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Assessment of Runoff and Soil Loss in the Hindu Kush-Himalayan Region

Mohammad Jehangir[1], Suhail Zokaib[1], Juerg Merz[2,3], Pradeep M. Dangol[2], Madhav P. Dhakal[2], Bhawani S. Dongol[2], Gopal Nakarmi[2], Basant K. Joshi[4], Padma K. Verma[4], Gao Fu[5], Xing Ma[5]

[1] Pakistan Forest Institute, Peshawar, Pakistan (PARDYP-Pakistan)

[2] ICIMOD, Kathmandu, Nepal (PARDYP-Nepal)

[3] Hydrology Group, Department of Geography, University of Berne, Berne, Switzerland

[4] G.B. Pant Institute for Himalayan Environment and Development, Almora, India (PARDYP-India)

[5] Kunming Institule of Bolany, Kunming/, China (PARDYP-China)

Abstract

The sediment loads of Himalayan rivers are amongst the highest in the world, causing problems such as the siltation of reservoirs, river channel blockage, and poor quality water supplies. The major sources of sediment are glacial debris, landslides, and over-grazed and intensively cultivated hill slopes. The research presented here was carried out to investigate soil erosion from different land uses. Hydrological, meteorological and soil erosion data was collected for four years from different land uses in the PARDYP watersheds in Pakistan, India, Nepal, and China. Runoff and sediment losses were monitored on erosion plots representing degraded, pasture (grassland), forest, and agriculture land use. The results show that runoff and soil loss were highest in May to September when rainfall duration and intensity were higher in all watersheds. A few big rainfall events contributed most of the annual runoff and soil loss. Annual rainfall ranges from 800 mm to 2400 mm with between 44 and 66% occurring in the monsoon period of June to September. Annual soil loss was highest from the erosion plots in the two Nepali watersheds across all four land use types. Levels of soil erosion were very low at the Hilkot, Pakistan, and Bheta Gad, India plots. At all the sites, for all land use types at least 80%, and in the case of Yarsha Khola and Jhikhu Khola 95 to 99% of soil loss occurred between April and September.

Introduction

The Hindu Kush-Himalayas is the source of Asia's six mighty rivers – the Indus, Ganges, Brahamaputra, Mekong, Yangtze and Yellow rivers. These arise in the Himalayas and flow down to the plains where they support the plains agriculture that feeds hundreds of millions of people (Banskota 2001). The environment of many Himalayan watersheds is degrading with poorly managed human activities leading to accelerated erosion. The most significant and obvious problem is the extensive deforestation of mountain slopes. This is happening as forests are converted into agricultural fields, and due to the unsustainable harvesting of firewood and timber, destruction caused by grazing animals, and forest clearance for the development of infrastructure.

The sustainable management of mountain watersheds is of global importance. The heavy monsoon rains and fragile geology pose major threats to the stability of the upland areas of the Hindu Kush-Himalayas. The expansion of agriculture, forest exploitation and populations are causing much degradation. Within upland watersheds and below, landslides and floods inflict much loss of life and damage to property and infrastructure (Suhail 1999).

The increasing population of the Hindu Kush-Himalayan region is creating a great demand for more farming land. The conversion of forests into agricultural land is accelerating whilst high population densities put more pressure on water resources. The main water problems are concerned with quantity, with too much water during the rainy season and too little in the dry period. In many places groundwater sources are being depleted and springs are drying up. Studies in Nepal show that communities on hill ridges face acute water shortages (Merz et al. 2000).

During the monsoon vast amounts of water leave the upland watersheds as surface runoff, causing slope erosion and sedimentation and flooding problems downstream. It has yet to be established to what extent these processes affect downstream areas (Bruijnzeel and Bremmer 1989).

This paper discusses the findings of runoff and soil loss research carried out by the People and Resource Dynamics in Mountain Watersheds of the Hindu Kush-Himalayas Project (PARDYP) in its five watersheds in China, India, Nepal and Pakistan. It focuses on the key factors that impact runoff and soil loss in these watersheds. The aim of these studies is to assess soil erosion, runoff and its seasonal distribution with the aim of providing recommendations on improving the use of runoff water and better controlling erosion.

Runoff and Soil Erosion Measurements

A network of hydrological stations, meteorological stations, and erosion plots were set up during 1998/1999 in the five PARDYP watersheds (Table 8.1). Ninety-four measurement sites were set up with daily measurements taken by local readers. These readers receive annual training sessions to keep them informed and motivated about their work.

Table 8.1: **Measurement sites in the five PARDYP watersheds**

Watershed	Hydrological stations	Meteorological stations	Erosion plots
Xizhuang - China	5	10	6
Bheta Gad - India	6	5	4
Jhikhu Khola - Nepal	5	10	7
Yarsha Khola - Nepal	6	11	4
Hilkot - Pakistan	5	6	4

In all the watersheds rainfall is measured using automatic tipping buckets, siphon rain gauges, and manual rain gauges. The readers record daily rainfall from the manual rain gauges. Siphon rain gauge charts for recording rainfall are replaced weekly. For the tipping buckets, the field hydrologist downloads the data once a month using the BoxCar programme. Tipping buckets and standard rain gauges are installed close to each erosion plot.

Information on the study erosion plots in the five watersheds is given in Table 8.2. These plots were selected for study because these were under similar land uses in all watersheds.

Surface runoff and soil loss was recorded from the 5 x 20m erosion plots ($100m^2$) for the different land uses in all five watersheds. The erosion plots were closed on the top and at either side with galvananised metal sheets pushed 15 cm into the ground with 30 cm sticking out.

