Preliminary assessment of flows and sediment load in the river system of the Sumberjaya, Lampung, Sumatra: Is land use change really the main culprit?

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Abstract: Land use change, and especially deforestation, is often blamed for the loss of watershed functions. Farmer-developed landscape mosaics with various degrees of tree cover are often perceived as not functional in providing these services. This perception is the root to often violent conflicts between guardians of (protection) forest ('hutan lindung') and farmers opening the land, e.g. for coffee gardens. ICRAF and partner institutions study land use, its change and the hydrological impacts in and around Sumberjaya watershed, West-Lampung, Sumatra, an area of about 730 km^2. The area was transformed in the past three decades from a large forest cover to a mosaic of forest and coffee on the ridges, coffee on the slopes and paddy rice in the valleys. Ambivalent government positions (attraction of migrants followed by eviction) has caused conflict with farmers over the past decades. Extrapolation of plot level research to the entire basin led to the conclusion that this was a 'critical' watershed. The (weak) knowledge base used for evaluating these landscape mosaics is now challenged. Turbidity and sediment concentration measurements in the Way Besai and its tributaries show large differences between catchments. Even under dense forest cover some pristine headwaters can turn quite turbid. It seems that land use per se is not the most determining factor, but other factors like geology, soils, roads and foot paths, ... play a significant role. In recent years an impressive amount of public money was spent on national reforestation campaigns, often intended to rehabilitate watershed functions, without specification of which functions are to be enhanced, where and how. Assessing key watershed functions in a more direct approach e.g. by monitoring the river discharge and its sediment load would allow a better diagnosis of the condition of catchments. As preliminary results differ significantly from a widely accepted belief, this could alter which catchments would need rehabilitation, and what might be appropriate measures. The above does not give 'carte blanche' for deforestation, but suggests that well established agroforestry gardens ('kebun lindung') can be an ecologically benign and economically more attractive alternative. Farmers also suffer from reduced watershed functions (paddy rice fields might be washed out in floods, lower dry season flows hampers the availability of household water). Rather than being traditional enemies in a top-down reforestation campaign, there is a potential to be partners in watershed assessment, river monitoring and eventual rehabilitation.

Keywords: Watershed functions; Land use; Multi scale assessment; Sediment load

1. Introduction

Water excess (floods), shortfalls (droughts) and quality, and the management of watershed functions are receiving increasing attention from society and policymakers. Large investments were made the last decennia in infrastructure for hydro-power, flood control or

irrigation. When some of these investments do not yield the expected results or fail, all too often deforestation by upland communities, is mentioned as the main culprit. Deforestation is held responsible for increased peak flows, reduced dry season flows, landslides, increased sediment load in the rivers leading to siltation of reservoirs and waterways.
The association of 'forest' and 'water' is strong in the public perception. A traditional prescription is the classification of large areas of land as 'protection forest' and as targets for reforestation if they are not currently forested. Upland communities are recommended to alter their land-use practices or to give up their land altogether, in the worst cases leading to evictions. This not only causes large economic losses and destroys farmer' livelihoods, it also generally fails to restore these watershed functions. In Indonesia alone, 70% of the land – and thus Indonesia's watersheds – is classified as State Forest Land, in total 143 million ha. Protection forest takes up 20 % of the forest area, despite the fact that much of the forest cover had already disappeared before its classification.

In articulating the policy context of watersheds we are faced with a paradox: Water management issues would have long been resolved and not be a topic of this forum, if it were a similar problem to all stakeholders. Existing institutions and policies are largely based on a forest - agricultural land use dichotomy and are 'blind' for the benefits of farmer developed so-called agroforestry landscape mosaics.
Key hypothesis in our current research is that some farmer-developed agroforestry mosaics (or 'Kebun Lindung') can be as effective in delivering watershed functions as the original forest cover. Hence conflicts between state forest managers and local population can be resolved to mutual benefit. The research approach chosen is based on a negotiation support system (NSS), a combination of *tools* for predicting impacts of land use change and a *process* of negotiation between stakeholders (van Noordwijk et al., 2002) (Verbist et al., 2002).

