Erosion Dynamics in the Jhikhu and Yarsha Khola Watersheds in Nepal

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have a direct influence on the physical and chemical properties of soil and on soil nutrient losses. Accelerated erosion threatens the sustainability of mountain farming systems, and seriously affects the hydrological regime and sediment transport processes downstream. To quantify the rate of erosion, test plots were established in the Jhikhu Khola watershed in 1992; the network was expanded to the Yarsha Khola watershed in 1997. Plots were installed on rainfed agricultural land, grazing land, and degraded sites. Rainfall amount, intensity, and duration are the critical factors, apart from management and site conditions, that influence rates of erosion. Seasonal effects also play a key role. Past data show that the two most damaging storm events can produce 50 to 90 per cent of the total soil loss in a year. These storms typically occur during the pre-monsoon season. In this paper, the overall effects of rainfall on runoff and soil loss are investigated.

In cultivated fields, the overall effect of rainfall on surface runoff was minimal when rainfall events were less than 20mm. In contrast, there was a close relationship between rainfall and runoff in grassland and degraded sites; but runoff from grassland contained very little sediment, the highest erosion rates were from degraded sites. At very high rainfall volumes, soil loss rates were of a similar order of magnitude for both degraded and cultivated sites. More than 90 per cent of the total annual erosion occurred in less than 15 annual events, suggesting that the timing of these needs to be examined more closely before any positive preventative actions to mitigate erosion can be suggested.

Introduction

Soil erosion processes lead to soil removal, losses in organic matter that affect the physical and chemical properties of the soil, and soil nutrient losses. Accelerated erosion therefore threatens the sustainability of mountain farming systems and seriously affects the hydrological regime and sediment transport processes downstream (e.g., by clogging up the irrigation network). Carver and Schreier (1995) established a close link between nutrient loss and soil movement from rainfed sites in the Jhikhu Khola Watershed (JKW). The rate of land denudation depends upon land management, particularly the maintenance of ground cover condition (Carver and Nakarmi 1995; Hashim *et al.* 1995). In order to quantify the rate of erosion, test plots were established in the Jhikhu Khola watershed (JKW) in 1992. The network was expanded to the Yarsha Khola watershed (YKW) in 1997. The plots are rectangular and each covers 100 sq.m. (20 x 5 m). A total of eleven plots were established in the two watersheds, seven on rainfed agricultural land, two on grazing land, and two on degraded sites. In addition to management and site conditions, the critical factors that influence rates of erosion are amount, intensity, and duration of rainfall. Carver (1997) suggested that in the JKW the threshold value above which rainfall intensity causes surface erosion is 30 mm/hr. Seasonal effects play a key role, and past data indicate that the two most damaging storm events in a year usually produce between 50 and 90 per cent of the total soil loss in that year, these storms typically occurring during the pre-monsoon season (Carver and Nakarmi 1995; Nakarmi 1998). This paper describes the results of an investigation into the overall effects of rainfall on runoff and soil loss.

Site Location and Study Approach

The JKW lies about 45 km east of Kathmandu between 27°33' and 27°42' N, and 85°31' and 85°41' E, with an altitude range from 860 to 2200 masl. The YKW lies about 180 km north-east of Kathmandu between 27°34' and 27°40 N and 86°05' and 86°11' E, with an altitude range from 1000 to 3200 masl. The YKW is accessible from the Lamusangu-Jiri road. There are striking differences between the two watersheds. The JKW is closer to markets (Kathmandu) and is subject to much higher land use pressures, with the result that triple annual crop rotations and cash crop production are common. In contrast, the YKW is far from main markets and is dominated by subsistence farming.

Five erosion plots were established on sloping agricultural land in the JKW in 1992, and two new plots on degraded sites were added in 1997. The plots are monitored on a daily basis, and runoff and sediment content are determined on a storm by storm basis; all stations are equipped with an automated tipping bucket rain gauge for continuous monitoring of rainfall events. Table 68 shows the physical characteristics of the plots. Four erosion plots were monitored in the YKW in 1997 and 1998, two on grazing land and two on rainfed agricultural land. All plots on rainfed agricultural land cover two terraces and one terrace riser, but otherwise the site conditions at the rainfed plots are highly variable. This complicates such studies, so for the purpose of this paper data are only presented for two of the four agricultural plots in the JKW.

