How do Indigenous Management Techniques Affect Soil and Water Movement?

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1. INTRODUCTION

Increasingly, there are concerns about the future viability of the farming system in the Middle Mountains of Nepal. Declining agricultural productivity and increased downstream sedimentation are frequently cited (Ives, 1989) as major concerns for the future. However, at the same time, there is a growing awareness of the effectiveness of indigenous farming practices throughout the world (Hudson, 1992; Wilken, 1987) and also of those specifically from this region (Gill, 1991; Tamang, 1993). Indigenous knowledge is becoming better recognised as both valuable and effective.

These two ideas are in conflict. How can indigenous knowledge be both adaptive, forward looking and innovative (Gill, 1991) while also be the cause of agricultural degradation (Eckholm, 1975)? How can these two views be reconciled? The missing link is a quantitative evaluation of the indigenous methods, especially in terms of soil erosion and soil fertility. Most evaluations to date have been qualitative (e.g. Muller-Boker, 1991); quantitative evaluations are very difficult to carry out especially in terms of soil erosion because there have been few or no data collected.

In terms of soil fertility, it is clear that soil fertility is on the decline. The farmers are "up against the wall" and are doing what they can with limited nutrients (Schreier et al., 1994). It is, however, far less obvious how effective they are in managing or "controlling" the soil's physical, chemical, and biological aspects relating to their farming environment. The focus of this paper is on the soil's physical aspects.

The goal of this paper is to evaluate the effectiveness of the local farmers at mitigating losses related to soil erosion by using the results from a three-year hydrometric study. First, the indigenous physical soil conservation techniques are described and classified. Second, selected techniques are evaluated using standard hydrological analyses. Conclusions and management recommendations are based on the results of these evaluations.

2. OVERVIEW OF INDIGENOUS SOIL-CONSERVATION TECHNIQUES

Western soil conservation has traditionally focused on preventing erosion from the field. Consequently, interest in indigenous methods has been oriented toward this aspect of soil erosion. However, Middle Mountain farmers use on-field methods as only a part of their overall strategy to keep soil losses at a manageable level. They use many methods to recapture eroded material once it has left the field. This differentiation between on-field and off-field methods forms the basis for the following classification of indigenous techniques.

On-field methods largely attempt to prevent upland erosion. Primary approaches include terracing, run-off ditches, intercropping, and fertility maintenance. Terracing is a successful and well-studied approach to cultivation on steep slopes (Carson, 1992). Farmers modify terrace characteristics to accommodate local slope and climate demands. Run-off ditches, like the one shown in Figure 1, are found throughout the terraced landscape. They serve to rapidly remove run-off from the steep fields, thus preventing terrace and hillside failure on the terraces. Intercropping both serves productivity needs and conveniently serves to enhance the vegetative cover of the field, decreasing the erosive action of intense rainfalls. Finally, farmers practise a wide range of fertility management activities such as composting and mulching which invariably serve to increase the organic matter content of the soil thereby increasing aggregate stability and decreasing soil erodibility.

Figure 1. Typical run-off ditch within the terraced landscape.

Off-field methods focus on the management of run-off, the sediment that is carried with it, and the frequent accumulation of this sediment during its passage out of the basin. These techniques include run-off canals, the entire irrigation system (dams and canals), streambank protection, and silt traps. Run-off canals are a necessary extension to the system of run-off ditches in the terraced slopes. These permanent, vegetated canals take swollen upland streams of run-off to the natural drainage network. The irrigation system captures stream flow, directing it into canals and ultimately into irrigated khet fields where previously-eroded soil is deposited and often held indefinitely. A typical irrigation dam is illustrated in Figure 2. Where land is threatened, farmers protect streambanks by using bamboo, stone walls, and occasionally gabions. Finally, silt traps are found in the wider valley bottoms and enhance the deposition of suspended sediments so that they can then be purposefully reincorporated into a productive field.

3. SELECTION OF TECHNIQUES FOR EVALUATION

Ideally, evaluation would involve first gaining a comprehensive, quantitative knowledge of sediment flows throughout the basin. With this understanding, management efforts would be judged on the basis of how effectively they are shaping these sediment flows. Unfortunately, it is essentially impossible to pursue this sort of an evaluation because it is extremely difficult to adequately describe the sediment budget in a way that can cope with its spatial and temporal variability.