Table 8.2: **Characteristics of the study erosion plots**

Site no.	Watershed	Site name	Land use	Elevation (masl)	Slope (degrees]	Textural class/soil type
4	Jhikhu Khola	Baghkhor	Grassland	940	11.5	Loam
6		Bela	Rainfed terrace	1240	20.4	Loam
14a		Kubindegaun	Degraded	880	15.0	Loam
14b		Kubindegaun	Degraded land planted with broom grass hedgerows	880	16.2	Sandy clay loam
16		Bhetawalthok	Rainfed terrace	1200	6.7	Sandy clay loam
5	Yarsa Khola	Thulachaur	Grass/shrub	2300	19.1	Sandy loam
6		Jyamire	Rainfed terrace	1950	17	Sandy loam
9a		Namdu	Rainfed terrace	1410	17.5	Loam
1	Bheta Gad	Majherchaura	Pine forest	1460	18.5	
3		Kaulag	Rainfed agriculture	1390	2	
4		Khaderia	Degraded	1350	28	
XE3a	Xizhuang	Wajintang	Pine forest	1860	12	Red soil
XE3b		Wajintang	Grassland	1860	14	Red soil
XE4c		Xizhuang	Farmland	1650	14	Red soil
1	Hilkot	Syed abad	Degraded	1677	22.7	Silt
2		Maira	Pasture	1707	19.6	Silt loam
3		Bojri	Forest	1707	19	Loam
4		Maira	Rainfed agriculture	1723	9.9	Silty clay

The lower end of each plot was left open for the gutter to divert runoff water and sediment into the collection system. The gutter was metallic and 5m long across the plot width. Rainwater ran off the plot and accumulated in the metallic gutter and flows into a drum. All plots were the same size but the slopes differed.

Four drums were placed in series below the outlet point on each plot (Figure 8.1). Where runoff is high, a splitter device was installed at the third drum's outlet. This meant that after the third drum was full then the water in the fourth drum represented only a tenth of the total actually passing into it. The volume of the runoff from the erosion plots was measured based on the amount of water collected. After each rainfall event, the volume of water in each drum was noted and sediment samples taken from each drum. For sampling, water in the drum was first agitated to mix the fine and course sediment. A composite sample of one litre was then taken from each drum. Each sample was tagged with a reference number and then the samples were filtered in the laboratory and oven dried to calculate the amount of sediment.

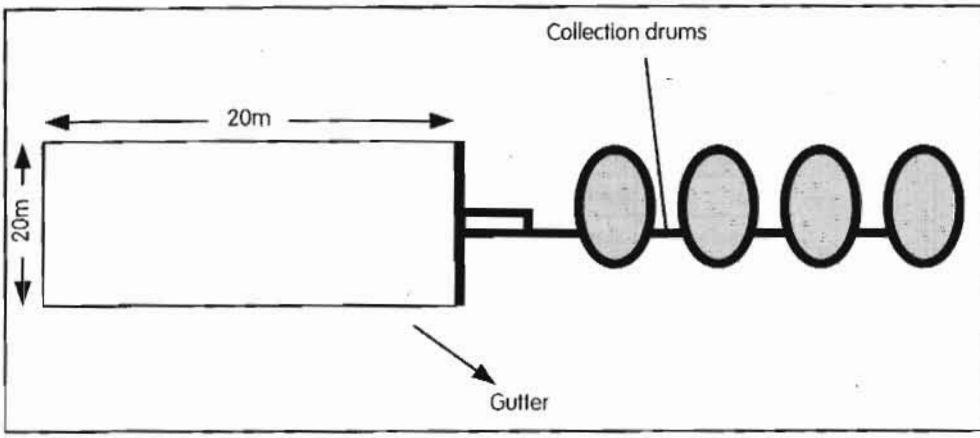

Figure 8.1: **Layout of erosion plots**

Samples were processed in the field laboratory by first drying a filter paper in an electric oven at 60-650C and weighing it before it could recapture any moisture. Then, a 100 ml sample from the drums was filtered through the filter paper following which the filter paper with sediment was dried and weighed while still warm. The weight of the sample was calculated using the following formula with grams as the unit of measurement:

Net weight of sediment = (weight of filter paper + sediment) — dry weight of filter paper (g)

All calculations were performed using an MS Excel macro developed by PARDYP (Nakarmi 1999). This creates a data entry sheet and calculates and summarises the data. Runoff and soil loss values were calculated in per hectare units. Common procedures were developed to allow results from the five watersheds to be compared. Hofer 1998b provides common guidelines for data collection, data handling, analysis, and processing. The readers and researchers responsible for collecting and analyzing data have been trained on these standard procedures. Also, researchers have visited other watershed study sites to compare approaches and to share data collection and analysis experiences and techniques. Data is cross checked within watersheds and across watersheds to maintain quality.

The type of land use and the period for which data is available from the five watersheds is shown in Table 8.3.

Table 8.3: **Available data sets for runoff studies in the five PARDYP watersheds**

	YK	JK	BG	HK	XI
Degraded					
Pasture					
Agriculture					
Forest					
Data period for the watersheds					
	YK	**JK**	**BG**	**HK**	**XI**
1999					
2000					
2001					
2002					

YK - Yarsha Khola, Nepal; JK - Jhikhu Khola, Nepal; HK - Hilkot, Pakistan, BG - Bheta Gad-Garur Ganga, India; XI - Xizhuang, China

Results

Rainfall

Monthly rainfall – The monthly rainfall varies in the five watersheds, but in all of them the most rainfall occurs during the monsoon (Figure 8.2). In the study period the Yarsa Khola watershed registered the highest month's rainfall with 716 mm in July 2000. The Jhikhu Khola's highest rainfall during the measured four years was 496 mm in July 2002. The most monthly rainfall for the other watersheds was 522 mm in Bheta Gad in August 2000, 458 mm in Xizhuang in September 2000, and 281 mm in Hilkot in March 1999.

