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A great deal has been written about the relationship between landsliding and land use change, especially deforestation, in the Himalaya. But few detailed quantitative studies have examined this relationship. The present article reports the results of a 3-year study of landsliding in 4 subcatchments of the Likhu Khola drainage basin in the Middle Hills, Nepal. During the years of study (1991–1993), 381 landslides were noted, the vast majority of which were small failures on the risers of irrigated terraces (khetland). Although significant in terms of labor input, these failures were insignificant with respect to land degradation and overall denudation. Most significant were larger failures on abandoned terraces and degraded forest. It was estimated that the average annual soil losses from the main land uses were 0.48 ton/ha for irrigated terraces, 3.65 ton/ha for rainfed terraces, 1.86 ton/ha for grassland, 0.80 ton/ha for forested land, and 23.95 ton/ha for forest scrub and abandoned land. The combined average erosion rate was 5.55 ton/ha. Thus, deforestation does not necessarily lead to large soil losses from landsliding; much depends on how the land is managed after deforestation.

Keywords: *Landsliding; land use; land degradation; deforestation; Himalaya; Nepal.*

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Introduction

During the 1970s and into the 1980s many people believed the Himalayan region was experiencing environmental degradation on a major scale. Increasing population pressure was leading to agricultural expansion onto steeper and more marginal land, and massive deforestation was perceived. The views of Eckholm (1975) and the predictions of almost total deforestation in the hills of Nepal by 1993 (World Bank 1979) added weight to this scenario. These ideas have been summarized by Ives and Messerli (1989) in the 8 components of what has come to be known as the Theory of Himalayan Environmental Degradation. The supposed cause and effect relationship can be expressed in graphic form (Figure 1). Increased landsliding as a result of land use change, especially deforestation, is a major component of this scenario and is the basis of points 4 and 5 in the 8-component degradation model.

The scenario as outlined appears eminently sensible, but many elements have been challenged, not the least by Ives and Messerli (1989). One problem is the extreme difficulty in establishing the specific links within the model. Thus, as argued by Thompson and Warburton (1988, p 1), a "complex series of interactions between man and nature in the Himalayan region has many experts from various disciplines speculating about the probable cause of events in the area."

It was for this reason that an interdisciplinary project was undertaken in the Middle Hills of Nepal between April 1991 and March 1994 to provide accurate and reliable field data on environmental processes relevant to an evaluation of the future sustainable development of soil and water resources (Gardner and Jenkins 1995). The overall aim of the project was to provide better understanding of the processes and rates of soil erosion and the characteristics of water quality and aquatic biology associated with different land use systems and, therefore, land use change. The results of the landslide component of the study are reported here, although brief comparisons are made with soil erosion rates.

Study area

The study area is located in the Likhu Khola watershed, to the north of Kathmandu (Figure 2). The area was chosen because of its wide range of land use systems, representative of those found in the rest of the Nepalese Middle Hills (Figure 3). Its nearness to Kathmandu means that the land is under intense pressure, with extensive use of chemical fertilizers and conversion of rainfed *bari* terraces to irrigated *khet* terraces with triple cropping in some areas. The 4 subcatchments chosen were of a suitable size for year-round monitoring and were characterized by different proportions of the various land uses, thereby enabling the influence of land use to be assessed. The existence of large areas of protected forest also provided good comparisons with other land uses, and there was good aerial photograph cover back to 1967.