Instead, specific aspects of the erosion and sediment transport system are examined and the efficacy of the chosen management efforts are evaluated in this context. Using basic understanding of how sediment and water moves through steep basins, we can reach conclusions about the effectiveness of specific indigenous management techniques. One on-field and one off-field management method have been chosen for evaluation. In addition, the erosion status of a sub-watershed managed using indigenous approaches is compared to that of another sub-watershed with extensive surface degradation and land no longer in farming use and, therefore, not maintained using the conventional Middle Mountain farming techniques.

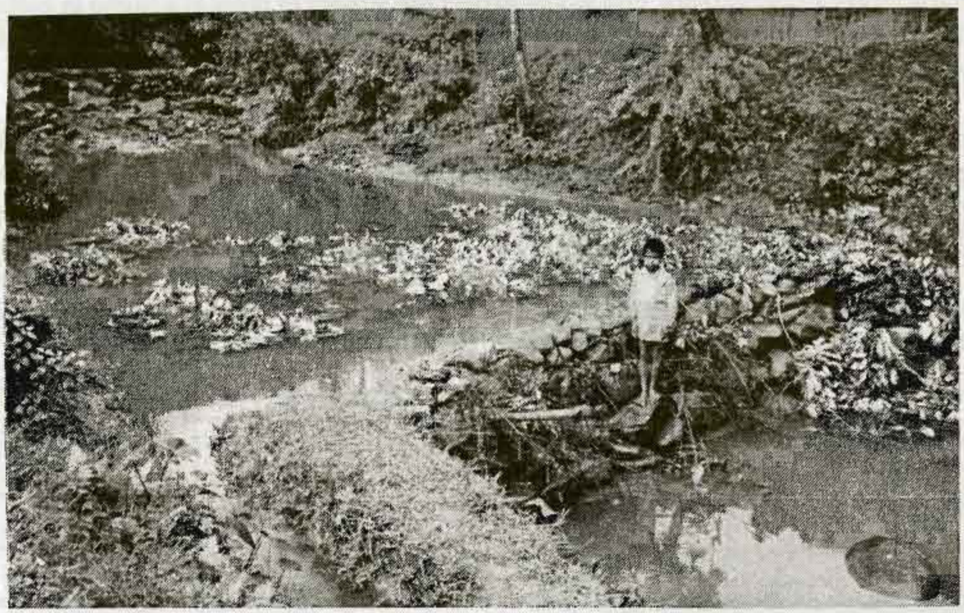

Figure 2. Diversion dam in the lower reaches of the Andheri Khola.

4. EVALUATION

4.1. On-Field: Vegetative Surface Cover

Elsewhere in this volume, Carver and Nakarmi (1995) present an analysis of the effect of crop development on the rate of surface erosion from cultivated fields. This analysis suggests that despite the presence of high-intensity rainfall events, the crop with its attendant root system, the intercrop and the weed cover form an extremely effective surface mat which restricts erosion during the monsoon season. Losses can be huge if the timing of heavy rainfall comes in advance of the development of an adequate surface vegetative cover.

This result is contrary to comments which say that "deforestation" of lands for cultivation results in high sedimentation rates downstream. A more reasonable assessment is that rates of surface erosion are, in fact, under control during most of the farming season and that elevated stream sediment concentrations from surface erosion occur during a period of vulnerability when indigenous techniques are inherently less effective at restricting soil loss at its source.

4.2. Off-Field: Irrigation System

The irrigation system serves as a sediment trap by diverting flow and halting the movement of eroded material out of watersheds. But how effective is this process? To what extent are the farmers able to recapture soil and nutrients lost from their upland agricultural fields and entrained in the drainage system? To answer these questions, two analyses are presented. The first focuses on the diversion of water while the second looks specifically at the extent of sediment accumulation in the irrigated fields.

As it progresses downstream, run-off is concentrated and thus streams generally increase in size. If rainfall is uniform over the basin and if there are no significant losses to the subsurface and no dramatic changes in the surface characteristics downstream, one would expect the stream to grow in volume in proportion to the ratio of the basin areas which contribute to their outflows. This principle is used here to evaluate the extent of diversion of floodwater by irrigation dams.

Figure 3 shows the Andheri and Kukhuri Rivers, the locations of the 62 diversion dams within this basin and the locations of two automated hydrometric stations. Table 1 summarizes pertinent information about each of these hydrometric stations. The ratio of the contributing areas of the two stations is 7.5:1. Assuming losses to the subsurface to be negligible and that surface run-off characteristics remain similar downstream, then we expect to see 7.5 times more flow at the Andheri station from rainfall events which provide even coverage over the entire basin. Further, if the lowland flow is half the "expected" value, then the flow ratio would be 3.75. If the total flow in the upland and lowland stations are equal, then the flow ratio is unity.

