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Understanding Himalayan Processes: Shedding Light on the Dilemma

Hans Schreier and Susanne Wymann von Dach

A Personal Introduction

Mountain hazards and their impact on the lowlands have been a subject that preoccupied Bruno Messerli for much of his scientific career. His many contributions to the national and international literature on climate change, mountain hazards and highland-lowland interactions are well recognized. One of the most fascinating things about Bruno is his international perspective of mountains and his early vision of multidisciplinary research on mountain environment and its impact on lowlands.

With his charisma, knowledge, breadth of experience, adventurous spirit and diplomatic nature he educated many students and politicians and brought about an awareness of mountain environments that culminated in making the 'Mountain Agenda' an issue that is now globally recognized. Probably the best testimony to his talent and his distinguished career lays in the fact that his last two studies include palaeoclimatic research in the highest and driest mountain desert in the world – the Atacama desert – and the flooding problems in one of the wettest and most extensive lowlands in the world: Bangladesh. Both studies address key issues of global proportions and consequences. We have been privileged to share many of these fascinating experiences with Bruno in the Pamir, Caucasus, Andes, Alps, Atlas and Himalayas and it is in the latter where we tried to unravel the mystery of the Himalayan Dilemma.

One of the Many Himalayan Dilemmas

In 1992, after 13 years during which Bruno Messerli had already conducted and supported many research projects in the mountains of Nepal we finally succeeded to start a joint research initiative to examine scale factors in water and sediment transport between the High Mountains in Nepal and the Ganges Lowlands. A most interesting excursion took us to near the Tibetan border in the remote valley of Chilime Khola (Fig. 1). The objective was to study the human impact on water and sediment dynamics in the High Mountains and link the processes and their effects through the Middle Mountains into the Lowlands. In search of tracing Chilime Khola sediments Bruno Messerli somehow found a very fast pathway down the Himalayas, and within one year he and Thomas Hofer had a foothold in the Ganges delta. Did he become impatient to follow the very slow movement of the sediments through the mountains or did he think the bottom up approach will succeed much faster than the top down one?

Our team followed a similar but more tortuous pathway down the High Mountains, and after 30 km down the Trisuli we got stuck in the Jhikhu Khola watershed,