Table 68: **Physical Parameters of Erosion Plots**

Plot No.	Location	Land use	Slope (°)	Elevation (m)	Aspect	Remarks
Jhikhu Khola Watershed						
JE 4	Luitelgaun	Degraded	12	1040	North	Red soil
JE 14	Kubinde	Degraded	15	1010	South	Red soil
JE 6b	Bela	Rainfed cultivation	18	1345	North	Red soil
JE 16	Bhetwalthok	Rainfed cultivation	15	1365	South	Coarse red soil
Yarsha Khola Watershed						
YE 5	Thulachaur	Grassland	19	2300	South	Dark brown soil
YE 9b	Namdu	Grassland	17	1410	South	Red soil
YE 6	Jyamire	Rainfed cultivation	17	1980	South	Brownish red soil
YE 9a	Namdu	Rainfed cultivation	18	1420	South	Red soil

The rainfed test plots in both watersheds are managed by farmers who are also responsible for keeping the records for erosion and runoff. Maize is the principal crop in both areas with millet as a secondary crop in the YKW and wheat as the dominant second crop in the JKW.

Results

Rainfall Characteristics

The amount, duration, and intensity of rainfall are the key external factors affecting erosion. The higher the energy of the falling rain, the greater is the power to detach soil particles—which are subsequently moved by the runoff water. In this paper, the effect of rainfall variability at the erosion plots on runoff and erosion is examined over the 1997 and 1998 period.

Four rainfall stations in the JKW and three stations in the YKW were used to analyse the annual and event-based rainfall. Figure 78 shows the monthly rainfall distribution in the JKW for 1998. The highest rainfall occurred during July followed by August. The elevation difference between the four stations is relatively small (305m on the north facing slope and 355m on the south facing side) and this is the main reason for the relatively small monthly difference between the stations. Only in May, during the pre-monsoon period, was there any marked difference. At this time the low elevation south-facing station received around fifty per cent more rainfall than the other stations.

Figure 79 shows the monthly rainfall distribution for the three stations in the YKW in 1998. There is a much greater elevation difference between these stations, and the influence of this elevation gradient is reflected in the differences in the monthly rainfall totals. The lowest station Namdu (1410m) received the lowest monthly rainfall throughout the monsoon, and the highest station Thulachaur (2300m) the highest rainfall. The differences were most pronounced in June and July.

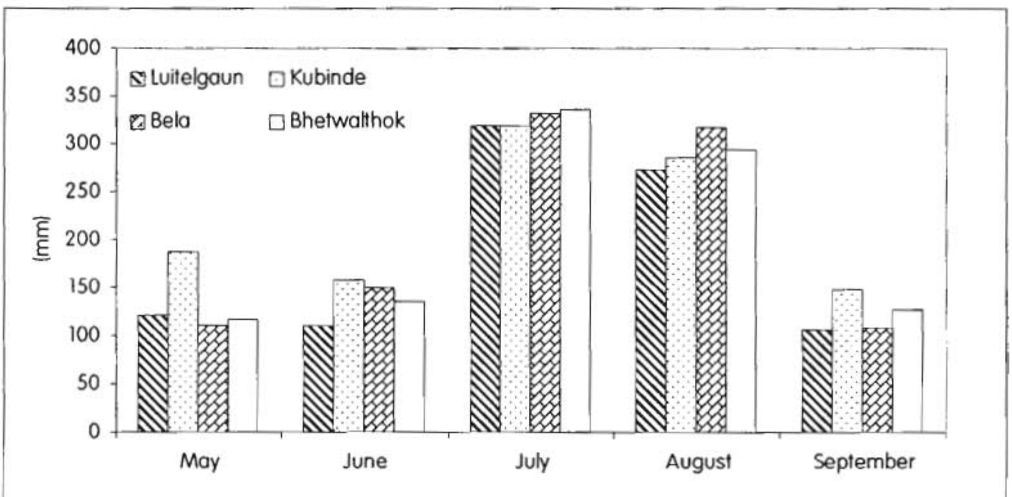

Figure 78: **Monthly Rainfall Distribution in the JKW during the 1998 Rainy Season**

