2 Soil loss and runoff

Background

One of the underlying assumptions behind the PARDYP research was that soil erosion is a major problem, leading to environmental degradation, lower yield, and ultimately increasing the poverty of mountain farmers. This is a plausible scenario and fits well with reports of deforestation and soil erosion in the Himalayas. However, the question of whether there is a soil erosion problem, especially on rainfed agricultural land in the middle mountains of the Himalayan region, demands critical review. PARDYP's studies indicate that the amount of soil erosion from agricultural land is much less than generally perceived; the greater part of transported sediment comes from stream and riverbank cuttings, landslips, and erosion from increased runoff associated with roads, footpaths, and settlements. It appears that the soil conservation measures adopted by farmers are effective in reducing soil erosion.

Several studies have shown that significant erosion is taking place in the Himalayan region and that these mountains are a huge source of sediment. In 1976, E.P. Eckholm concluded in his book *Losing Ground, Environmental Stress and World Food Prospectus* that "There is no better place to begin an examination of deteriorating mountain environments than Nepal". Some sediment observations are described in the following.

- The annual sediment measured at Tribeni in the Tamur, Sunkoshi, and Arun rivers were equivalent to losses of 61, 27, and 12 m^3/ha in the watershed areas, respectively (after Gupta 1975).
- The Koshi River in Bihar shifted over 110 km from east to west between 1731 and 1963, destroying about 7,800 sq.km of land in Bihar, India (Gole and Chitale 1966), and 1,300 sq.km in Nepal with sand deposits, wiping out towns and villages, and displacing 6.5 million people (Rieger 1976).
- Satellite imagery reveals that a 40,000 sq.km island is forming in the Bay of Bengal from the silt transferred by Himalayan rivers (Sterling 1976), of which Nepal is the major contributor. The riverbeds are estimated to be rising by 10 to 30 cm per year from silt being deposited (HMGN 1975).
- A sedimentation survey of the Kulekhani Reservoir indicated that the average sediment contribution between the time it was dammed in 1982 to March 1993 was equivalent to a loss of 42 m^3 per ha per yr across the 125 sq.km watershed. During the disastrous 1993 monsoon, this rate increased to 415 m^3 per ha (Sthapit 1996).

The various studies indicate that the major sources of sediment are gully erosion, landslides, stream bank cutting, and sediment-laden flow (Figure 9). The PARDYP study sought to find out which part of the watershed and what land uses are the major sediment contributors and where and when the major erosion processes occur. PARDYP-Nepal set up plots in the Jhikhu and Yarsha watersheds to monitor and analyse differences in runoff and erosion from rainfed agricultural land and degraded land. The plots are described in Annex 3 and detailed results are given in Annexes 4 and 5 and summarised briefly below.

Figure 9: Major sources of sediment

Soil Loss and Runoff Monitoring

Average annual soil loss and runoff

Jhikhu Khola

The soil loss and runoff studies were carried out on two different land use types – rainfed outward sloping agricultural land (bari) and degraded land. The latter was further divided into degraded shrub and degraded treated land. The soil type in five plots was red soil and in two plots non-red soil. The erosion plots were located at the same altitudinal range of about 1,200 m and at sites with similar annual rainfall of about 1,200 mm; therefore differences caused by altitude and rainfall were not significant. Typical plots are shown in Figure 10, and analysis procedures in Figure 11.

The average annual soil loss from rainfed outward sloping agricultural land ranged from 1.3 t/ha (Gharti Thok, non-red soil) to 20.2 t/ha (Higher Chiuribot, non-red soil) (Annex 4, Table 1). The annual runoff from the same plots ranged from 330 m^3/ha to 1,197 m^3/ha (Annex 4, Table 2), about 3 to 9% of the annual rainfall.

Figure 10: Soil loss and runoff plots

Figure 11: Sediment and runoff sample analysis

The natural slope of the agricultural land has been modified to varying degrees by terracing. The slope of the terraces depends on the height of the risers and the natural slope of the terrain. In the plots, the amount of soil loss depended strongly on the slope of the cultivated terrace. Annual soil loss from a rainfed outward sloping agricultural plot with terrace slope 3º to 8º (Bhetwal Thok and Gharti Thok) ranged from 1.25 t/ha to 1.5 t/ha (Table 8, and Annex 4, Table 1), but losses from land with a terrace slope of 15° to 18º (Bela) and 22º (Chiuribot) were as high as 11.38 t/ha and 20.22 t/ha, respectively. The annual runoff from the land with terrace slope 15º to 18º remained close to 3% of the annual rainfall, but increased to 9% of annual rainfall when the terrace slope increased to 22º (Annex 4, Table 2).