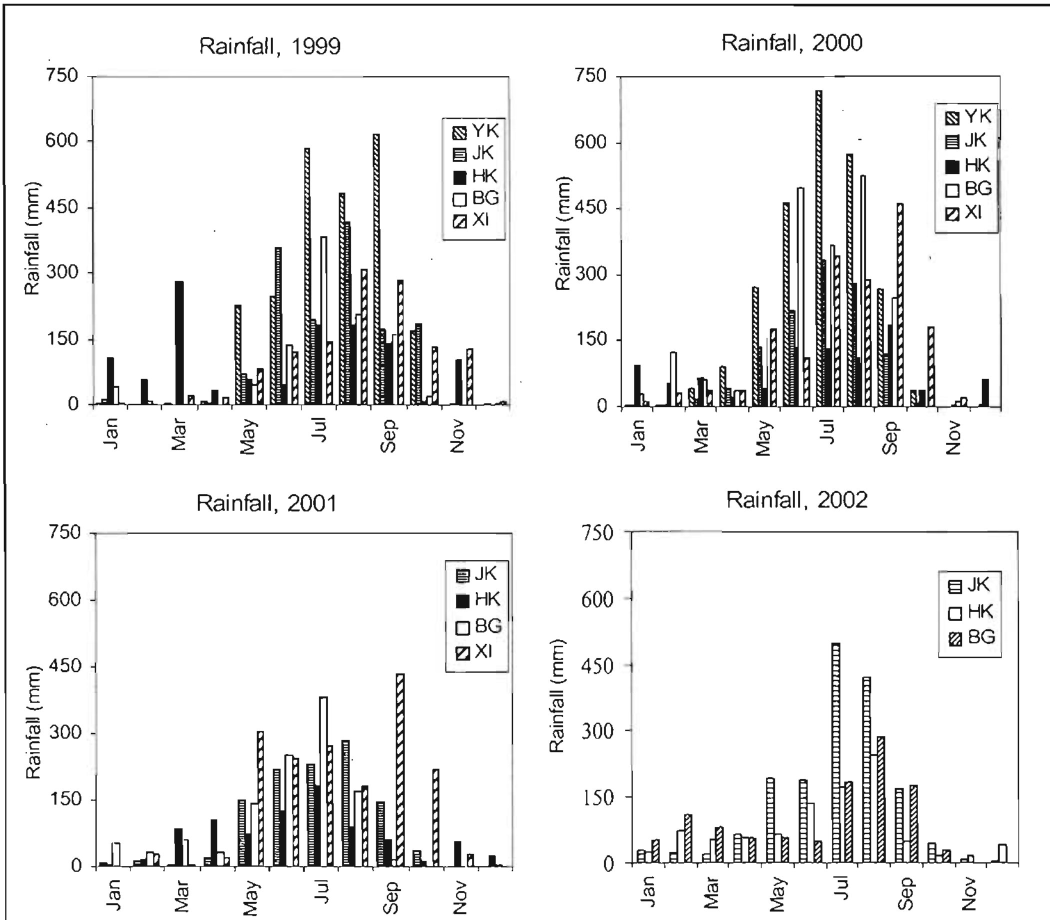

Figure 8.2: **Monthly rainfall data for five PARDYP watersheds, 1999-2002**

Annual rainfall – Annual rainfall in the five watersheds ranged from 800 mm to 2400 mm between 1999 and 2002. In this period the Yarsa Khola had the highest annual rainfall with 2469 mm in 1999 whilst Hilkot had the lowest with 837 mm in 2001 (Table 8.4).

Quarterly rainfall distribution – Between 44% and 66% of all rainfall occurred between July and September at all five sites corresponding with the monsoon season. The April to June period received between 22 and 30% of rainfall. The October to March period was largely dry except for Hilkot (Figure 8.3a). Yarsa Khola and Jhikhu Khola receive almost all their rainfall

Table 8.4: **Annual rainfall totals in the five PARDYP watersheds**

	1999	2000	2001	2002	Average
Yarsa Khola	2343	2469	na	na	2406
Jhikhu Khola	1419	1167	1110	1656	1338
Hilkot	1197	948	837	946	982
Bheta Gad	1011	2048	1147	1089	1322
Xizhuang	1254	1689	1706	na	1550
na - not available					

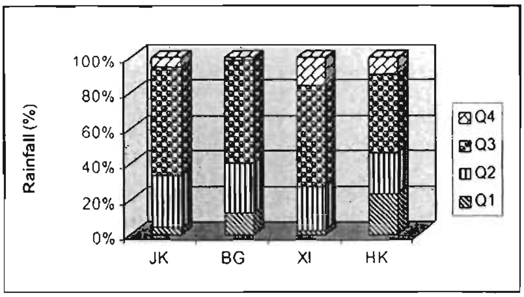

Figure 8.3a: **Quarterly distribution of rainfall**

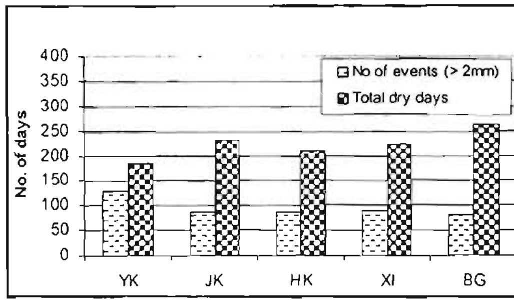

Figure 8.3b: **Rainy and dry days in watersheds**

between April and September with negligible winter rain. In contrast Hilkot receives rainfall throughout the year and, in contrast to the other areas, gets significant winter rainfall.

Rainfall intensity – Rainfall intensity, vegetation cover, aspect and slope have a direct impact on runoff and soil erosion. The maximum hourly rainfall intensity measured in Pakistan was 42 mm, which amounts to only half of the highest Nepal amount of 80 mm. Rainfall intensity is higher in the watersheds during the monsoon season. The monsoon usually starts in early June in India, in mid-June in Nepal, and in July in Pakistan. In India and Nepal high intensity rainfall events are more common in June and early July. In the Hilkot, Pakistan watershed, where rainfall occurs throughout the year, there are few high intensity rainfall events. In Nepal, most runoff and soil erosion occurs during monsoon high intensity rainfall events.

Runoff

Annual runoff

The highest measured runoff was recorded in the Yarsha Khola and Jhikhu Khola watersheds for all land use types (Figure 8.4). The rates of runoff were very low in Bheta Gad and Hilkot due to low amount and intensity of rainfall. The runoff from the different land uses differed widely due to differences in vegetative cover, soil texture, slope, and other factors.

On the degraded land plots the most runoff recorded from the Jhikhu Khola treated (planted with broom grass hedgerows) and untreated degraded plots was 6740 m^3/ha. The lowest recorded amount was from the Hilkot degraded plots where it ranged between 505 and 756 m^3/ha annually. In Bheta Gad the annual values ranged from 510 to 2262 m^3/ha over the four years.