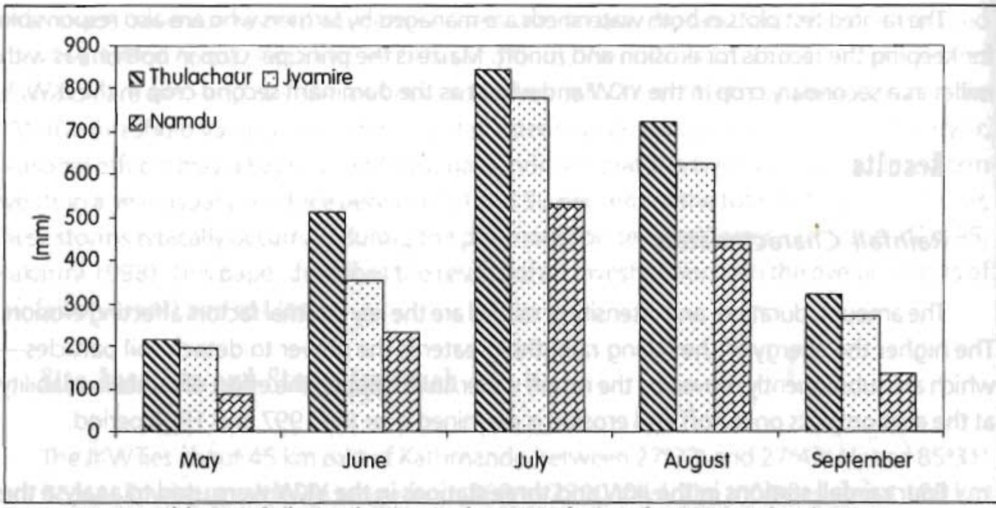

Figure 79: **Monthly Rainfall Distribution in the YKW during the 1998 Rainy Season**

Figure 80 shows the total monsoon precipitation in both watersheds in 1997 and 1998 rainy seasons. The values for 1997 and 1998 were very similar in the lower elevation Jhiku Khola watershed but not in the higher elevation Yarsha Khola watershed. This suggests that annual variations may be more marked at higher elevations, although longer-term records will need to be analysed to confirm this.

Runoff versus Rainfall

Runoff from the 100 sq.m. erosion plots was collected in drums and measured. Runoff values were determined for the two degraded and two cultivated sites in the JKW, and the two grassland and two cultivated sites in the YKW. Figures 81 to 84 show the rainfall/runoff

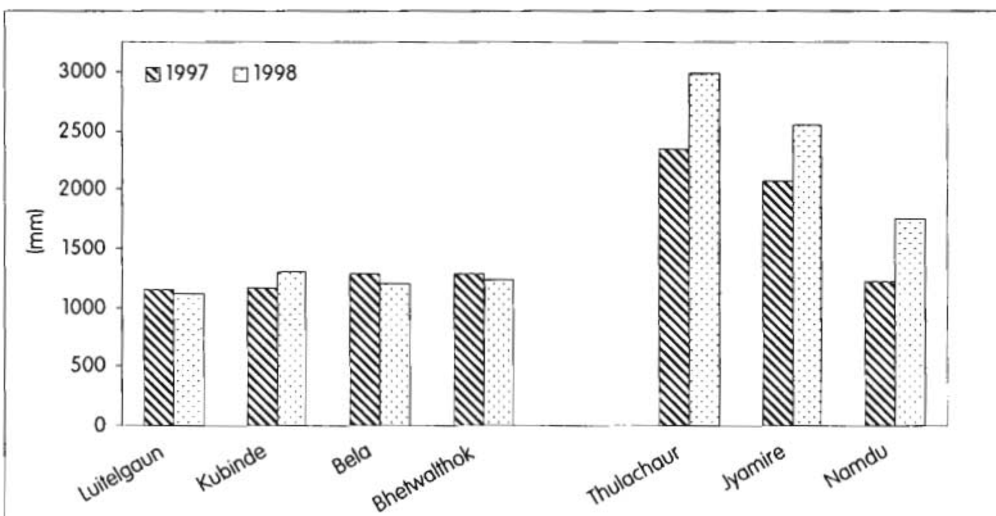

Figure 80: **Comparison of Rainy Season Rainfall Distribution in 1997 and 1998 in the JKW and the YKW**