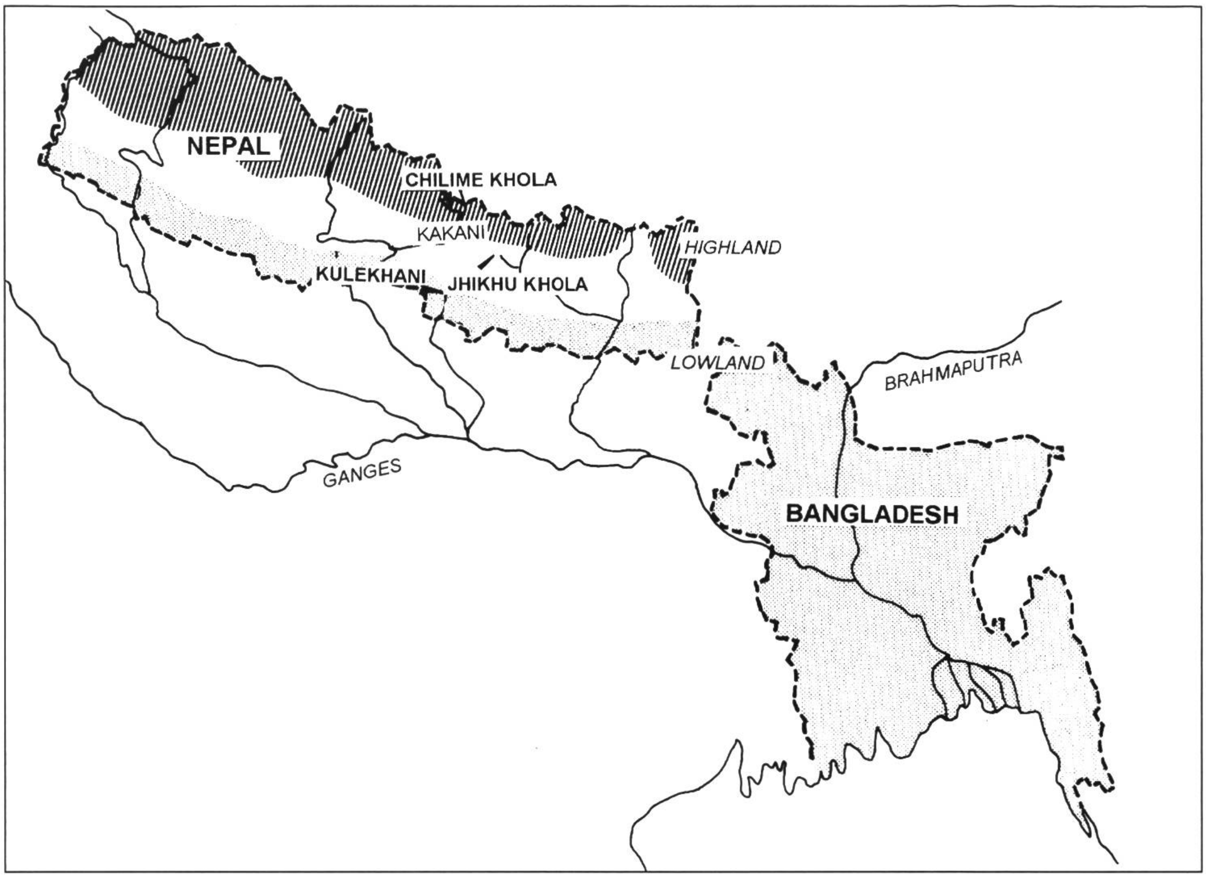

Fig. 1: Overview of Bruno Messerli's study areas, from the Highlands to the Lowlands

a small Middle Mountain tributary of the Sun Kosi, where we were so bewildered by the sediment dynamics that we examined them in detail.

We spent years digging soil pits, constructed sediment traps and collected thousands of samples trying to understand how sediments affected by human land use move through a small watershed in the Middle Mountains. After five years we do not have answers but we have a few clues that might shed some light on the Himalayan Dilemma of human impact on large-scale effects and we share some of these clues with you today.

One of the controversial questions that was put to rest in IVES' and MESSERLI's 1989 book on the Himalayan Dilemma is that human impact on forests and agricultural land in the mountains has no visible impact on the flow of water and sediments deposited in Bangladesh. The question of how long it takes for water and sediments to travel down the 300–500 km pathway from the mountains into the Ganges delta, however, remains unanswered. We think it takes thousands of years for sediments to reach the final destination in the delta, and the cycle of deposition, suspension and redeposition of sediments is tortuous and enormously complex.

While we await proof and evidence for this from future research by other scientists, we reduced the complexity of the question and examined human impact on the water and sediment regime in a 11,000 ha Middle.Mountain watershed. Of particular interest was to determine the water and sediment dynamics at different scales within the watershed. What are the pathways of water and sediments from the headwaters of the watershed down to the outlet into the Sun Kosi, and how rapidly are they moving through the system? How are the farmers affecting these pathways, and how do we show the effect of scale as we move down the stream channel?

Tracing Sediments in Erosion Plots and Catchment Areas

We started with a farmer's field (a two terrace system) of 70 m^2 in size and delineated the terraces by building an erosion plot where all run-off water and sediments were collected after storms. The monitoring continued over three monsoon seasons during which more than 100 events were recorded. The field is a typical dryland terrace system (bari) under double annual crop rotation. Further down a first stream monitoring station was established that drains a mini-watershed of 70 ha, while a second stream station was built some 4 km below draining a 520 ha subwatershed, and a third station was set up at the mouth of the Jhikhu Khola watershed draining the 11,000 ha catchment area.

All four stations were equipped with an automated pressure transducer, and flow and sediment sampling was carried out at frequent storm intervals by three teams of two people each that were permanently present at the sampling sites throughout the monsoon seasons. The four monitoring stations are interconnected and the fields are contained within the mini-watershed, the mini-watershed within the sub-watershed and the sub-watershed within the watershed. The sediment quantity and the phosphorus content within the sediments were measured for as many storms as was possible. Also, a network of fifty 24-hour-raingauges and four automated tipping bucket gauges were used to characterize the rainfall input.