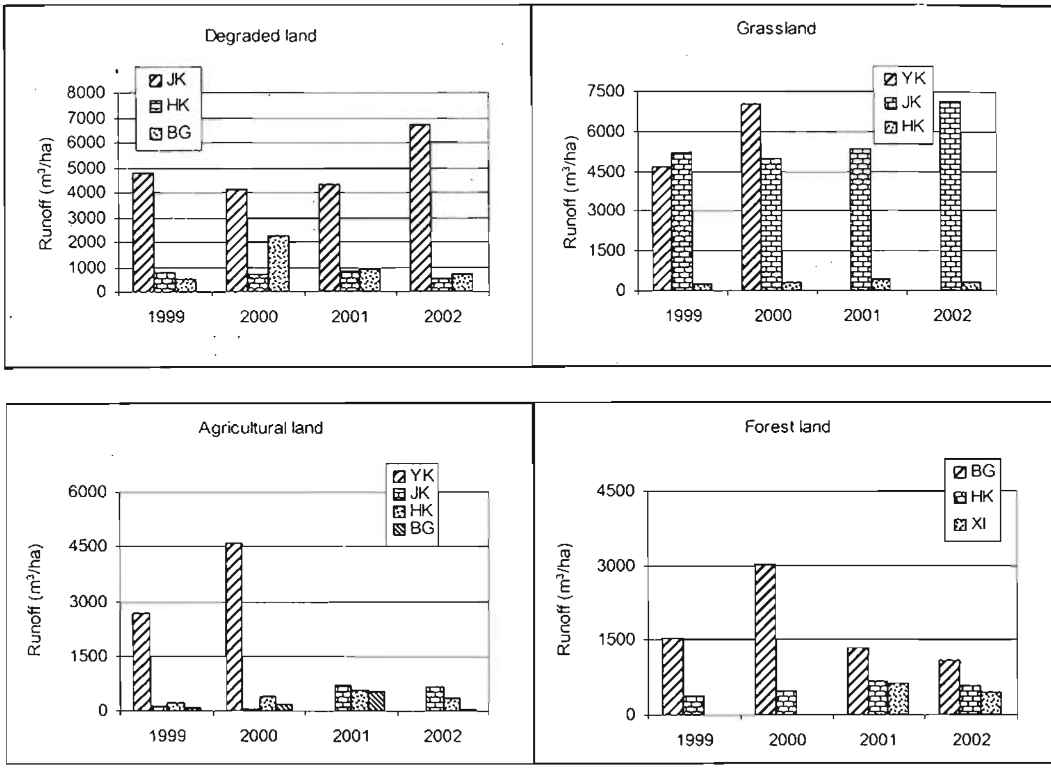

Figure 8.4: **Annual runoff from four types of erosion plots in PARDYP watersheds**

On the grassland plots the highest annual runoff was recorded in the Jhikhu Khola plots with up to 7142 m^3/ha and Yarsa Khola with up to 7040 m^3/ha. The lowest annual runoff on this type of plot happened in Hilkot with between 226 and 436 m^3/ha over the four years. Runoff was also very low on the Xizhuang grassland plots.

Annual runoff from agriculture land was very high in Yarsha Khola at 4587 m^3/ha. Runoff at Yarsha Khola was the highest due to the lesser vegetation cover and the high intensity rainfall. In the Jhikhu Khola watershed only 50 and 61 m^3/ha annual runoff were recorded due to the plot being on well maintained agricultural terraces.

On the forest erosion plot the highest runoff was recorded at Bheta Gad with between 1102 and 3026 m^3/ha. The amount of runoff was low in Hilkot and Xizhuang's forest plots.

Distribution of runoff

The monthly results show higher levels of runoff occurring from May to September when rainfall duration and intensity is highest in all the watersheds. The monthly runoff was the highest:

- from the degraded land plots in the Jhikhu Khola with 2068 m^3/ha in July 2002;
- from the grassland plots in the Yarsa Khola in July 2000 with 2235 m^3/ha;
- from the agriculture plot in Yarsa Khola with 1822 m^3/ha recorded in July 2000 (runoff from the Bheta Gad agriculture plots was very low at 62 m^3/ha); and
- from the forest plots in Bheta Gad with 938 m^3/ha.

High intensity monsoon rainfall caused most annual runoff on all land use types in all watersheds. Figure 8.5 shows that in Yarsha Khola more than 92% of runoff, and in Jhikhu Khola 92% to 96% of runoff in all land uses occurred between April and September. There was almost no runoff in these two watersheds from January to March. In Hilkot, 75% and 90% of runoff occurred between April and September and only 6-7% in the October to December period. In Bheta Gad between 83% and 94% of runoff occurred between April and September. There was low runoff in the January to March period except in the Bheta Gad and Hilkot degraded plots where 15% of runoff happened in this period. At Xizhuang 87% to 90% of runoff was recorded in the April to September period. No runoff was recorded in the January to March period at Xizhuang across all land uses.