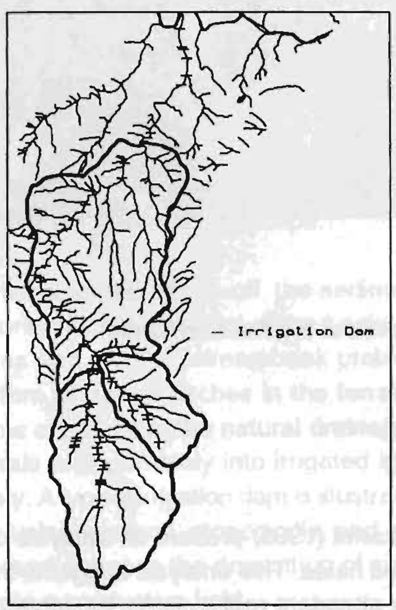

Figure 3. Location of all irrigation diversion dams on Kukhuri/Andheri drainage.

During the period of monitoring, 16 events were monitored simultaneously at both stations by the automated equipment and are available for comparison. For each of the flood events, the total flow through the two stations has been calculated and its season noted. The pre-monsoon season is the initial part of the rainy season when rainfall is infrequent but can be heavy. During the monsoon season, rainfall is frequent and surface soils are often saturated. (The transition season is a period in between the pre-monsoon and monsoon seasons which has sediment-regime characteristics in common with both seasons.)

Table 1. Contributing areas and number of irrigation dams for Kukhuri and Andheri hydrometric stations.

	Kukhuri Basin	Andheri Basin	Ratio
Total Contributing Area (ha)	72	540	1:7.5
Irrigated area (ha)	6	36	1:6.0
Number of dams	14	62	1:4.4

Table 2 presents the results seasonally in terms of the ratio of the flows of the lowland to upland stations. In all but two cases, the ratios are far less than would be expected under unmanipulated hydrological conditions. In fact, 31% experience **less** flow at the lowland station than at the upland station.

Table 2. Flow-ratio comparison for Kukhuri and Andheri hydrometric stations.

Outflow Ratio Class (Andheri/Kukhuri)	Number During Pre-Monsoon and Transition Seasons	Number During Monsoon Season	Total Number During All Seasons	Percentage of Total
0 - 1.0	2	3	5	31
1.0 - 3.75	3	5	8	50
3.75 - 7.5	1	0	1	6
> 7.5	1	1	2	13
Total	7	9	16	100

There is further support for the conclusion that irrigation dams divert a large proportion of floodwaters. Table 1 indicates that the number of irrigation dams and the amount of irrigated land are proportionally greater in the Kuhkuri basin than in the Andheri basin. This greater diversion should cause the flow ratio (lowland-flow/upland-flow) to be bigger, not smaller. Further, the water-holding characteristics of the surface soils in the lowland are lower in the upland. This should also cause the ratio to be greater than if this factor was equal. Presumably, if these other factors were equal, the flow ratios in Table 2 would be even **lower**.

The seasonal separation shown in Table 2 suggests that the tendency for a reduction in basin output is about equal during the pre-monsoon/transition and monsoon seasons. Due to greater need for irrigation water in the pre-monsoon season, it was hypothesized that the diversion in this season would be greater. Though these data do not support this hypothesis, because of the small number of events available, this seasonal consideration will have to be revisited when there are more events monitored in this comprehensive way.

The flow-ratio analysis supports the hypothesis that the diversion dams are very effective at directing floodwater out of the stream and into the irrigation system. In fact, it appears that a majority of the floodwaters is redirected into the irrigation system. And we know from the hydrometric data set that large amounts of suspended sediments are carried with the floodwater. If the hypothesis is correct, then there should also be evidence of soil accumulation within the irrigation system. We know that the farmers maintain the canals by annually removing considerable deposition but what of the fields themselves?

To examine the sediment accumulation in the fields, pins have been placed in a wide selection of khet fields before the onset of the flood season. The pins were collected after harvest and the soil level noted and compared to the level before the pre-monsoon season began. The results suggest that there is considerable deposition within the khet fields themselves (Table 3). Of the 25 fields involved, 76% showed accumulation and 40% showed more than 5 mm of accumulation. Further, these enriched deposits enhance the soil-nutrient condition: laboratory analyses show that base cation levels are higher in the deposition than in the underlying field.