Farmers Redistribute Sediments

With this setting we thought it would be easy to determine storm events and trace their effects in the downstream direction. This would enable us to define the dynamics of each system and to illustrate the scale effects as we move down from the field to the bottom of the watershed. Some of the early results have been published by CARVER and SCHREIER (1995), and the results gave a fascinating insight into the complexity of scale over very short distances.

At all stations it became evident that the movement of water and sediments is extremely variable. The watershed is dominated by a distinct monsoonal rainfall pattern where 70% of all precipitation occurs between June and September. This is followed by an extended dry period from October to April, followed by a few intensive pre-monsoon storms. It is well known that in mountain areas the rainfall distribution is highly variable, but it appears that there is relatively little difference in intensity between pre-monsoon and monsoon storms, whereas the spatial variability in the amount of rainfall within the overall watershed is very large.

The episodic nature of rainfall and its effect on water and sediment dynamic was clearly evident in all evaluations. How do these storms translate into run-off and sediment dynamics?

At all stations the sediment rating curve showed a very distinct difference between the pre-monsoon and the monsoon storms (Fig. 2). Since there is little difference in the storm intensities and amounts of rainfall we can clearly attribute the differences to surface conditions, as supposed by CARSON (1985). The pre-monsoon storms occur at the end of a prolonged dry season when the agricultural land is barren and ready to be tilled and planted. The soils are unprotected and hydrophobic, generating more run-off and sediment losses in the uplands. Therefore it is not surprising that 60–80% of the annual sediment losses in the erosion plot occur in two storms, usually during pre-monsoon events (CARVER and NAKARMI, 1995).

How do the sediment dynamics change downstream with the increasing scale of surface area contribution? To show this, CARVER and SCHREIER (1995) calculated the budget of sediments and the phosphorus content in sediments for three storm events: A typical pre-monsoon event, a monsoon event and an extreme storm – with a return period of less than 10 years – in the transition period of pre-monsoon to monsoon. The results provided in Table 1 show the sediment and phosphorus budgets calculated for the different receiving areas as we move over the four different spatial scales (plot, mini-, sub-, and whole watershed).

The local effect at the plot level is evident and the pre-monsoon storm is very effective in moving massive amounts of sediments and phosphorus while the monsoon storm produces a very small amount of sediments. In fact, the pre-monsoon storm mobilized an even larger amount than the extreme event with almost twice the rainfall. The downstream effects are also very distinct. Little changes occurred