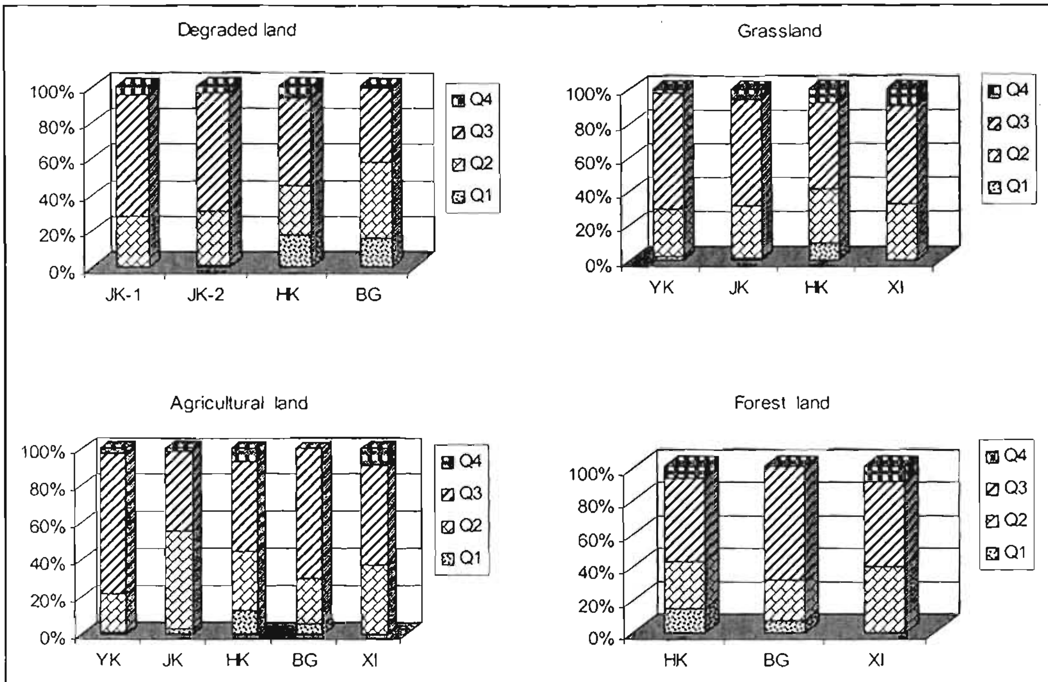

Figure 8.5: **Quarterly distribution of runoff from PARDYP watersheds**

Biggest runoff events

A runoff event is the point during rainfall where the intensity of rainfall exceeds the soils infiltration capacity. Such events contributed the major portion of total annual runoff from different land uses in all watersheds. Runoff events in Jhikhu Khola were larger than other watersheds especially in the degraded and grassland plots. The biggest runoff events in the watersheds were:

- in the Jhikhu Khola area, with 588 m^3/ha of yearly runoff on the grassland plots, and the second-most in the Jhikhu Khola degraded plot with 561 m^3/ha. This is thought to be because of the negligible infiltration of the rainfall into the surface. In this area about seven events of over 300 m^3/ha occurred on the degraded and grassland plots between 1999 and 2002;
- in the Yarsha Khola area – 320 m^3/ha on the grassland plot;
- in Bheta Gad – at 300 m^3/ha on the degraded and forest land (runoff on the agricultural plot was very low due to good terrace management including grasses planted on risers);

- in Hilkot – only 80 m^3/ha on the grassland plot; and
- in Xizhuang – generally low with only between 28 and 33 m^3/ha.

Soil loss

Annual soil loss

Rainfall and surface runoff are responsible for the detachment of particles on the land surface. Sediment from upland catchments is delivered to a stream and then transported downstream. The results of the soil loss studies for the four land use types were as follows (Figure 8.6).

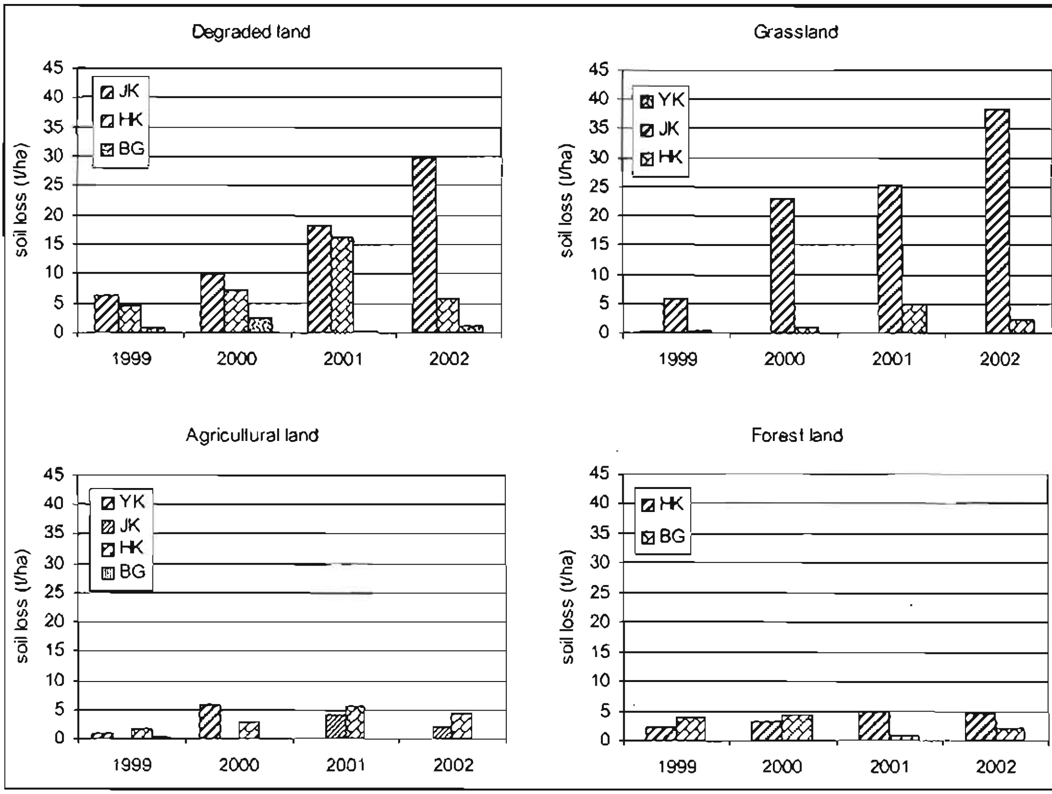

Figure 8.6: **Annual soil loss from land use plots in the PARDYP watersheds**

- In the degraded land plots annual soil loss was highest in the Jhikhu Khola watershed on the treated degraded land in 1999 at 40 t/ha when the broom grass was newly planted. In the same year soil loss on the untreated plot was only 6.4 t/ha. In all four years soil loss was highest from the Jhikhu Khola degraded plots. On the Bheta Gad plots soil loss was very low probably because of its rocky soil.
- The Jhikhu Khola grassland plots had much higher annual soil loss than the Yarsa Khola and Hilkot plots. The most soil loss was 38 t/ha at Jhikhu Khola in 2002 due to the sparse vegetative cover on its plots. In the Yarsha Khola and Hilkot there was hardly any soil loss due to the well-established vegetative cover and compacted soil on the plots.
- The total annual soil loss on the agricultural plots was low. Most was recorded from the Yarsha Khola in 2000 at 5.7 t/ha of soil lost. The negligible losses from Bheta Gad were

probably due to the well-maintained terraces and the dense grasses grown on the terrace edges. This suggests that current farmer practices prevent soil erosion.