Watershed concerns are usually based on a combination of

A. on-site loss of land productivity
B. off-site concerns on water quantity
    B1. Annual water yield
    B2. peak (storm) flow
    B3. dry season base flow
C. off – site concerns on water quality (e.g. silting up of reservoirs, irrigation channels, ...)

Concerns B and C are mainly valued by lowland interest groups who will perceive changes when land use changes, especially in the case of deforestation, whereas aspect A is mainly an uplander issue (van Noordwijk et al., 1998). Many projects or programs intervening through e.g. "Regreening" or reforestation for soil conservation are often expected to both alleviate poverty in the uplands and take care of lowland interests. Many 'participatory' projects have been implemented around this win-win model.

Although there is indeed some truth in this soil conservation paradigm, the case has been oversimplified. An increasing body of literature indicates that the supposed link between lowland and upland concerns is not as clearcut (van Noordwijk et al., 1998; Bruijnzeel, 2004) and that conventional wisdom has often led decision-makers to implement misguided policies that adversely affect the livelihoods of millions of people living in upland areas (CIFOR; FAO, 2005)

Erosion plot experiments are traditionally used to test if certain land use types or practices do yield more erosion. The extrapolation of these results to entire catchments is however less straightforward: Dominant geomorphic processes which control sediment production and transport vary with their spatial scale. In mountain basins infrequent influxes of sediment from landslides, debris flows and bank erosion can dominate. Off-plot erosion of roads, tracks, footpaths, drains, ... are disproportionally sediment producing areas, when these cause high runoff function as point sediment sources, especially when there are some local outcroppings of highly erodible lithologies (Enters, 1998; Brown and Schneider, 1999; Ziegler et al., 2004). The spatial distribution of sediment sources and sinks makes that catchments with the same sediment production will have different sediment yields because of re-deposition of sediment within the catchment. This re-deposition is largely controlled by the spatial organisation of land use and the connectivity between sediment sources and the river network (Steegen et al., 2000).
It is therefore necessary to investigate processes at both the field scale and the catchment scale. The advantage of multi-scale studies is that the understanding of both local and regional processes can feed into management at different scales (farm level, district, national). The disadvantage is that the plot-level studies cannot be undertaken everywhere and it is notoriously difficult to aggregate results up to the basin scale (Brown and Schneider, 1999).

In the next paragraphs we look into past and ongoing work in Sumberjaya regarding off-site concerns on water quantity (discharge) and quality (sediment load).

2. Description of the study area

Sumberjaya, a large caldera of about 40.000 ha in West-Lampung, Sumatra has seen a lot of conflict and may represent possible future trajectories for many other watersheds in Southeast Asia. It is situated in one of the largest coffee-producing areas in Indonesia and has a large variety of coffee systems. A hydro-power dam was constructed in the late 1990s on the Way Besai, which winds almost 360° around Bukit Rigis (Fig.1 and 3). The population density is now 150 people per km^2. Spontaneous immigration of more Sundanese and Javanese increased in the late 1970s triggered by high coffee prices.

The rapid expansion of smallholder coffee gardens in the 1970s worried many forestry officials and was seen as the major cause of deforestation in the area, and thus as having a negative impact on watershed functions (reduced dry season flows and a high sediment load in the rivers). Finally in 1990 a forest land use map (or 'Tata Guna Hutan Kesepakatan' [TGHK]) was published. For Sumberjaya, the boundaries of the State Forest land were the same as those delineated by the Dutch in 1935, which had been practically abolished following independence (Verbist and Pasya, 2004). Many villagers, often veterans of the independence war who were settled there by the Sukarno government in the 1950s and had obtained legal land titles during the tenure of the government, found their land suddenly classified as State Forest land (Kusworo, 2000).
About 40% of the Sumberjaya area was then classified as 'protection forest' to preserve watershed functions (Fig. 1), although a Landsat MSS-image reveals that a large part of it was already deforested before 1973.