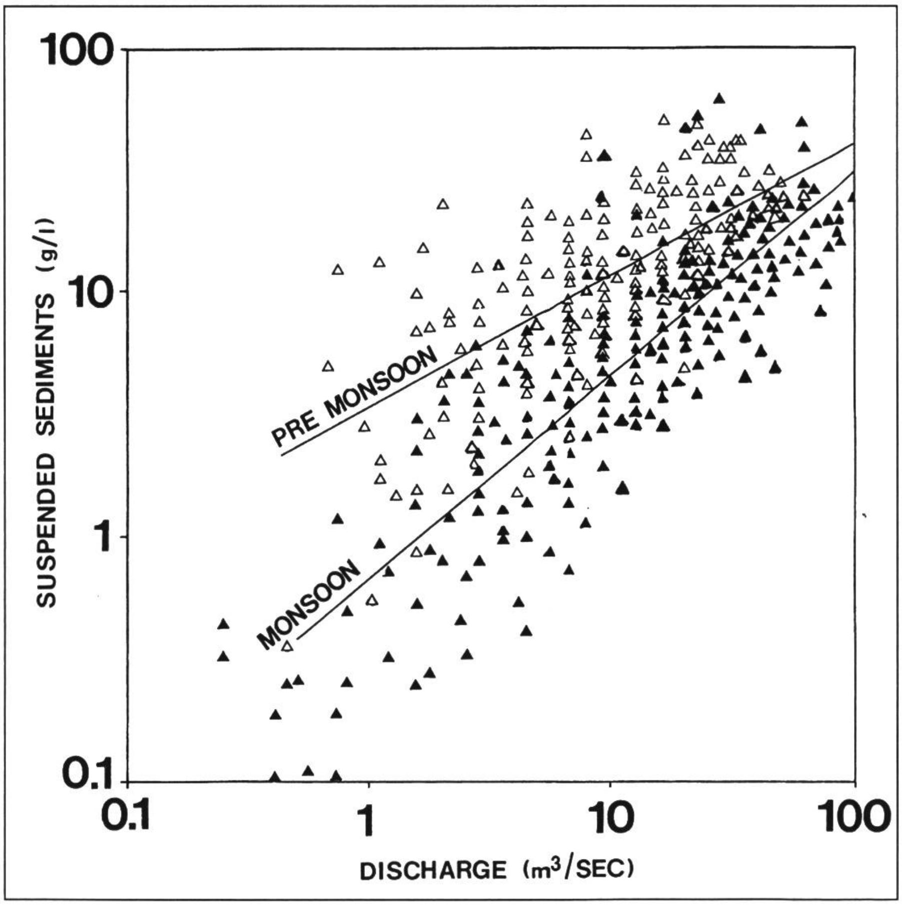

Fig. 2: Differences in discharge-sediment-relationship between the pre-monsoon and the monsoon period.

in the sediment production and phosphorus losses during the monsoon at all scales, but a marked decrease occurred in the downstream direction during the pre-monsoon, and a distinct increase occurred during the extreme event in July. However, no such effect could be discerned at the watershed scale.

Table 1: Sediment and phosphorus budgets across four different catchment scales. (Based on Carver and Schreier, 1995)

	Sediment Budget/Storm Event (t/ha)			Phosphorus Budget/Storm Event (g/ha)		
Storm Rainfall	50 mm	36 mm	90 mm	50 mm	36 mm	90 mm
Time of Storm	Pre-Monsoon	Monsoon	Transition	Pre-Monsoon	Monsoon	Transition
Terrace Plot (70 m^2)	20	0.02	10	300	0.1	10
Mini-watershed (72 ha)	5	0.8	7	200	20	200
Sub-watershed (540 ha)	2	0.4	40	40	4	1000
Watershed (11,000 ha)	0.1	0.1	2	1	0.8	60

The explanation for the different responses of the systems is complex and only by looking at the human intervention an answer can be found. We discovered that one reason why the pre-monsoon storm behaves differently across the four spatial scales from the extreme event in July is that local farmers have built 72 small indigenous checkdams between the erosion plot and the sub-basin station. During the pre-monsoon period as much water and sediment as possible are effectively diverted into the adjacent khet land (irrigated fields). Whereas, during the monsoon season the water is no longer needed and the vegetation cover has stabilized the soil surface. In the extreme event more than 75% of all the checkdams were destroyed, and hence there were significantly less opportunities to retain sediments. Since all these storms were of local extent there was no response in sediment and phosphorus load at the watershed scale.

The implications of this are that expanding agriculture into marginal sloping environments leads to large local losses at the terrace scale, but does not translate into large losses of soils out of the watershed system. The checkdams make sure that material is deposited into lower fields making the sediment pathway extremely tortuous. Most of the soil lost at the plot level will be redistributed many times before it will reach the mini- or sub-watershed or even the bottom of the watershed. Only after extreme events we get large losses, but even in these cases the losses are only substantial in the sub-watershed and not in the watershed.

This means that human intervention plays a significant role in sediment dynamics at the local scale by redistributing the losses created by cultivation of steep slopes. This fact should also be reflected in the soil quality of the irrigated fields in the valley bottoms. WYMANN (1991) already showed that the lower the rice paddies are located, the higher is the nutrient content of the soils.

To illustrate further the enrichment of the soil by diverting the sediments we examined a number of rice paddies at the end of the monsoon season and analyz-