- On the forest plots annual soil loss was similar in all watersheds with a range of 0.93 to 4.35 t/ha in Bheta Gad, 2.17 to 4.6 t/ha in Hilkot and 1.32 to 3.89 t/ha in Xizhuang.

Monthly soil loss

For the degraded plots most soil erosion was recorded from the Jhikhu Khola's treated degraded plot in August 1999 at 18 t/ha when the plot was newly established. Due to the planting of broom grass hedgerows soil erosion reduced to less than 1 t/ha/year in 2002. The maximum soil loss on the Jhikhu Khola's untreated degraded plot was 12 t/ha in June 2002. Hilkot recorded a high of 5.5 t/ha in June 2001 on its degraded plot. The main reasons for the high soil losses on these degraded plots was the sparse vegetation and the soil type (sandy loam). Soil loss was very high in the Jhikhu Khola at a maximum of 10 t/ha but very low on the grassland sites in Hilkot, Xizhuang, and Yarsha Khola.

In the agricultural plots soil loss was comparatively low because most rainfall occurs in the monsoon period when the plots were well-covered with vegetation. The highest monthly loss was recorded in May and June at Hilkot and Jhikhu Khola because at that time the plot soil was bare and the high intensity rain eroded much of the soil away. After July, when the plant cover had established, soil loss became very low for the rest of the year – much lower than from the degraded and grassland sites. In the forest plots soil loss was comparatively high in Hilkot and Bheta Gad watersheds as compared to other watersheds. Maximum monthly soil loss was recorded at Bheta Gad in September 1999 at 3 t/ha. See Figure 8.7 for graphical representation on monthly soil loss data for all watersheds and land use types.

Distribution of soil loss

Monsoon rainfall in the five watersheds is often of high intensity causing sudden runoff and much soil loss. All the plots show the highest rates of soil loss in the April to September monsoon period. Soil loss in the April to September period across all land types accounted for 95% to 99% of Yarsha Khola and Jhikhu Khola soil loss, 80% to 90% of Hilkot soil loss, 83% to 96% of Bheta Gad soil loss, and 90% of Xizhuang soil loss (Figure 8.8). Soil loss in the January to March period was negligible on all land uses.

Biggest soil loss events

The highest levels of soil loss at one time occurred pre-monsoon when the land surface was desiccated and in the early monsoon when fields were bare and vulnerable to erosion. High intensity rainfall in June-July will cause much soil erosion as the newly planted crops have not developed. Heavy rain that occurs when surface cover is only partially developed are very likely to cause significant soil losses. The highest single soil loss event on the degraded plots was about 10 t/ha and 7.5 t/ha on pasture land in the Jhikhu Khola watershed. In Hilkot only one big soil loss event was recorded with 3 t/ha lost at a time of year when the soil was bare and soft after sowing. On Hilkot's degraded plot one soil loss event of 2.2 t/ha was recorded while all other events on all land uses in Hilkot were below 1 t/ha due to good vegetative cover. There was only one significant heavy soil loss event in the Bheta Gad watershed with 2 t/ha lost from the forest plot.

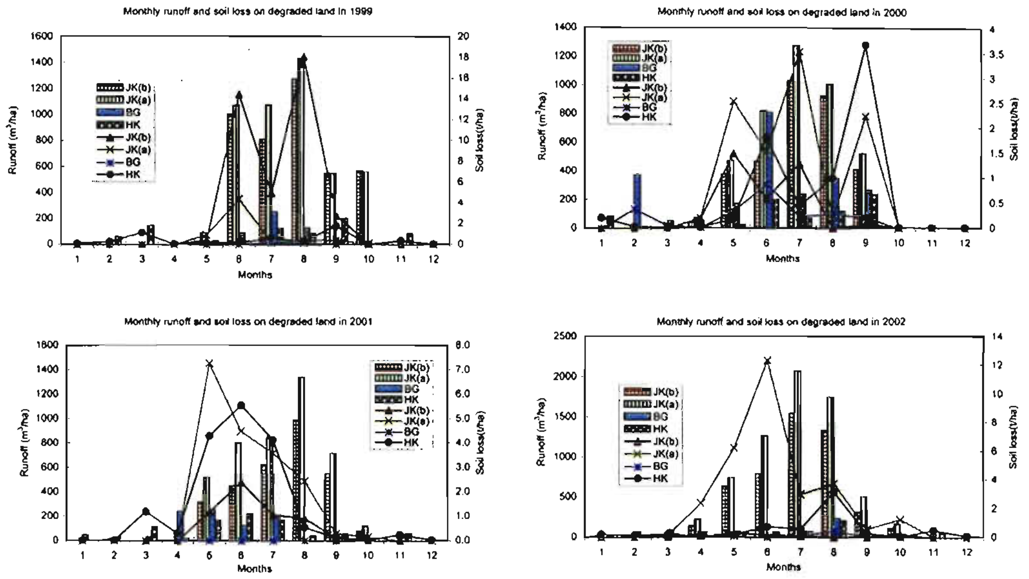

Figure 8.7a: **Monthly runoff and soil loss on degraded land PARDYP plots, 1999-2002**