Table 3. Accumulation in irrigated fields measured using pegs.

Accumulation Category (mm)	No. of Fields	Percentage of Total
-5 to 0	6	24
0 to 5	9	36
5 to 15	5	20
15 to 25	3	12
over 25	2	8
Total	25	100

4.3. Overall: Degradation

There are extensive areas of land in the Middle Mountains on which farming has ceased because of an exacerbated state of soil degradation due to surface erosion. Most farmers put enormous energy into their land to maintain it in a healthy productive state. If instead, they abandoned their land and allowed it to degrade, how might this affect downstream sediment concentrations? Such neglected land would also be subject to uncontrolled grazing, preventing natural regeneration.

The Dhap Khola basin is within the Jhikhu Khola watershed and is of the same size as the Andheri basin, but its condition is severely degraded. This provides an opportunity to examine the effect of degradation on sediment regime. The sediment rating curves for these two basins are given in Figure 4.

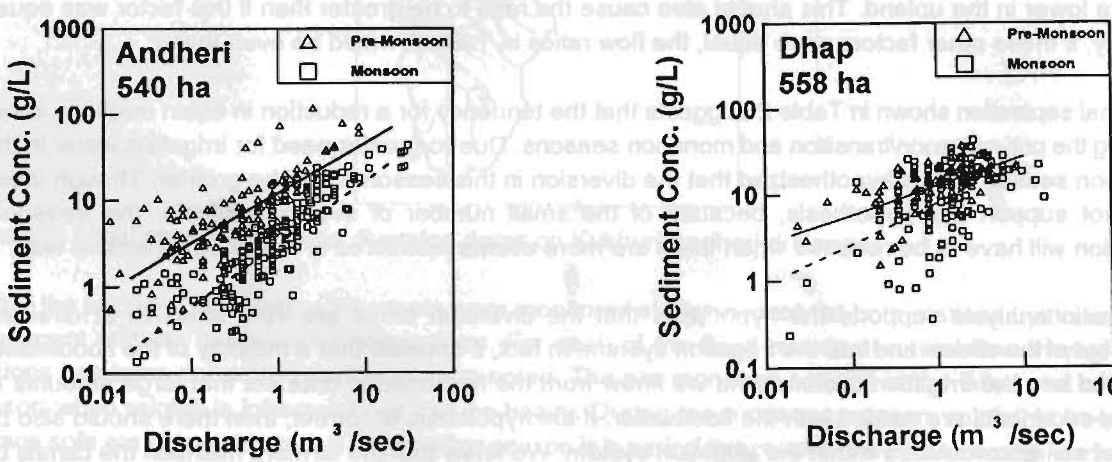

Figure 4. Seasonal sediment rating curves for Andheri and Dhap Khola basins.

The topography and land use of these two basins are given in Table 4, which shows that land use is largely the same in the two basins but that the topography in the Dhap basin is much gentler than that of the Andheri basin. Based on these factors alone, one would expect a greater sediment output from the Andheri basin.

Table 4. Topography and land-use comparison of Andheri and Dhap basins based on 1990 1:20,000 mapping.

	Andheri Khola	Dhap Khola
Total Area	540 ha	558 ha
Land Use		
Irrigated Agriculture	6.1	24.6
Rain-Fed Agriculture	39.3	36.7
Forest and Shrub	49.1	24.7
Degraded, Grazing and Other	5.5	14.0
Slope (degrees)		
0-19	26.1	78.9
20-34	35.9	18.1
35-49	33.2	3.0
≥50	4.8	0.0
Elevation (m)		
750-999	27.4	98.7
1000-1199	32.6	1.3
≥1200	40.0	0.0
Aspect		
Flat	2.6	20.4
N, NW, NW	73.3	9.1
E	12.4	9.7
S, SE, SW	8.7	47.0
W	3.0	13.8

Note: All numbers are % of total basin area.

Figure 5, however, reveals that the opposite is true: sediment output from the Dhap basin appears to be higher in both seasons than that from the Andheri basin. The reason for this lies in the level of degradation present in the two basins. The Dhap basin contains 14% degraded land (areas which are rilled and/or gullied and have less than 25% surface cover) while the Andheri basin has only 5.5% degraded land. At the highest flows, there is evidence that, regardless of the state of degradation and perhaps independently of season, the basin response merges. At these flow levels, the farmers have little ability to modify the basin sediment output. This is true in basins throughout the world, especially those where limited financing is available to build structures.

