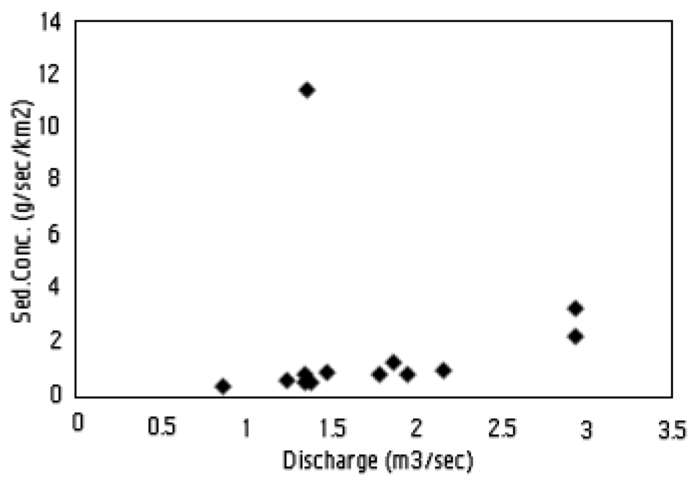
Annual soil loss rates on hill rice and ginger fields varied considerably (Table 1 and 2) from 68.6 t/ha/year to 669.5 t/ha/year and were to a large extent determined by the *LS* factor values. Whereas estimated soil loss rates for plots at 20-30-degree slopes are comparable with measured soil loss rates in Malaysia (Hashim et al. 1995; Department of Environment 1996), soil loss rates from 40-degree slopes appear excessively high. It is important to keep in mind that average soil loss rates will be lower because of the shifting cultivation system with the fallow periods during which substantial ground cover can be established. This is supported by Brooks et al. (1993) who found that soil detachment, which is a parameter related to cover, is one of the main parameters determining erosion rates. The length of the fallow period is hence crucial to the actual risk of erosion. Soil loss rates on forested land is negligible (Department of Environment 1996) and no estimates of this was therefore made in Tikolod.

Sediment transport and land use patterns

The average river discharge was $1.3m^3$/s for the Bolotikon river and $2.3m^3$ /s for the Tikolod river which should be seen in the light of a watershed size of 18.4 and 32.4km respectively. Figure 1 shows sediment concentration as a function of river discharge and follows a close to exponential relationship except for one incidence at which sediment concentration was much higher than expected. Unfortunately, it was not possible to establish a correlation between turbidity measurements and sediment concentration due to the small number of samples collected. If it is assumed that the turbidity measurements can be related directly to sediment concentration, the Tikolod watershed is estimated to have between 1.6 and 4.9 times higher sediment concentration per unit area as compared to the Bolotikon watershed.

On the afternoon of the 21 October a flooding event occurred associated with a rainfall event of just 15mm but with maximum intensities of 63.2mm/h. The lag time was around 70 minutes. In a matter of only 2-3 minutes, the water level at the gauging station rose by 40cm in the two rivers and tree trunks were carried by the flow at a tremendous speed. River discharge was estimated to be 12.9m^3/s in the Bolotikon river and 34.0m^3/s in the Tikolod river and turbidity was so high that the turbidimeter was unable to measure (i.e. >1000 NTU). It is estimated that a considerable amount of sediment was transported on this occasion and can be supported by previous studies in the region pointing to significant soil losses at rainfall intensities as low as 18mm/h (Voon and Teh 1992). Murtedza (personal communication) has observed incidences in the watershed whereby a plume of sediment was transported through the system after rainfall events. Farmers in Tikolod reported that on those occassions they were unable to drink the water as they usually do when working in the field.

Figure 1 Sediment concentration as a function of river discharge in Tikolod.



Differences in sediment transport in the two sub-watersheds may be attributed to the differences in geology, topography and rainfall. The most important parameter though is the land use pattern. As table 4 shows, there is hardly any difference in terms of land use pattern percentage wise though there are more plots in the Bolotikon as compared to the Tikolod watershed. The land use map drawn by the villagers indicated a smaller percentage of the Tikolod watershed is cultivated as compared to Bolotikon though one should be careful to conclude as the map was not drawn at the right scale. A plausible explanation to the differences in sediment transport according to the land use map is the tendency in the Tikolod watershed to cultivate plots close to the river which means that there is no buffer zone to capture sediment from upslope areas. This is particularly critical if rice and/or ginger are grown on steep slopes close to the river.

The future land use changes in Tikolod and the associated effect on soil erosion and water quality are to a large extent related to land tenure. The establishment of the CRNP has cut the people off from accessing new primary forest, while there has been a significant increase in land applications and grants to secure land. Acquisition of land is hence gradually becoming a matter of inheritance as a consequence of the Land Ordinance, though the local Adat system still works with the village headman manifesting the legal pluralism that exists between the Adat and the Land Ordinance (Andersen et al. 1999). Ownership (i.e. holding a grant) does to a large extent determine land use. Within the Tikolod area, a grant had only been obtained for 14% of the plots (14 plots). On 13 of these plots, crops were grown for which a subsidy may be obtained from the Department of Agriculture (wet rice, fruit trees and rubber). The length of the fallow period is also an important parameter which is likely to be determined by the pressure on the land. If the pressure continues to rise, the introduction of conservation practices will be of paramount importance to prevent accelerated erosion rates. At the moment, the Department of Agriculture in the area does not provide any training in conservation practices to address the issue.

CONCLUSION

The present study showed that although soil erosion is a well-defined concept among farmers in Tikolod, it is not linked by farmers to land use or farming practices but entirely to rainfall. The main crops are rice and ginger grown for home consumption and cash respectively. Soil conservation is not practiced explicitly but the use of herbicides rather than weeding is widespread among young farmers and this prevents disturbance of the soil surface when the weeds are pulled out of the ground. Weeds are often left on plots with mature ginger thereby protecting the soil from raindrop impact.

Erosion risk expressed as annual soil loss rates for hill rice and ginger varied from 68.6 t/ha/yr to 669.5 t/ha/yr and were mainly determined by high *LS* factor values. It is questionable whether soil loss rates from 40-degree slopes are realistic and whether the USLE can be used for predictions where topography is significantly different from conditions for which the model was developed. The soils could be characterised as having medium erodibility and *C* factor values for ginger were calculated to be 0.44 as compared to 0.36 for hill rice. These values are medium.

Based on the land use patterns in the two sub-watersheds Bolotikon and Tikolod and the turbidity measurements, it seems that the tendency in the Tikolod watershed to cultivate plots close to the river may be the reason why turbidity is higher as compared to the Bolotikon watershed. Future land use and in particular the length of the fallow period are crucial in terms of erosion and are related to land tenure. A shift towards more intensive agriculture and a shortening of the fallow period would require the adoption of conservation practices and/or the use of buffer zones to prevent loss in soil productivity and deterioration of water quality due to high sediment concentrations.

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