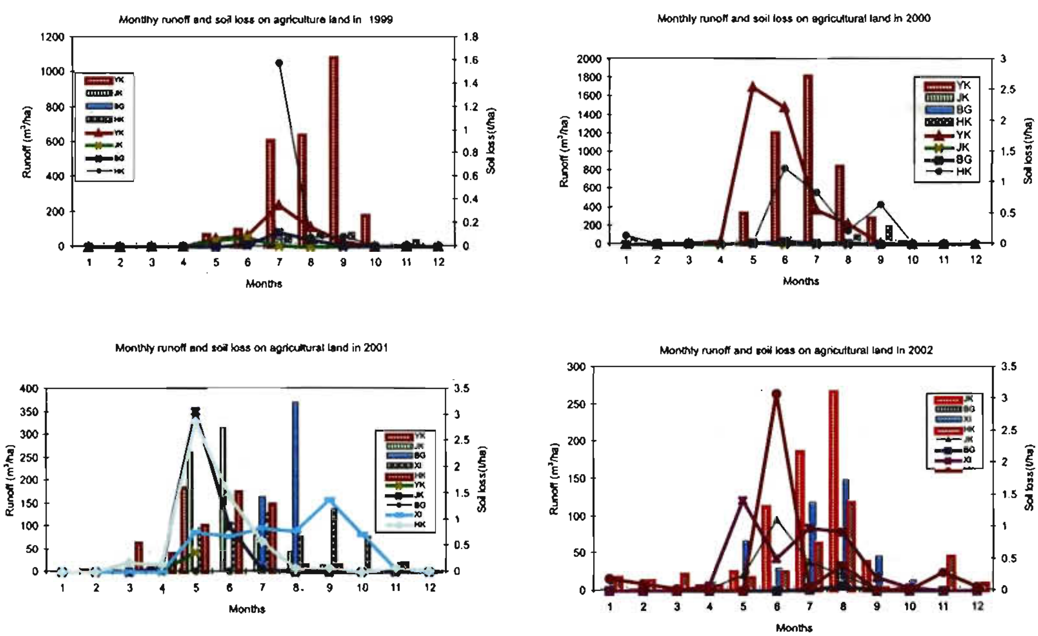

Figure 8.7b: **Monthly runoff and soil loss on agricultural land PARDYP plots, 1999-2002**

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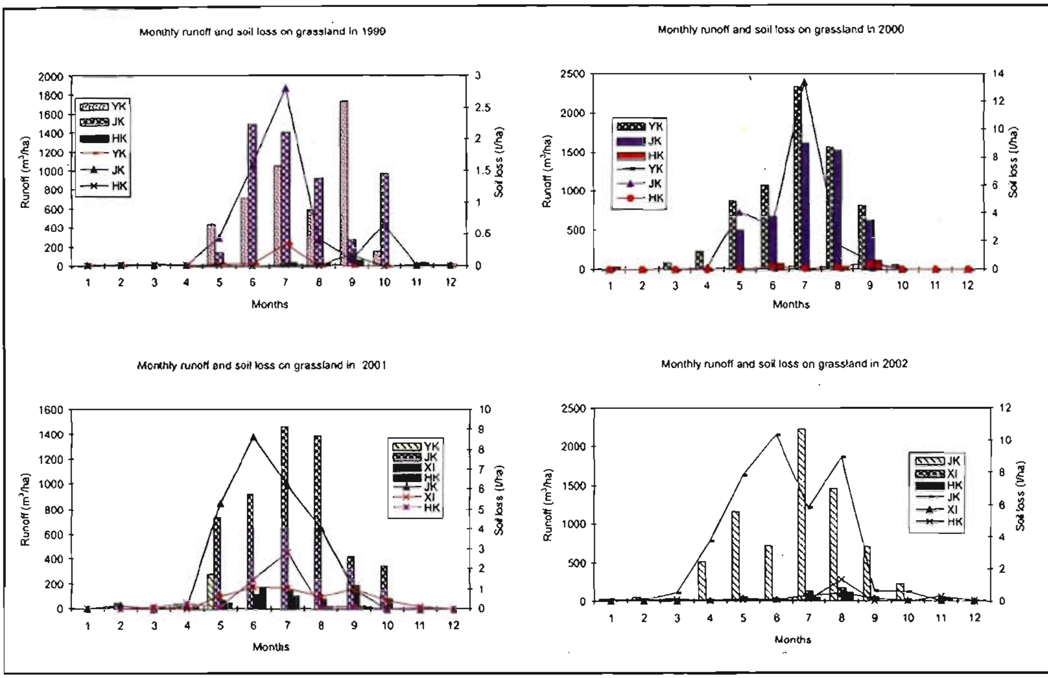

Figure 8.7c: **Monthly runoff and soil loss from grassland PARDYP plots, 1999-2002**

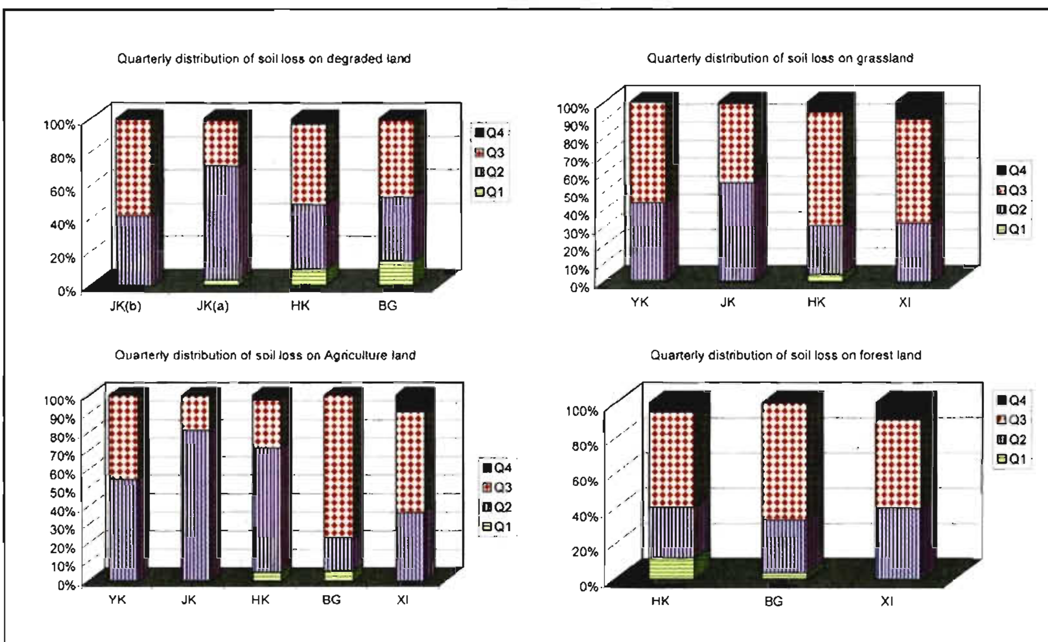

Figure 8.8: **Quarterly distribution of soil loss from different land uses**

Rainfall-runoff relationship

Runoff was measured on degraded, forest, grass and agriculture land in most of the watersheds on equal area plots of 100m². A meteorological station was placed at each plot. Table 8.5 shows the recorded relationship at all sites between rainfall and runoff, runoff and soil loss, and between rainfall and soil loss. The general trend unsurprisingly shows that runoff increases with increased rainfall and decreases with decreased rainfall. There is a clear and strong relationship between rainfall and runoff on most plots. This rainfall-runoff relationship was very strong in both agriculture and grassland for the Yarsha Khola where R2 value were about 92% and 95% respectively. On the Jhikhu Khola plots this relationship was very weak on the degraded (12%) and agriculture (19%) plots, but very strong for grassland (83%).