Between 1991 and 1996 thousands of people were evicted in an effort to enforce the 'protection forest' boundaries (Kusworo, 2000), resulting in often-violent confrontations between the local population and government officers.

A land use change study using multitemporal satellite imagery (Landsat MSS and TM) (Dinata, 2002) and available maps (Syam et al., 1997) revealed a steady decline in forest cover from 60% in 1970 to 12% in 2000 (Verbist et al., ***). The tenfold increase in the area of coffee, from 7% of the total land area in 1970 to 70% in 2000, is striking. In a first wave of forest conversion, coffee was mainly planted without shade trees ('sun coffee'). Since the mid-1980s, however, a 're-treeing phase' occurred whereby sun coffee was converted to simple shade coffee systems, in which *Erythrina* spp. and *Gliricidia sepium* were used as shade trees (Verbist et al.).

Soil conservation practices (terracing, dead-end furrows, use of soil cover, ...) have been taken up by many farmers in the last 6 years. The on-site loss of land productivity (case A above), made that techniques demonstrated on-farm by a soil conservation project and which were evaluated positively by farmers, spread relatively rapid (Agus et al., 2002).

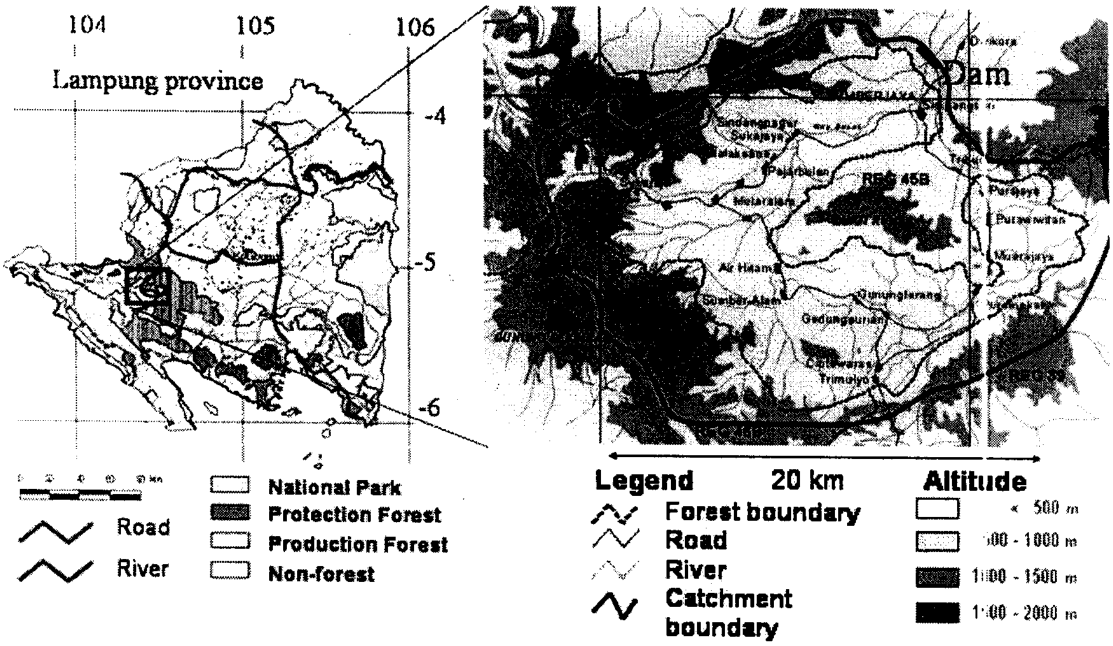

Fig.1 The forest land use plan of 1990 of Lampung province, Sumatra. The black rectangle corresponds with the Sumberjaya area, which contains the Way Besai watershed. Reg 46 B around Gunung Sekincau is National Park, while Register 39, 44 B, 45 B with Bukit Rigis are classified as protection forest