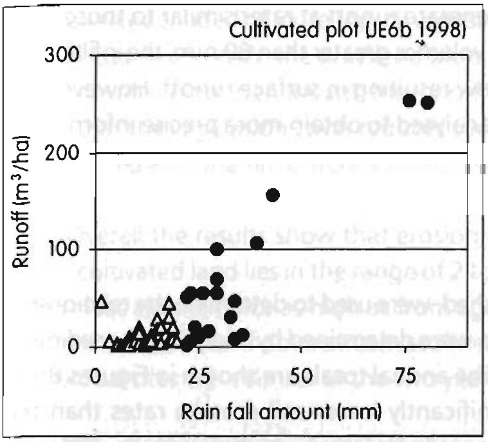

Figure 81: **Runoff by Event from Cultivated Plot, JKW**

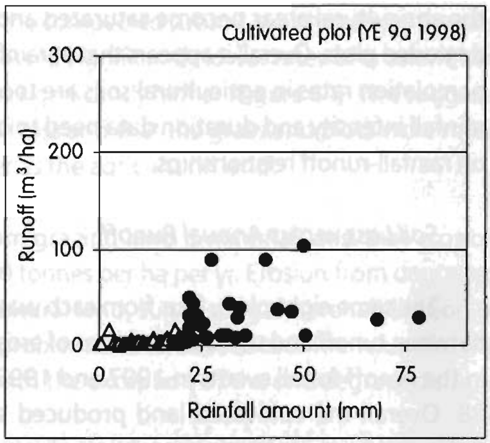

Figure 82: **Runoff by Event from Cultivated Plot, YKW**

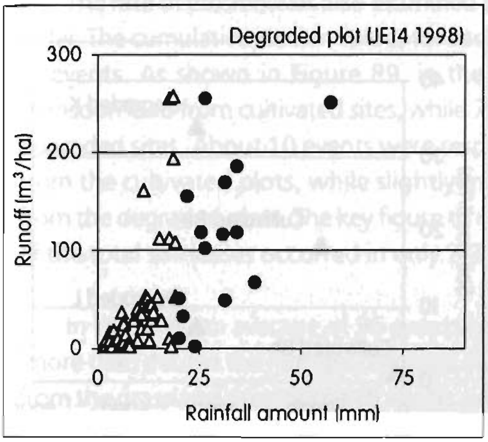

Figure 83: **Runoff by Event from Degraded Plot, JKW**

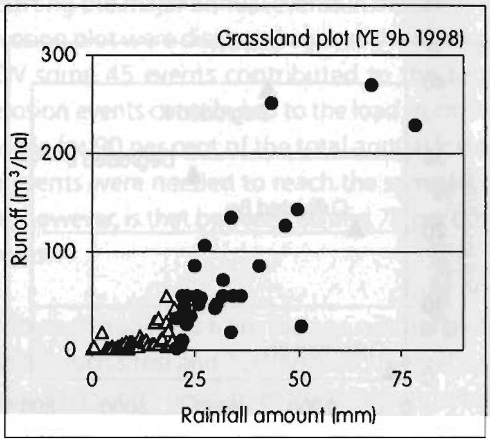

Figure 84: **Runoff by Event from Grassland Site, YKW**

relationships for one site of each type as an example for all events recorded in 1997 and 1998. Events with less than 20mm of rainfall are indicated by a pale triangle, those with more than 20mm of total rainfall by a black dot.

During low rainfall events (<20 mm), there was little or no runoff from the cultivated sites, and only a very small amount from the grassland sites, but the runoff from degraded sites was substantial (Figure 81). The runoff for rainfall events of 20-40 mm reached 100 m^3/ha from both cultivated and grassland plots, with slightly higher values from grassland, but the values were significantly higher from the degraded sites reaching more than 200 m^3/ha. Only at very high rainfall events of around 80 mm did the runoff values from some cultivated sites reach similar values to those from the grazing and degraded sites.

Thus it appears that during storms with low amounts of rainfall, water in agricultural areas infiltrates the soil and is stored, resulting in minimal runoff, while in degraded land little water infiltrates the surface and the runoff is much higher. Only in very high rainfall events do the agricultural areas become saturated and generate runoff at rates similar to those from degraded plots. Overall it appears that at rainfall volumes greater than 60 mm, the infiltration/percolation rates in agricultural soils are too slow resulting in surface runoff. However, the rainfall intensity and duration data need to be analysed to obtain more precise information on rainfall-runoff relationships.