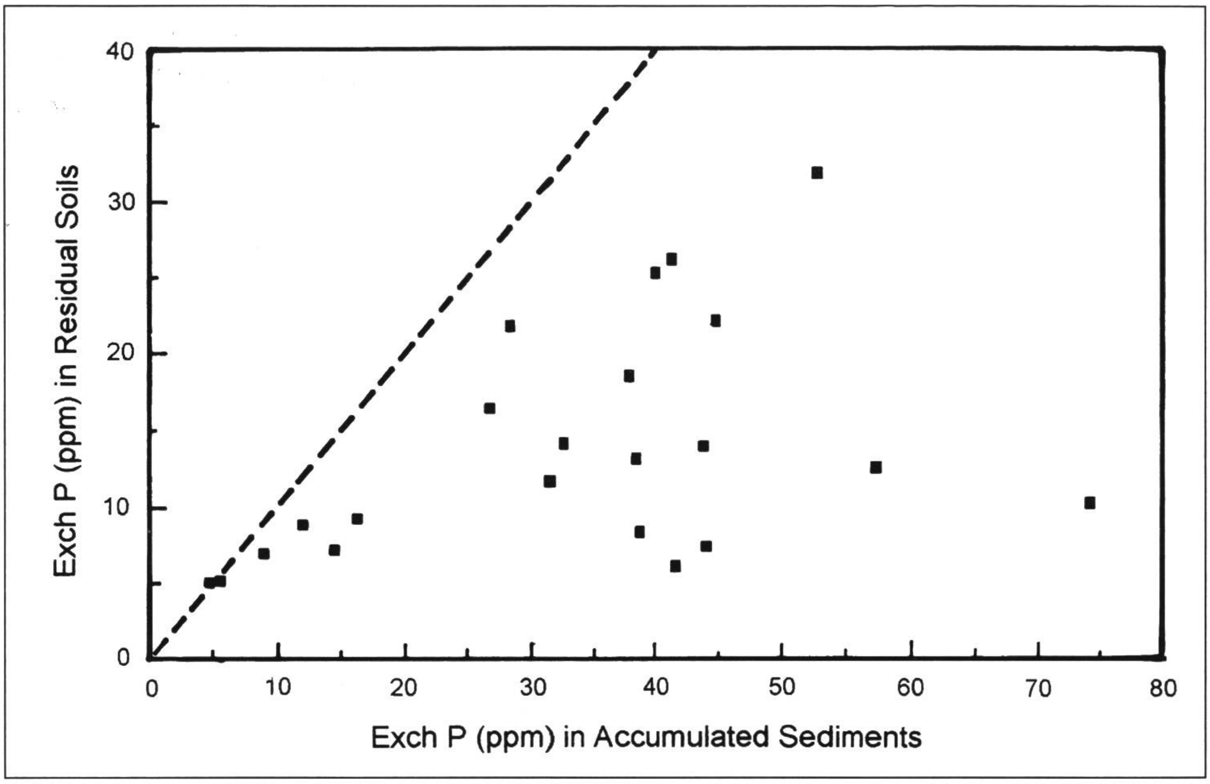

Fig. 3: Enrichment of available phosphorus in irrigated fields.

ed the nutrient content in the layer accumulated during the season. These samples were then compared with the buried soil materials which form the growing media for rice. We noticed that there is a distinct enrichment in nutrients in the sediments, since all of the samples fell below the 45 degree line of equal concentration (Fig. 3). This indicates that the upland farmers with rainfed agricultural land (*bari*) are losing nutrients and soils, while farmers who are able to irrigate their fields below the bari land enrich their soils in the redistributing process.

The lesson learned is that we were unable to trace the sediments from the headwaters to the bottom of the watershed because the farmers are effective in retaining and redistributing sediments within their elaborate indigenous system. Only in extreme events we get some response that is measureable at the sub-watershed scale. Therefore, the expansion of agriculture into marginal land has little effect on watershed scale processes. This provides further evidence to diffuse the myth of human impact at the Himalayan scale.

The Human Impact Fades Away

Now we wonder more than ever why Bruno Messerli has chosen to work in the lowlands of Bangladesh, as even at the micro-watershed scale the farmer's influence disappears.

This made us think in another Himalayan dimension: A very extreme event at the Himalayan macro-watershed scale. So, in 1995, we ventured into the Kulekhani watershed some 30 km south of the Jhikhu Khola watershed. This watershed is dammed by a large hydropower barrage that represents 45% of the hydropower capacity of the country. This reservoir is one of the biggest sediment traps in the Nepalese Himalaya. From July 19 to July 21, 1993, a most unusual rainfall event occurred with rainfall intensities up to 70mm/hr and a 24 hour total of 540 mm (GALAY et al., 1995). What happens to watersheds during such events? How do the sediments behave under such conditions, and how are the human land use activities affecting the movement of water and sediments?