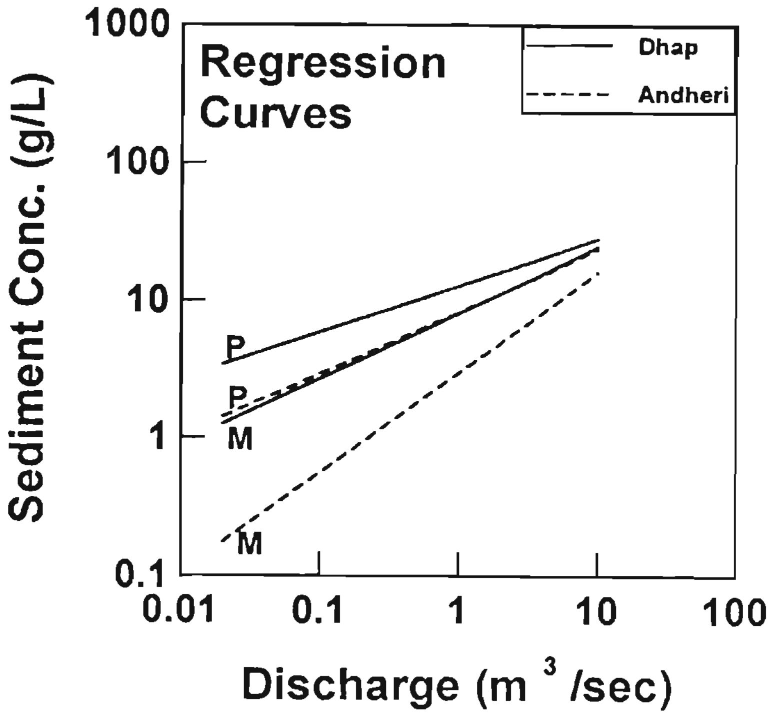

Figure 5. Seasonal sediment rating curves from Dhap and Andheri basins overlain for comparison.

It is important to also consider flood frequency to understand the overall significance of the seasonal suspended-sediment behaviour. The sediment loads during the pre-monsoon season, though generally quite high throughout the Middle Mountains, are short-lived because this season is brief and rainfall infrequent. The monsoon season, in contrast, lasts longer and experiences a greater number of flood events. The increased flood frequency in the monsoon season underlines the importance of the declining suspended sediment regime as the pre-monsoon season ends. In a basin with a degraded surface condition like the Dhap basin, the elevated pre-monsoon sediment levels are maintained during almost twice as many floods through the monsoon season. Local management which encourages the rapid return of a complete vegetative cover is therefore a key strategy to reducing net sediment output.

5. DISCUSSION

These three analyses all suggest that farming practices in the Middle Mountains are potentially quite effective in reducing downstream sediment concentrations. The farmers put enormous effort into maintaining the erosion-control and water-management structures of their agricultural system. It is, therefore, not surprising that in many cases they slow the movement of soil on its way downstream.

This is not to say, however, that everything that the farmer does is inherently positive for soil conservation. Farmers have limited time and money and must make choices. For instance, when they clean out the irrigation canals, soil is removed from the bottom of the canal, soil which has essentially been prevented from leaving with floodwaters. However, though some farmers use this material to raise or strengthen the canal sides or use it in adjacent irrigated fields, many others throw it directly into the stream, essentially facilitating its departure from the basin. The farmers would like to make use of this "free" soil (if it is not too sandy), but it is frequently not worth their time to do so.

6. CONCLUSIONS AND RECOMMENDATIONS

The principal conclusions of this paper are:

1. The development of a surface vegetative cover in the monsoon season serves as an effective approach for erosion control at the field level. A notable exception is in the pre-monsoon season when unfortunate timing of rainfall events can result in huge soil losses.

2. The indigenous irrigation system appears to capture a majority of storm run-off thereby capturing a large amount of entrained soil, preventing it from leaving the basin, and contributing to both soil fertility and accumulation in the irrigated fields.

3. Degraded land results in elevated stream sediment concentrations on a year-round basis.

4. Indigenous techniques appear to be effective at low and intermediate flows, but are far less discriminating at high flows, regardless of season and surface condition.

These conclusions suggest the following management recommendations:

1. In general, support rather than try to change current farming practices concerning erosion control and run-off management.

2. To reduce downstream sedimentation, rehabilitate degraded lands.

3. To enhance farm productivity, assist farmers in reducing soil loss during the pre-monsoon season and at high flow.

7. REFERENCES

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