On the Bheta Gad plots a strong relationship was found between amount of rainfall and amount of runoff in the forest plots (73%) while in degraded land it was only 28%. In Xizhuang the rainfall-runoff relationship was very strong across all land uses and was strongest on the agricultural plot at 94%. In Hilkot the rainfall-runoff relationship was similar in all four plots ranging from 55% in the forest plot down to 38% for the grassland.

8

Runoff-soil loss relationship

Runoff water plays an important role in soil erosion. The results of the statistical analysis (Table

Table 8.5: Relationship between rainfall, runoff, and soil loss in terms of R^2 values for different land uses in PARDYP watersheds

Watersheds	1. Rainfall-runoff relationship			
	Degraded	**Pasture**	**Agriculture**	**Forest**
Yarsha Khola	na	0.95	0.92	na
Jhikhu Khola	0.12	0.83	0.19	na
Bheta Gad	0.28	na	0.56	0.73
Xizhuang	na	0.88	0.94	0.90
Hilkot	0.48	0.38	0.44	0.54
	2. Runoff-soil loss relationship			
Yarsha Khola	na	0.32	0.30	na
Jhikhu Khola	0.27	0.21	0.45	na
Bheta Gad	0.46	na	0.55	0.44
Xizhuang	na	0.78	0.79	0.67
Hilkot	0.69	0.55	0.23	0.86
	3. Rainfall-soil loss relationship			
Yarsha Khola	na	0.29	0.30	na
Jhikhu Khola	0.02	0.06	0.04	na
Bheta Gad	0.41	na	0.19	0.30
Xizhuang	na	0.80	0.96	0.67
Hilkot	0.33	0.24	0.19	0.38

Note: R^2 values show the relationship between two parameters — the effect of one factor on the other. However, many other factors also have effects which is why relationships vary at different times.

8.5) show that in the Yarsha Khola plots the relationship was only 30% for the agricultural plot and 32% for the grassland plot. In the Jhikhu Khola the relationship was 45% for the agriculture plot but 2% for the degraded plot. In Bheta Gad the relationship was quite good between runoff and soil loss on all plots (45 to 55%). Xizhuang had very good relationships ranging from 79% on the agricultural plot to 67% on the forest plot. In Hilkot the relationship was very good on all plots except for agriculture where it was only 15%. This is explained by the fact that in this area, although there is not so much rain in the pre-monsoon season, runoff and soil loss is quite high due to the bare and loose soil being exposed to the rain that does occur. The strongest runoff-soil loss relationship at Hilkot was on the forest plot (86%).

Rainfall-soil loss relationship

Intense rainfall plays a major role in detaching soil and moving it downhill. The relationship between the amount of rainfall and the amount of soil loss on a monthly basis in the erosion plots were also calculated (Table 8.5). The rainfall-soil loss relationship was not very strong across all land uses. This is probably mainly because of rainfall intensity, soil texture, plant cover, rainfall duration and previous rainfall history causing soil erosion. If the soil is already saturated from previous rainfall the infiltration will be reduced and more runoff will occur resulting in more soil erosion.

Forests tend to check soil erosion because of their ground vegetation and litter and the stabilising effect of their root networks. On steep slopes the net stabilising effect of trees is usually positive. Also, it is believed that vegetation cover can prevent shallow landslides from occurring (Bruijnzeel 1990) although large landslides on steep terrain are not influenced by vegetation cover.

Analysis of the study results show a good rainfall-soil loss relationship in Yarsa Khola on the agricultural and grassland plots with a 30% relationship recorded. The Jhikhu Khola plots showed a weak relationship across all land use types. At Bheta Gad the strongest rainfall-soil loss relationship was on the degraded plot (41%). The Xizhuang results showed a very good relationship on all three plots with a 96% relationship on the agriculture plot. In Hilkot the best relationship was on the forest plot (38%) due to it being protected from rainfall by the forest canopy while on the agriculture plot it was only 19% due to the intensity, time and duration of rainfall at the times when there was little crop cover.

Findings and Conclusions

- Annual rainfall in the study areas ranged from 800 mm to 2400 mm in the 1999 to 2002 period. Between 44% and 66% of rainfall occurred in the July to September period mostly in the monsoon season. The April to June period received between 22% and 30% of rainfall.
- The amount of rainfall lost through runoff was 37% from the Jhikhu Khola plots, 24% from the Bheta Gad plots, and 7% from the Hilkot plots. About 75% to 95% of runoff was recorded in the April to September period.
- Most runoff and soil loss was recorded in the monsoon. In all five watersheds 80 to 99% of soil loss occurred between April and September.
- The results from the erosion plots showed that runoff increases with increased rainfall and decreases with decreased rainfall.
- Runoff and soil losses were highest in the agricultural land when the land was being prepared for sowing as the soil is loose and most susceptible to erosion at these times. Soil erosion is less when the land is covered with crops.

- The erosion rates from forest and grasslands were low due to the presence of ground cover. Good crop canopies reduce the rainfall intensity and increase soil infiltration consequently reducing runoff and soil losses. Also, soil loss is less in forest areas as an area densely covered with vegetation yields less runoff than bare ground.

Recommendations

- In studies of runoff and soil erosion, treated and control (untreated) plots should be established for every land use to compare results and see the impact of treatments.
- New advanced types of data collection techniques and analysis tools enable the comparison of results from different areas and countries.
- Data analysis models need to be developed for regional data analysis.
- Vegetation cover should be improved in the PARDYP watersheds to improve the infiltration of soil and control runoff and soil loss.
- Water harvesting technologies should be applied to collect water lost as runoff during the monsoon to use in the dry periods to get maximum advantage from water resources in the PARDYP watersheds.

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