3. Concerns on water quantity: Analysis of rainfall and discharge

A statistical analysis of available rainfall and discharge data collected between 1975 and 1998 learnt that there was no significant in- or decreasing trend due to large year-to-year variations (Fig. 2). However the run-off ratio (yearly discharge divided by annual rainfall) did increase significantly, which we attributed to the lower evapotranspiration of the coffee

gardens compared to forest. The number of days per year that the dam can operate at its target discharge of 25 m^3/s has increased with 16 % from 1975 to 1998. The hydropower dam now has the potential to generate significantly more electricity than when it was designed (Verbist et al.). Perhaps farmers should get a reward, rather than a punishing eviction for this increase of watershed functions?
Most of the additional discharge became available as storm flow. Periods with low flow rates (< 10 m^3/s) were indeed more frequent in the nineties than in the preceding decades, but that coincided with 'El Niño' years with a prolonged dry season (1976, 1991, 1994 and 1997). Research is ongoing to explain how much of these low flows should be attributed to the effect of deforestation or to the dry 'El Niño' years in the 1990s.

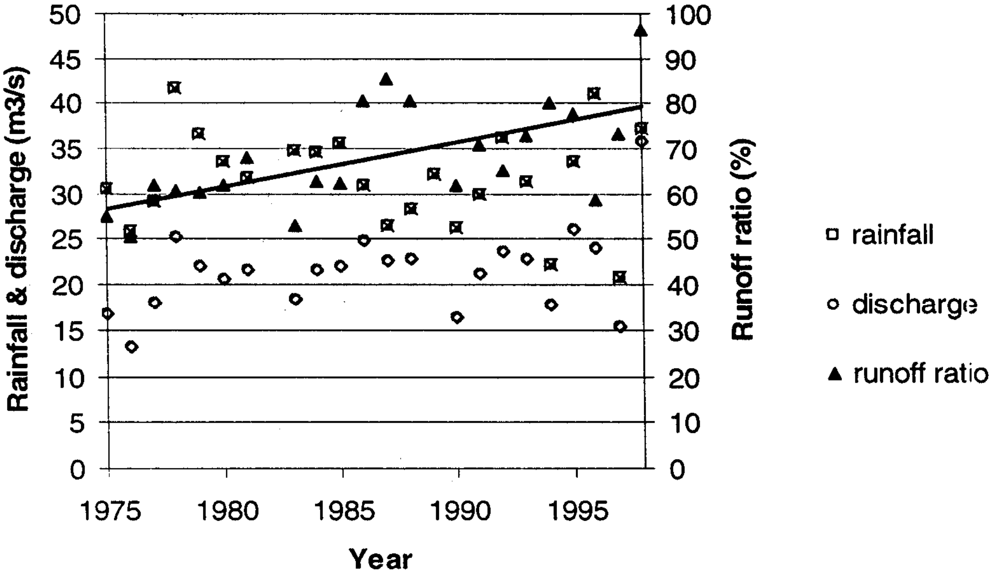

Fig. 2 Average yearly rainfall, runoff discharge and runoff ratio in the upper Way Besai watershed; source: (Verbist et al., xxx)

4. Concerns on water quality: Sediment transport

4.1. Plot level

Plot level research was carried out by research teams from Brawijaya University (UNIBRAW) and the Center for Soil and Agroclimatic Reseach (CSAR). Erosion was measured under various landuse types (forest, bare soil, coffee with different degrees of tree cover) on 80 plots in two locations between 2001 and 2005.
Nearby the area where the Forestry Department did erosion research in the '80^{ies} erosion rates between less than 1 Mg ha^{-1} $year^{-1}$ (forest), 37 Mg ha^{-1} $year^{-1}$ (sun coffee) and 70 Mg ha^{-1} $year^{-1}$ (bare soil after deforestation) were confirmed (Hairiah et al., 2005). Over time runoff and erosion tends to decrease, as the growing coffee provides more shade and litter. However, in the second site 6 km closer to the outflow, erosion ranged between 0.1 (forest) and 4 Mg ha^{-1} $year^{-1}$ (bare soil) under the same treatments. The conservation treatments in this area did not give any significant effects on runoff and soil loss (Dariah et al., 2005), but erosion under sun coffee would differ a factor 10 between sites! This difference was attributed to distinct differences in soil structure (presence of a clay illuviated horizon below 22 cm depth) and porosity (Dariah et al., 2005). This from an erosion perspective important information is not available on the soil maps, which were derived from an only limited amount of samples.