Soil erosion and runoff increase significantly on steeper slopes and demand intensive conservation measures such as levelling of the cultivated slope, stable riser construction (stone), and surface runoff management, without which such slopes should not be cultivated.

Table 8: **Soil loss from rainfed agricultural land**				
Description	Site Code and Name			
	16A Bhetwal Thok	17A Gharti Thok	6A Bela	20A Higher Chiuribot
Ground slope in degrees	6.7	9.2	20.4	24.5
Terrace slope in degrees	3 and 8	8	15 to 18	22
Average annual soil loss, t/ha	1.5	1.25	11.38	20.22

The annual surface erosion rate in plots of untreated degraded land with red soil and slopes of 15º and 11.5º was 17.6 t/ha and 22.2 t/ha, respectively. One degraded plot with red soil and a 16º slope was treated by planting three double rows of broom grass 5m apart, each row containing two lines of plants 20 cm apart, with individual plants planted 10 cm apart. The annual surface erosion rate in this treated plot was only about 7.7 t/ha (Annex 4, Table 1).

The average annual runoff from the untreated degraded land (100m^2 plot) ranged from 4,100 to 5,300 m^3, 32 to 42% of the total rainfall. Average runoff from the treated degraded plot was only 3,200 m^3, 25% of the total rainfall (Annex 4, Table 2). It seems likely that the lines of broom grass helped to increase infiltration and reduce the surface runoff.

Yarsha Khola

The soil loss and runoff studies were carried out on two different land use types – rainfed outward sloping agricultural land and grassland. The latter was further divided into fallow grassland and grassland with shrubs. Two plots (one each of each type) had red soil and two plots non-red soil.

The average annual soil loss from rainfed outward sloping agricultural land was about 9 t/ha at Jyamire, with non-red soil, and about 16 t/ha at Namdu with red soil, even though the average annual rainfall was higher at Jyamire (2,505 mm; Annex 5, Table 4) than at Namdu (1,676 mm; Annex 5, Table 5). The annual runoff was 3,910 m^3 at Jyamire and 1,889 m^3 at Namdu, 16% and 12% of the annual rainfall, respectively (Annex 5, Table 2). The natural slope of both plots was about 17°, but Jyamire is located at 1,950m with a higher annual rainfall, and Namdu is located at 1,410m with a lower annual rainfall. The plot at Jyamire was moister than the plot at Namdu as a result of the higher elevation, lower soil temperature, and higher rainfall, and generated more runoff.

The average annual soil loss from the grassland with shrubs at Thulachaur (2,300 masl with non-red soil and 19° slope) was only 0.34 t/ha compared to 1.29 t/ha from the fallow grassland at Namdu (1,410 masl with red soil and 17.5° slope) (Annex 5, Table 1). The low rate of soil loss at Thulachaur might be due to the presence of shrubs and non-red soil, but could also be the result of lower temperature, higher soil moisture, more rainfall, and less human interference at the higher altitude. The annual runoff from the same plots was 5,870 m^3 at Thulachaur and 3652 m^3 at Namdu, 21% and 23% of annual rainfall respectively. Namdu had significantly less rainfall than Thulachaur (1,585 and 2,768 mm respectively, see Annex 5, Table 2).

Seasonal variation and maximum events

There were marked seasonal variations in soil loss and runoff, which are highest during the monsoon, followed by the pre-monsoon, and then the post-monsoon. Soil loss and runoff were insignificant during winter in all land use types.

Jhikhu Khola

Soil loss during the pre-monsoon period (March-May) was significant even though only about 15% of annual rainfall occurs in this period. About 44 % of the annual soil loss from degraded land, 26% from degraded shrubland, 8% from treated degraded land, and 32 to 68% from rainfed outward sloping agricultural land occurred during the pre-monsoon period (Annex 4, Table 7).