Soil Loss versus Annual Runoff

The same eight plots, four from each watershed, were used to determine the relationship between runoff and soil loss. The rates of erosion were determined by analysing the sediment in the runoff for all events in 1997 and 1998. The annual totals are shown in Figures 85 to 88. Overall the cultivated land produced significantly lower soil erosion rates than the degraded lands, with the exception of one degraded plot which showed a much lower erosion rate, but still with high run off, in the second year. This site had become almost

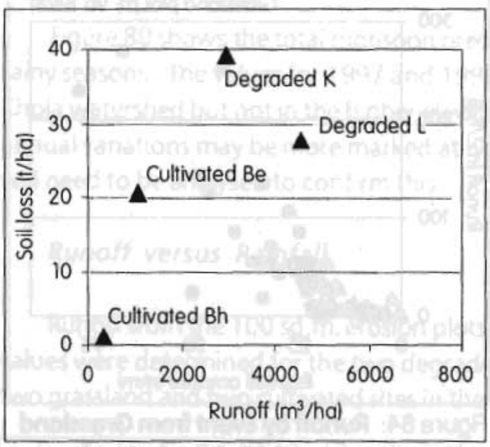

Figure 85: **Annual Soil Loss versus Runoff, JKW, 1997**

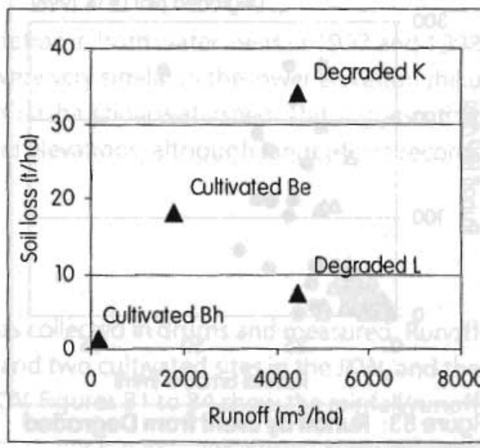

Figure 86: **Annual Soil Loss versus Runoff, JKW, 1998**

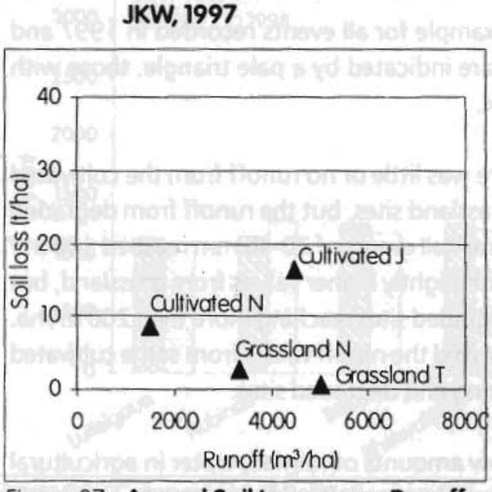

Figure 87: **Annual Soil Loss versus Runoff, YKW, 1997**

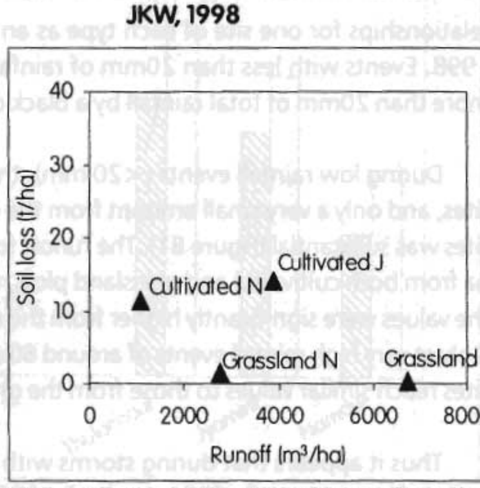

Figure 88: **Annual Soil loss Versus Runoff, YKW, 1998**

completely denuded of loose topsoil exposing the compacted subsoil, which reduces the rate of soil loss. In the YKW, the grassland plots showed significantly lower rates of erosion than the cultivated plots even though the runoff was significantly higher (Figure 84). This suggests both that the vegetation cover reduces the soil loss and that the grassland plots were more compacted and unable to store as much water as the agricultural land.

Overall the results show that erosion from grazing land is minimal, and that erosion from cultivated land lies in the range of 2 to 20 tonnes per ha per yr. Erosion from degraded lands was almost twice as high as from agricultural land, suggesting that rehabilitation of these lands is critical if downstream sediment problems are to be reduced. The values for the individual sites were similar in the two years with the exception of the one degraded site.