Erosion peaked in coffee gardens of up to 3 years old and then gradually declined as litter layers established soil cover (Agus et al., 2002). Under coffee of 12 years or older or under multistrata coffee, soil loss was lower than 5 Mg ha^{-1} year^{-1} in the first site (Hairiah et al., 2005). So, soil loss on farmer managed coffee systems decreases over time and approaches a similar order of magnitude as under forest.

4.2 Catchment level

High sediment load is notorious for having negative impacts on the filling up of lakes and irrigation channels. On the other hand it can also have beneficial effects e.g. for paddy rice farmers at the bottom of eroding slopes or valley bottoms, who receive free inputs of fertilizer and soil.

4.2.1 Selection of sampling points and subcatchments

Available data on sediment transport in the Way Besai and its tributaries are very limited. Previous monitoring to assess the potential for hydropower production and the feasibility of the construction of the Way Besai dam focused mainly on discharge (PT Indra Karya with Nippon Koei Co, 1990).
Objectives of this research were to gain insight in the spatial variability of suspended sediment between various subcatchments and to test low-cost monitoring techniques.

Twenty measuring points were identified in the Way Besai (Fig. 3) and also in the Way Ringkih subcatchment. At each point staff gauges were installed and the cross-profiles measured. Sampling points were chosen as much as possible on bridges to allow easier access. In the Way Besai catchment (35.000 ha) the measuring points covered the 11 largest subcatchments and 9 points along the main river.
In the Way Ringkih subcatchment (800 ha) sampling points were selected along the largest river branches. On two tributaries more points were selected higher-up in an attempt to isolate homogeneous land use types (forest, coffee, vegetables, paddy rice) and their contribution to the sediment load in the water.

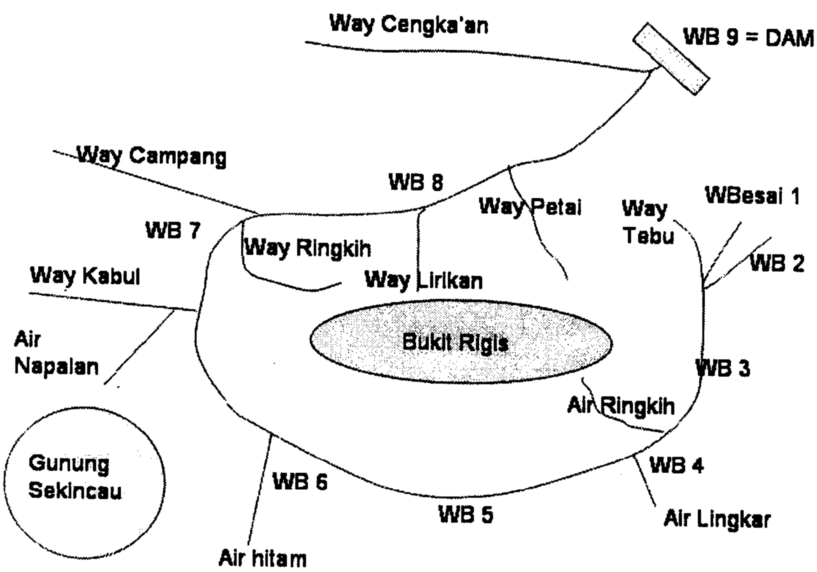

Fig. 3 Sketch of main rivers and the location of measuring spots in the Way Besai catchment

4.2.2 Measurements

Due to the high spatial variation of rainfall, the available three rain gauges were deemed insufficient and four automatic tipping bucket raingauges and fifteen manual raingauges were added in the Way Besai catchment. The manual gauges are checked on a daily basis by farmers, who received training and the necessary utensils (forms, measuring glass). An information and training day was held for representatives from local communities and the way Besai hydro power company PLTA-PLN to explain about the objectives and methods of the research and water samples collection campaign. Twenty people recorded water level and collected 0.5 to 1 liter water samples every 15 minutes between 12.00 and 18.00 during one week, when chances of rain and increased sediment load are higher than in the morning.. It was encouraged to take more samples outside this timespan of 12.00 – 18.00, especially when the water is turbid.