More than 75% of annual rainfall occurs during the monsoon (June-September); the annual soil loss during this period was 54% from degraded land, 72% from degraded shrubland, 91% from treated degraded land, and 31 to 68% from rainfed outward sloping agricultural land (Annex 4, Table 7). Soil loss during the post-monsoon and winter periods was insignificant.

The highest soil loss events observed in each of the plot types were during the pre-monsoon period (Annex 4, Table 8). The highest event in untreated degraded land was 9.66 t/ha on 8 May 1998, when 10 minute (I10), 30 minute (I30), and 60 minute (I60) rainfall intensities were 100, 44.3, and 23.2 mm/hr, respectively, and in the treated degraded plot was 10.05 t/ha on 10 June 1999, when I10, I30, and I60 were 65.7, 37.8, and 20.9 mm/h, respectively. The highest soil loss event observed in rainfed outward sloping agricultural land was 25.96 t/ha on 28 May 1993, during a cloudburst. This runoff plot was only established in 1993, and the high value of soil loss might have been caused by excessive soil work. The highest soil loss events observed during the monsoon were 8.34 t/ha on 10 June 1999 from degraded land, when I10, I30, and I60 rainfall intensities were 93, 36, and 23 mm/hr, respectively; and 11.95 t/ha on 27 June 1996 from rainfed outward sloping agricultural land, when I10, I30, and I60 rainfall intensities were 76, 42, and 33 mm/h, respectively (Annex 4, Table 9).

Seasonal runoff correlated well with seasonal rainfall in rainfed outward sloping agricultural land — annual runoff during the monsoon period from 70 to 82% compared to rainfall proportion of 78% — and for the degraded shrubland at Baghkhor — annual runoff during the monsoon period 77%, compared to rainfall proportion of 80% (Annex 4, Table 7). However, the proportion of runoff during the monsoon from the untreated degraded land at Kubinde was higher than the proportion of rainfall — 85% compared to 71%.

The highest runoff events occurred during the monsoon (5 plots) or pre-monsoon (2 plots) (Annex 4, Table 10). The highest runoffs were generally the outcome of intense and high rainfall. The highest daily runoffs recorded were all from degraded land (shrub, treated, and untreated) and above 500 m^3/ha, with daily rainfall of were 140 mm or higher. One day with similarly high rainfall in the rainfed agricultural land plot led to a similarly high runoff of 457 m^3/ha. Land use did have an effect on runoff, but when rainfall exceeds the absorptive capacity of the soil there will always be excess runoff. High runoff can contribute to flooding.

Yarsha Khola

Soil loss during the pre-monsoon period (March-May) was also significant in the sites in the Yarsha Khola watershed, 19 to 24% of annual soil loss from grassland and 25 to 53% from rainfed outward sloping agricultural land compared with only 15% of annual rainfall. The proportion of soil loss during the monsoon period — with 75% of the annual rainfall — was 75 to 80% of the annual total for grassland and 47 to 75% for rainfed outward sloping agricultural land (Annex 5, Table 6).

The highest soil loss event observed in grassland was during the monsoon: 0.56 t/ha on 11 July 1998, when I10, I30, and I60 were 74.4, 43.2, and 29.2 mm/hr, respectively (Annex 5, Table 7). The highest soil loss event observed in rainfed outward sloping agriculture was during the pre-monsoon: 5.23 t/ha on 25 May 1999, when I10, I30, and I60 were 34.8, 24, and 22.2 mm/h, respectively. The highest soil loss event observed in rainfed outward sloping agricultural land during the monsoon was 2.54 t/ha on 18 July 1997 (Annex 5, Table 8).

Overall, the percentage of runoff during the monsoon in grassland and rainfed outward sloping agricultural land was slightly higher than the percentage of annual rainfall; whereas the percentage of runoff during the pre-monsoon, post-monsoon, and winter seasons was lower (Annex 5, Table 6).

All the highest runoff events per plot occurred during the monsoon, with a maximum of 432 m^3/ha in grassland and 513 m^3/ha in rainfed outward sloping agricultural land, following a total daily rainfall of 119 and 98 mm, respectively (Annex 5, Table 9).