The Role of Critical Events

The rate of erosion was also examined by sorting the major annual events in descending order. The cumulative erosion values for each erosion plot were displayed against the number of events. As shown in Figure 89, in the JKW some 45 events contributed to the total monsoon load from cultivated sites, while 70 erosion events contributed to the load from the degraded sites. About 10 events were responsible for 90 per cent of the total annual losses from the cultivated plots, while slightly more events were needed to reach the same level from the degraded plots. The key figure to note, however, is that between 60 and 70 per cent of the total soil losses occurred in only 2-3 events.

In the YKW, an average of 96 events contributed to soil loss from the agricultural plots (more than double the number recorded in JKW for such sites) and 110 events to the soil loss from the grassland sites. Some 15 events generated about 90 per cent of the total annual soil loss in all sites (Figure 90).

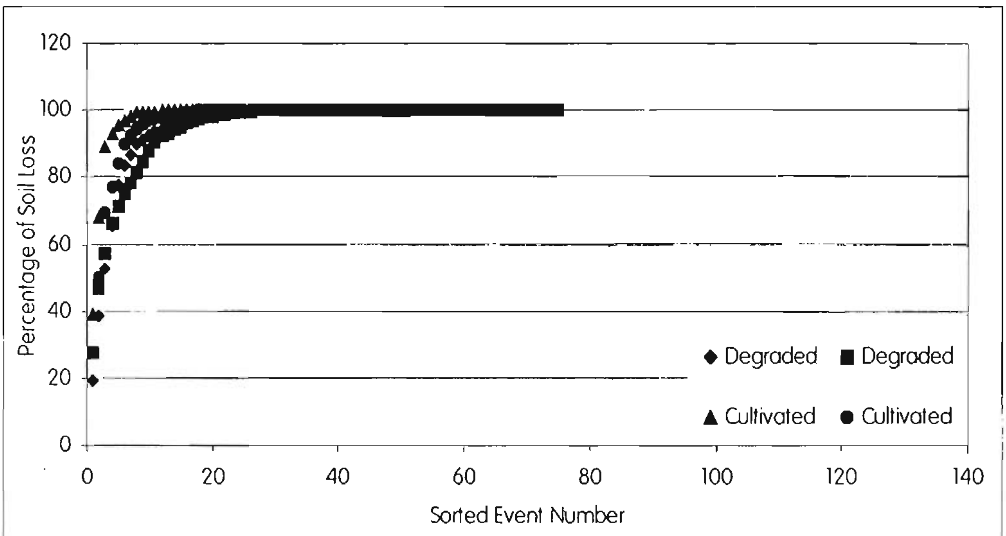

Figure 89: **Cumulative Soil Losses in the JKW by Event, 1998**

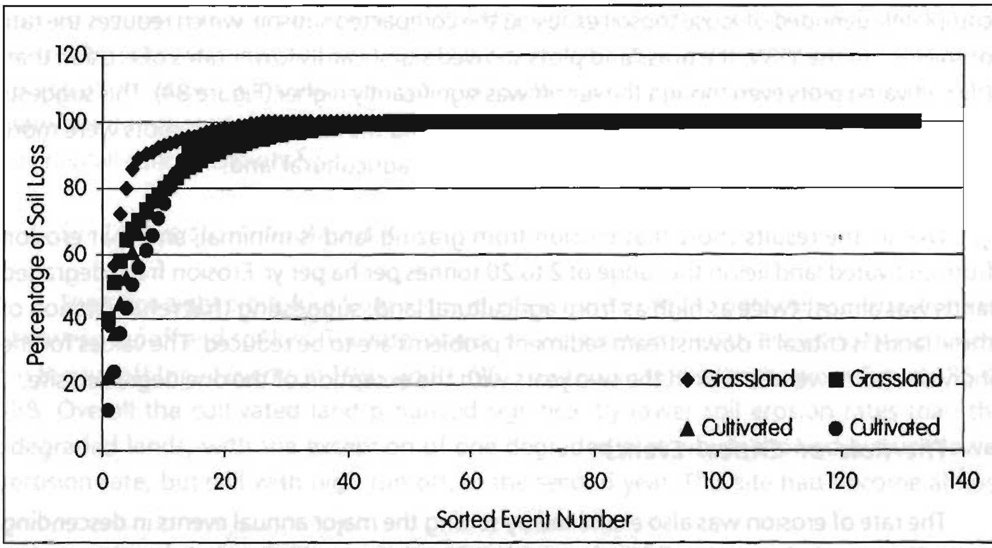

Figure 90: **Cumulative Soil Losses in the YKW by Event, 1998**

Predicting when the few major storms will occur that are responsible for 60-80 per cent of the soil losses remains the main challenge. Clearly, greater attention needs to be directed towards these events and their intensities and duration because they are the most destructive to the environment, and the most detrimental to the farmers in terms of topsoil and nutrient loss.