Per measuring point at least 25 samples were collected daily. They were arranged in chronological sequence and then a subset which characterized basic flow conditions was selected for analysis. In case of an event (with increased water level or turbidity) all samples were selected for analysis.

A small field lab was established where turbidity, conductivity and sediment concentration of the selected water samples was measured.

When possible, participants measured average river surface flow velocity at various waterlevels with floating objects. Multiplication with 0.8 gives an estimation of the average stream velocity (Wohl, 2000). More precise flow velocity measurements were carried out with a flow probe. From the cross profile and the various observations of waterlevel and flow velocity, the rating curve, which gives the relationship between waterlevel and discharge can be calculated.

Sediment load was then normalized using flow velocity. As the flow velocity-weighted suspended sediment concentrations are calculated from measurements taken during a limited time, it is important to assess to what extent these observations vary over time. Herefore, we opted for a regular assessment, whereby at each measuring point only one sample was collected within one day. This also allows to test a less intensive and thus cheaper method. In the Way Besai and Way Ringkih campaigns 4000 water samples were collected each time. So, results of this first campaign still need to be interpreted with caution, although this approach allows a comparison between subcatchments.

In the one week campaign at least one flood was sampled in every subcatchment.

The relationship between turbidity (expressed in Nephelic Turbidity Units or NTU) and sediment concentration (mg/l) can vary as it varies with soil particle size, but was found to be close to 1 for each subcatchment. This relationship was valid up to 1000 NTU, the maximum range of the turbidity sensors used (fig. 4).

Differences in turbidity, sediment concentration and maximal sediment load normalised for flow velocity vary up to one order of magnitude. For five catchments flow velocity measurements are still missing because of failure of the flow probe and local conditions made the use of floating objects cumbersome. For some other catchments flow velocity measurements do not yet cover the full range of water levels and a rating curve could not yet be derived.

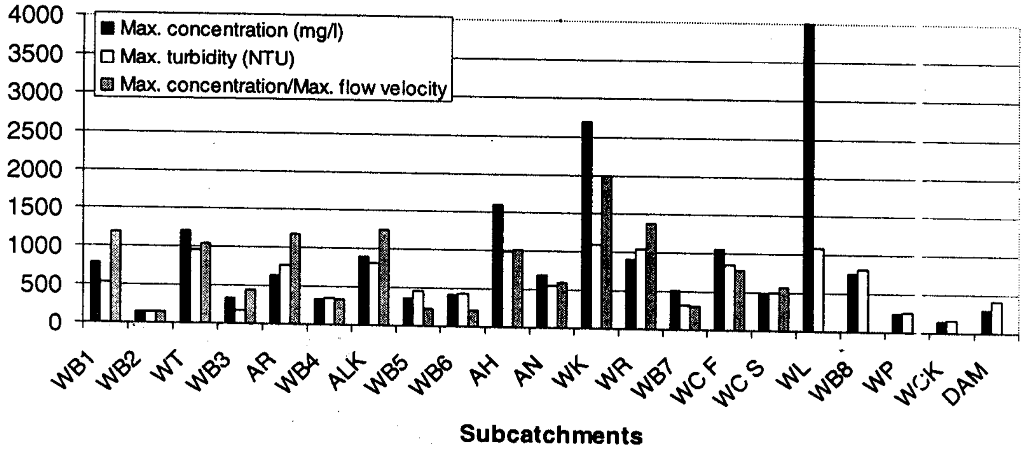

Fig. 4 Maximum turbidity, maximum concentration and the ratio maximum sediment concentration/ flow velocity for the various subcatchments of the Way Besai of the sediment measuring campaign 12-18 February 2005.