Discussion

Although soil loss from the rainfed outward sloping agricultural land with a terrace slope of more than 15° and from degraded land was significant, the greater part of soil loss actually appears to come from non-agricultural land. Sthapit (1996) showed that the high rate of sediment contribution from the watershed to the Kulekhani reservoir under the extreme rainfall conditions in 1993 (377 mm in Simlang, 419 mm in Sarbang, and 535 mm in Tistung over a 24-hour period with intensities of 67 and 70 mm/h in Simlang and Tistung, respectively) was mainly from slope failures and stream-bank cutting, rather than from surface erosion from agricultural land.

In general, the quantity of soil loss from surface erosion of agricultural land is less than soil loss from degraded land. However, the value of the soil lost from agricultural land is higher because agricultural land gives higher economic returns than degraded land.

Therefore, conservation measures on agricultural land must be given high priority. Effective conservation measures include improved farmland water management, grass planting on risers, hedgerow planting, terracing, and multiple cropping.

In rainfed outward sloping agricultural land, the coincidence of intense rainfall with soil preparation for planting crops results in high soil loss events. The highest soil loss event observed in rainfed agricultural land was 25.96 t/ha in the Jhikhu Khola during the pre-monsoon period on 28 May 1993, and resulted from land preparation for a new May crop. The ground cover was almost nil and the rainfall intensity high. This is a primary reason for the high erosion rate during the pre-monsoon in rainfed outward sloping agricultural land. Although the exceptionally high value of soil loss in the Jhikhu Khola plot was partly due to soil work for plot construction, the second-highest soil loss event in rainfed agricultural land was from a plot that had been established for six years: 17.2 t/ha at Chiuribot on 22 June 2004. This loss also occurred during the early monsoon when ground cover was low.

Designing cropping patterns to maintain some cover crop during the pre-monsoon, along with conservation measures such as multiple cropping, mulching, and conservation tillage, could help reduce loss of fertile topsoil during the pre-monsoon period. Managing water for growing cover crops during the dry period would be the first step for addressing this issue.

High-intensity rainfall and lack of ground cover also resulted in high soil loss events in degraded land in both the pre-monsoon and monsoon periods.

Farmer's Perceptions

In the 'Water Demand and Supply Survey' carried out in 1998 in the Yarsha Khola and in 1999 in the Jhikhu Khola, PARDYP asked farmers about major water related issues (Merz et al. 2002). Farmers in both watersheds considered water quantity for irrigation to be the most important issue followed by water quantity for drinking. Only a few respondents considered flooding, surface erosion, or slumping, respectively, to be the major water related issue (see Chapter 3).

If separate questions had been asked on erosion issues (landslide, slumping, gully erosion, riser failure, surface erosion, and flooding) rather than mixing the issue with water availability and quality, the responses might have been different. The perception of farmers depends on the information and knowledge they have. If the farmers had been aware that most of their total manure inputs are washed away in the first few rains, their perception towards erosion issues might have changed. Furthermore, if people don't have solutions to their problems, they may not perceive them as problems but rather consider them as simply part of life. Therefore, farmers might not have perceived surface erosion as a problem.

Farm Management

Stream bank erosion, gullying, road slope erosion, riser failure,and slumping are actually major soil erosion problems. Stream bank erosion, however, only affects a small number of farmers who own land along rivers. Gullying is often observed along trails and on severely degraded, often community-owned land. Stream bank erosion and gullying require external support for treatment. Treating road slope erosion is generally beyond the scope of the community and is best left to the concerned agencies. Generally farmers repair small riser failures that affect a few terraces in bari and khet lands. Larger-scale slope failures affecting dozens of terraces can take several years to repair. Slope failure on agricultural land is normally managed by farmers within a fairly short time, reducing the sediment yield and overland flow.

Erosion from small irrigation canals is mostly managed and repaired by farmers themselves. Irrigation also returns a significant amount of sediment to agricultural land, and vegetation on risers traps soil from surface runoff. Proper irrigation systems and vegetation on risers can play a significant role in managing sediment within a watershed. Figure 12 shows the typical appearance of managed slopes.