Conclusions

Almost twice as much rain fell in the higher elevation YKW during the wet months (July–September) as in the lower elevation JKW. July was the wettest month at all stations in both 1997 and 1998. There was hardly any variation in the annual totals in 1997 and 1998 between the lower elevation stations in the two watersheds, but significant differences were found at the higher elevations. The Yarsha Khola watershed showed a clear altitudinal gradient, with annual precipitation at the highest station almost twice that at the lower station. The altitudinal increase was approximately 10 mm increase in rainfall per 100 m increase in elevation.

The overall effect of rainfall on surface runoff was minimal in cultivated fields when rainfall events were less than 20mm, and on grazing land when rainfall was less than 18 mm. A close relationship between rainfall and runoff was observed in grassland and degraded sites when rainfall events exceeded 20mm; the main difference between the two was that runoff from grassland contained very little sediment, whereas erosion rates in the degraded sites were high. At very high rainfall volumes, the soil loss rates from degraded sites and cultivated sites were of a similar order of magnitude.

The degraded land in the JKW generated between 28 and 39 tonnes of sediment per ha per year with a total runoff of 3,000 to 5,000 m^3/ha; in contrast, grassland released less than

3 t/ha. Cultivated fields generated between 1 and 20 t/ha with a total runoff of 1,000 to 4,500 m^3/ha. These findings indicate the following.

- Water storage in the soil is less effective in grazing land than in agricultural land.
- Erosion problems are worse on cultivated sites than on grazing land.
- Degraded areas are the main source of sediment.
- Changes in land management and land cover would have little effect on soil loss rates during high volume rain storms unless there was some way of ensuring that cultivated land had a 'mat' of vegetation during the premonsoon and monsoon seasons.
- Soil compaction influences infiltration rates and soil water storage capacity, and these are key elements in the relationships between rainfall, runoff, soil loss, and land use.

Finally, more than 90 per cent of the total annual erosion occurred in less than 15 annual events, suggesting that the timing of these needs to be examined more closely before positive preventative actions to mitigate erosion can be suggested.

Bibliography (not necessarily cited in the text)

Carver, M. (1997). *Diagnosis of Headwater Sediment Dynamics in Nepal's Middle Mountains: Implications for Land Management*, Ph. D Thesis (Submitted). Vancouver: University Of British Columbia.

Carver, M. and Nakarmi, G. (1995). 'The Effect of Surface Conditions on Soil Erosion and Stream Suspended Sediments'. In Schreier, H.; Shah, P. B. and Brown, S. (eds) *Challenges in Mountain Resource Management in Nepal: Processes, Trends and Dynamics in Middle Mountain Watershed*. Kathmandu: ICMOD.

Carver, M. and Schreier, H. (1995). 'Sediment and Nutrient Budgets over Four Spatial Scales in the Jhikhu Khola Watershed: Implications for Land Use Management'. In Schreier, H.; Shah, P. B. and Brown, S. (eds) *Challenges in Mountain Resource Management in Nepal: Processes, Trends and Dynamics in Middle Mountain Watershed*. Kathmandu: ICMOD.

Hashim, G.M.; Ciesiolka, C.A.A.; Yusoff, W.A.; Nafis, A.W.; Mispan, M.R.; Rose, C.W. and Coughlan, K.J. (1995). 'Soil Erosion Processes in Sloping Land in the East Coast of Peninsular Malayasia'. In *Soil Technology*, 8: 215- 233.

Nakarmi, G. (1998). 'Erosion Dynamics in the Middle Mountains of Nepal. Aspects and Impacts of a Changing Sediment Regime'. In Proceedings of the Workshop held in Nov. 16-20 in AIT, Bangkok. Paris: UNESCO/IHP.