Except for its head watersheds (WB1 and WT) the Way Besai (WB2-WB8) has a much lower sediment concentration at comparable flow velocities than its tributaries, which suggests internal buffering. The Way Kabul (WK) has a relatively high sediment load for respective flow velocity.

The catchments with the upper reaches on Gunung Sekincau and Bukit Rigis seem more prone to high sediment loads than the other catchments. This suggests that the underlying geology and the soil that developed from it, plays a very important role. This would confirm the results from the above mentioned plot-level erosion research that land use is not the most dominant explaining variable.

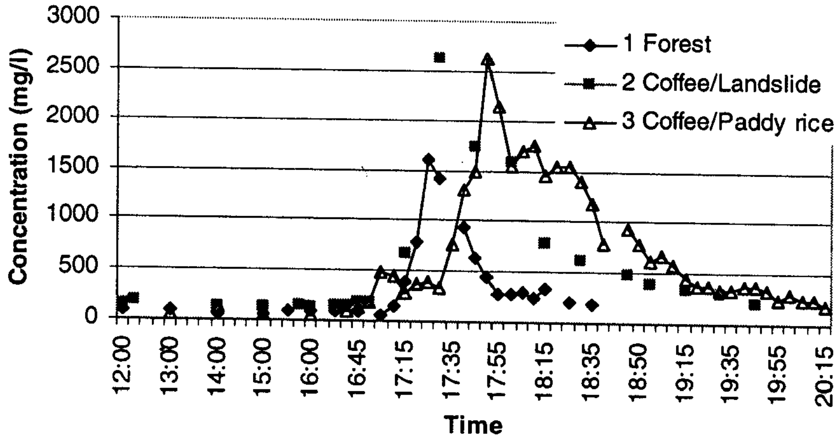

Fig.5 Sediment concentration measured at three measuring points on 14 March 2005 on the Way Ringkih river

Figure 5 illustrates that increased sediment load in the Way Ringkih river lasted longer and reached higher levels outside forest, when it passes through an area with coffee, a large land slide and paddy rice. Nevertheless, it is interesting to note that already within the 'pristine' natural forest the water turned more turbid than one might expect from the plot level research.

4.2.3 Spatial analysis subcatchments

A digital elevation model (DEM) was generated from the 1:50.000 scale topographical map. The vectorised contour lines with a 20 m interval were gridded and then interpolated at a resolution of 10 by 10 m. A more precise DEM was generated from 1:25.000 aerial photographs from 1993 covering about 70 % of the Way Besai catchment and the entire Way Ringkih catchment. Comparison between the DEM derived from the topographical map, the more detailed DEM derived from the aerial photographs and field observations learnt that a quarter of the subcatchments was erroneously delineated using the topographical map DEM. Differences in catchment area were more than 200 % for the smaller Way Besai sub-catchments.

Validation with higher resolution maps or field observations is thus vital. It is interesting to note that some years ago in a neighbouring watershed (Way Rarem) a similar overestimation based on the topographic map severely affected an irrigation project. The shortfall in water supply was consecutively blamed on deforestation activities by farmers (sic!).

5. Negotiation Process

In Indonesia the protection of watersheds is an important task of the Ministry of Forestry, which has dealt with the issue through the establishment of 'Protection Forest' (*Hutan Lindung).* Since regional autonomy in 1999 a few interesting policy experiments have started. One of them is the establishment of community forestry programs in 'Protection Forest'. Sumberjaya is one of the pilot areas. Hereby, farmer groups make a management plan, agree to protect existing forest and plant more (mainly forest) trees in their coffee gardens. After approval by the Forestry Department, farmers can get temporary land use rights for a period of 5 years. Upon positive evaluation after those first 5 years by the Forestry Department these farmer groups can get land use rights of 25 to 30 years. Until now, the discussion about criteria and indicators mainly focussed on the amount of trees per ha needed and the proportion of fruit tree vs. forest tree species. About 2000 ha of 'Protection Forest' is now under community management, but it remains to be seen how this promising example will further evolve, especially with regard to the used criteria and indicators and if it will gain more acceptance in forestry circles. It is interesting to note here, that as mentioned in the description of the study area, that a 're-treeing phase' already started in the mid eighties (Syam et al., 1997; Verbist et al., xxx) without government intervention.