The soil loss from the experimental plots actually shows erosion processes under artificial conditions, because there is no effect from the runoff and sediment flow from up-slope. Due to the plots' galvanised iron boundary plates and narrow width, farming practices, especially ploughing, are carried out differently. Many fields are ploughed by bullocks, but not the plots. Biotic interference (mainly from animals) is less in plots than

Figure 12: Farmers' management of agricultural lands

on farmers' land. Slope failure is thus less likely in the runoff plots than in farmers' fields. On the other hand, soil is significantly more disturbed when establishing runoff plots. Overall, soil loss from runoff plots is generally higher in the initial period and lower in the following years compared to the real situation.

According to Mathema and Singh (2003), erosion plots only provide information on surface soil loss. Simple extrapolation of research results from these small-scale studies to a larger scale can lead to meaningless or even dangerous generalisations, because the processes involved are different at different scales. Misleading or inappropriate conclusions can be drawn when erosion plot data are quoted out of context.

Lessons Learned and Recommendations

Soil loss and runoff monitoring

Annual soil loss

- In general, soil loss is higher from degraded land than from agricultural or pasture land.
- Soil loss from rainfed outward sloping agricultural land increased with increasing slope.
- Soil loss from degraded land can be cut by half with simple conservation treatment (hedgerow planting across the slope).
- In disastrous rainfall conditions (such as cloudbursts), most sediment comes from mass movement such as landslides, riverbank cutting, road slope failure, and riser failures.
- Soil erosion from properly managed agricultural land is significantly lower than from unmanaged agricultural land.

Annual runoff

- Rainfed outward sloping agricultural land generates significantly lower runoff than grassland, which in turn generates lower runoff than degraded land. However, an increase in terrace slope in the rainfed agricultural land increases the runoff significantly.
- Red soil contributes more runoff than non-red soil as a result of the lower infiltration.
- Significant increases in annual rainfall increase runoff.
- Vegetative barriers can reduce runoff significantly by increasing the infiltration rate.

Conservation priorities

- Although in terms of quantity soil loss from agricultural land is less than from degraded land, in economic terms the loss from agricultural land is more significant.
- Agricultural land should be given top priority for conservation of soil and nutrients, but erosion from degraded land may lead to off-site impacts and so cannot be ignored. If degraded lands are common resources, priority must be given to them as well. Once degraded land is rehabilitated, it becomes a vital resource for the poor.

Seasonal variations and maximum events

- The study of seasonal variations in surface erosion processes is very important for designing conservation measures, but the total amount of annual soil loss should also be considered when deciding on investments.
- Cover crop and soil work during land preparation are key factors affecting the amount of surface erosion occurring during intense rain.
- Conservation measures to maintain ground cover during intense rain play an important role in reducing surface erosion. These include maintaining cover crops during the pre-monsoon period, mulching, relay cropping (growing of another crop before clearing the previous one), and multiple cropping.
- Year-round irrigation with full management control is essential so that appropriate crop cover patterns can be designed and implemented.
- Stall feeding with a cut-and-carry system can reduce surface erosion in grassland and pasture; erosion rates are very low in protected grassland runoff plots but are quite high in free-grazing areas.
- The highest runoffs are generally the outcome of intense and high rainfall. Land use does effect runoff, but when rainfall exceeds the absorptive capacity of the soil, excess runoff will cause floods.
- In general, peak runoffs are observed when daily rainfall exceeds 100 mm.

Farmers' perceptions

- It is important to consider farmers' perceptions when managing natural resources. When designing survey questions, it is appropriate to separate questions regarding water availability from those related to erosion.
- Research on nutrient loss due to surface erosion needs to quantify the nutrient loss. Extension services must share information with farmers and encourage farmers to adopt necessary conservation measures.
- Proper conservation of agricultural land is essential for its sustainable use.

Overall

- Soil erosion is a complex process. For better comparison of results, it is recommended to establish erosion plots under similar climatic, soil, geology, and landform conditions, preferably in one place, rather than in different places with different conditions.
- The complex nature of erosion and runoff studies can result in unexplainable data. The probable causes of such unexplained data must be verified and documented to permit appropriate analysis. For example, on some days with high rainfall and runoff there may be no soil loss, whereas on other days in the same week with low rainfall and runoff there may be significant soil loss.
- Systematic documentation of the information and process is essential, especially if there is staff turnover, to permit valid data analysis at the end of a project.
- Standard procedures for measurement must be strictly followed if valid data are to be obtained. Continuous supervision and reflection must be integral to the study and deviations from stated procedures must be documented.