We relied on the extensive previous work by STHAPIT (1994) and GALAY et al. (1995) to get sediment data before and after the event. The dam was completed in the early 1980's, and the bottom of the reservoir was surveyed at that time and on several occasions in the early 1990's, prior to the 1993 event. The survey was continued in 1993 after the storm, and again in 1994. Table 2 provides a summary of these evaluations and indicates that the dam design based on an estimated average annual sediment input of 11.2 t of sediments/ha of the watershed. From 1984 to 1993, the annual rate of sediment accumulation was calculated to average somewhere between 20 and 45 t/year (STHAPIT, 1995 and GALAY et al., 1995). The extreme event produced a staggering rate of 410–500 t of sediment/ha, a result of massive failures resulting in hundreds of landslides. The resevoir was estimated to last for 60–70 years, but the 1993 event reduced it to the order of one decade.

Table 2: Historic sediment production in the Kulekhani watershed.

	Sediment Production for the entire Kulekhani Watershed (in t/ha/year)	
Authors	GALAY et al. (1995)	STHAPIT (1995), and Research & Soil Conservation Section (1994)
Pre 1993 rate	20	45
1993 storm	500	410
1994 post storm		85
Mean over 13 years	53	
Engineering design	11.2	11.2

DHITAL et al. (1993) estimated that during this single storm about 47 landslides occurred per km^2 and that more slides occurred on grasland and forested slopes than on man made terraces under agriculture. A large percentage of the forests grows on intensively weathered rocks (slate, quartzite, phyllites and marble), and it appears that such an environment is more fragile and sensitive to failure than the human controlled terrace systems.

The large areas of the landslides are now unprotected, and, together with all the sediment in the transitional storage within the watershed, we have a long term legacy where future rates of sediment transport will be much higher than during the prestorm period. STHAPIT estimated the annual rate for 1994 to be 85 t/ha, which is twice the pre-storm event average.

We do not know how long it will last until the watershed returns to a somewhat steady-state condition. But comparing this event with the one in the Lele Khola watershed in 1981, when a prolonged rainfall produced a similar scarred landscape with hundreds of landslides (CARSON, 1985), we assume that stabilization processes can be rapid. During our 1988 Kathmandu Conference a fieldtrip took Bruno Messerli and us to the Lele Khola. We had great difficulties to find the 1981 landslide scars. Many former landslide areas were again under terrace farming, and most slopes had a good vegetation cover. This suggests that the stabilization takes only 5–7 years and is enhanced by human activities.

These extreme events have devastating effects orders of magnitude larger than any of the storms we measured in the Jhikhu Khola. But once again they are only of limited spatial extent. The major precipitation event in 1993 was very local, and we were unable to measure any simultaneous increase in rainfall in the Jhikhu Khola watershed some 30 km from the Kulekhani basin. We do not as yet know what is the return period of this amount of rainfall, but it has been speculated that it was an event with a return period of less than 100 years. Old farmers confirmed to us that a similar event occurred during their childhood, and historic depositional features, similiar to the 1993 boulder fields, were clearly evident in the lowlands.

Nature and Complexity

Bruno Messerli suggested a long time ago that different processes are dominant moving from a micro-scale (50 km^2) to the meso-scale (50–20,000 km^2) and to the macro-scale (>20,000 km^2) watershed and that it will be unlikely to discern human impacts at the macro- and meso-scale. We would suggest that in the context of the Himalayas it is difficult to discern the human impact even at the micro-scale. In the 11,000 ha Jhikhu Khola watershed storm events produced different responses depending on the natural setting and rainfall distribution pattern, and only at the plot and mini-watershed level we were able to show changes that could directly be attributed to human activities.

In case of agriculture some of these human-induced processes even encourage the redistribution of material lost from cultivated steeply sloping land to lower terraces and irrigated fields. For most of the small and intermediate storms the sediments remain within the system, and only during very large stroms material is directly lost for the mini-watershed. Only during the type of storm recently experienced in the Kulekhani we expect to see watershed-scale effects. During such events it remains difficult to identify the human factors contributing to such sediment dynamics.

It appears that at the macro- or meso-scale watershed nature dominantly governs sediment transport. As we moved from a first order stream system in the Middle Mountains to the complexity of the Himalayan foothills we were overwhelmed by the scale of processes, and the question of human impact simply fades away by the sheer magnitude of the natural processes.

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