In the light of the above mentioned research results, counting trees can be a (crude!) indicator to assess watershed functions at the plot level, but not at the catchment level. Recent research suggests that at the plot level 'presence of a litter layer' is more directly linked to changes in infiltration and erosion, than criteria based on trees per se (van Noordwijk et al., 2004). At the catchment level river discharge is being measured by the Ministry of Public Works, but there is no systematic collection of waterquality data.

In an effort to come to an integrated assessment of the catchment, a watershed forum (*Forum DAS)* was established two years ago. The forum has been successful in bringing various stakeholders (farmer groups, NGO's and government agencies) around the negotiation table and to meet at regular intervals. It became clear that a lot of the existing legislation is confusing and contradicting. A law or decree was generally passed with only one sector or agency in mind and without much attention if it would conflict with already existing legislation. The need for integrated catchment management was expressed by the forum, but it hasn't been translated yet into policy action. Current legal and institutional unclarities and inconsistencies provide little incentive for stronger agencies to give up their privileged position for a new catchment-based organisation or for more interagency collaboration.

6. Implications for management and research

1. The underlying basis of many policies regarding water and watershed management cannot be substantiated by science and is often little more than myth or is patently incorrect. Policies should be based on facts, not fiction:

2. In volcanic areas the heterogeneity of soils, geology, ... seems to have a more important effect on sediment transport than land use per se. Available spatial datasets (e.g. 1/50.000 topographic maps, soil maps, ...) generally do not capture that variability and are too crude to make a proper diagnosis if a watershed is 'critical' or not. Their use needs to be verified by field data or other higher resolution data.

3. Relatively small landscape elements like roads, footpaths, ... can be true point sources of sediment, but are generally missed out in current policies and traditional (plot level) assessment methods. It is necessary to examine a range of sediment sources and measurement techniques at different scales (not just plots) to determine the responsibility for sediment load in the river, i.e. whether it is farmers' or others' responsibility. The assumption that it is the cultivated land that is the largest sediment source is just that ... an assumption. More diagnostic efforts are needed at this scale level!

4. Land use at the plot level is receiving the main focus of diagnosis and rehabilitation efforts. Plot level research showed that under favourable conditions it didn't matter, if soil conservation was implemented or not. Under less favourable conditions, it remains desirable to keep the soils covered. The existence and condition of a litter layer can e.g. be a good and simple criterium of plot health from a soil conservation perspective. Soil conservation practices can be taken up rather quickly, if there is a clear benefit for the one who does the conservation. This would be more effective and cost only a fraction of the current government led reforestation efforts. Extension to farmers on diagnosis and design of soil conservation can play a favourable role.

5. A more comprehensive monitoring would reduce the errors associated when only few samples are taken. A less expensive and practical, albeit partial alternative for the drive for more comprehensive monitoring (how desirable that is!) is the identification of the main runoff and sediment generating processes in the catchment and then focus the management to minimise their effects.

6. A shift in paradigm is needed whereby the perceived need of forest cover is replaced by the use of established cause-effect relationships and measurable criteria and indicators (e.g. water yield, buffering of peak events, secure low flows, water quality) to

evaluate watershed functions delivered by a certain watershed. This would be a major step forward in resolving conflicts and focus on realistic targets

7. Conclusion

Overall, our conclusion is a hopeful one: Refocusing the 'watershed management' debate on measurable functions rather than perceptions of an intrinsic need for 'forest cover' can help resolve current conflict. Agroforestry systems or 'kebun lindung' can deliver many of the desired watershed functions, while at the same time preserve the livelihoods of upland farmers. The public debate on this issue needs to be stimulated to gain a broader platform for 'resultbased natural resource management', to replace the current focus on unrealistic targets.

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