The Likhu Khola is a tributary of the Trisuli drainage system that has its headwaters in the Langtang region of the High Himalaya. The study was conducted within 3 south-facing and 1 north-facing subcatchments, all of which are less than 5 km^2 in area. Altitude varies between 600 and 1800 m, and the lithology is largely composed of gneisses of the Kathmandu Complex. The rocks are weathered to a depth in excess of 7 m, with the deeper parts dominated by silts and fine-medium sands. Most of the soils are freely drained and have been mapped by the Soil Survey Division of His Majesty's Government, Nepal, as Cambisols and Luvisols (Maskey 1995). On steeper slopes and where there has been past erosion, soils are essentially Arenosols,

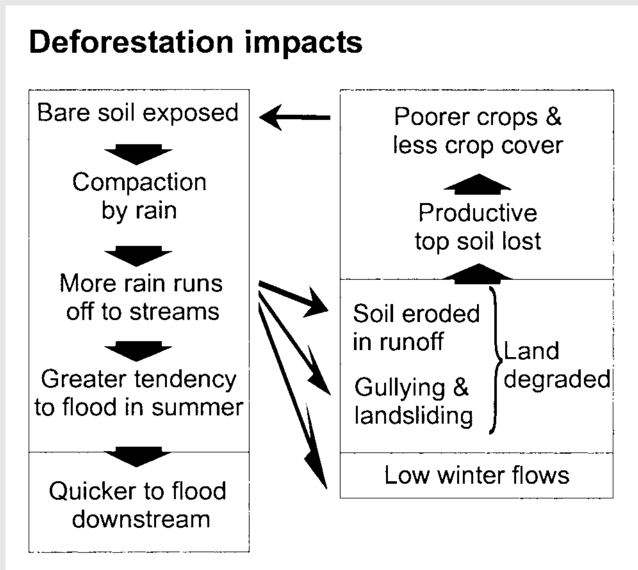

FIGURE 1 A representation of the degradation scenario sketched for the Himalaya. (Adapted from Gardner and Jenkins 1995)

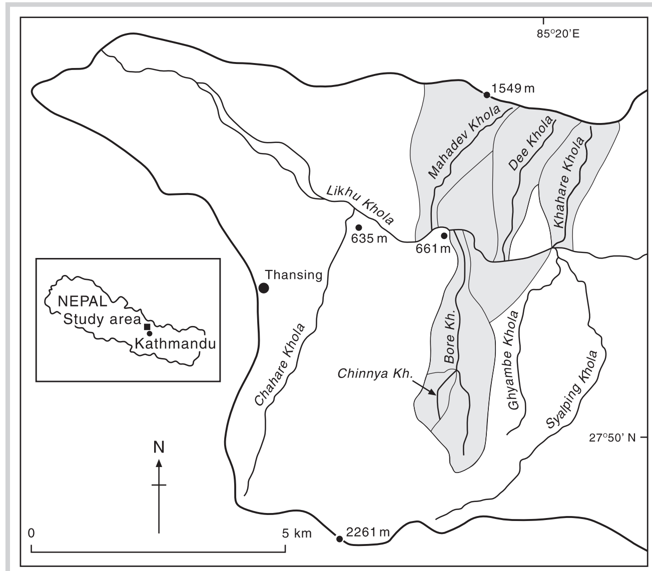

FIGURE 2 General location of the study area, Middle Hills, Nepal. (Map by John Gerrard)

Regosols, and Leptisols. Slope angles are generally steep, with usually over 25% of the slopes being steeper than 30° and over 70% steeper than 20°.

The natural land cover of the area is subtropical with tropical hardwoods on the lower slopes and mixed broadleaved formations at higher altitudes. But much of the forest has been cleared for 3 main types of agricultural land: grazing, *bari,* and *khet.* Bariland comprises relatively gently outward-sloping rainfed terraces, frequently with a ditch at the back of the terrace to minimize overland flow and erosion. Khetland represents the system of irrigated terraces usually used for the growing of rice (Figure 4). It is important to make the distinction between double-irrigated and single-irrigated khetland. Double-irrigated khetland produces 2 rice crops, 1 during the premonsoon period and 1 during

FIGURE 3 General view of the Dee subcatchment of the Likhu Khola (visible in the foreground), with *khet* terraces on the lower slopes and patches of woodland and *bari* terraces on the higher slopes. A few landslide scars are visible. (Photo by John Gerrard)

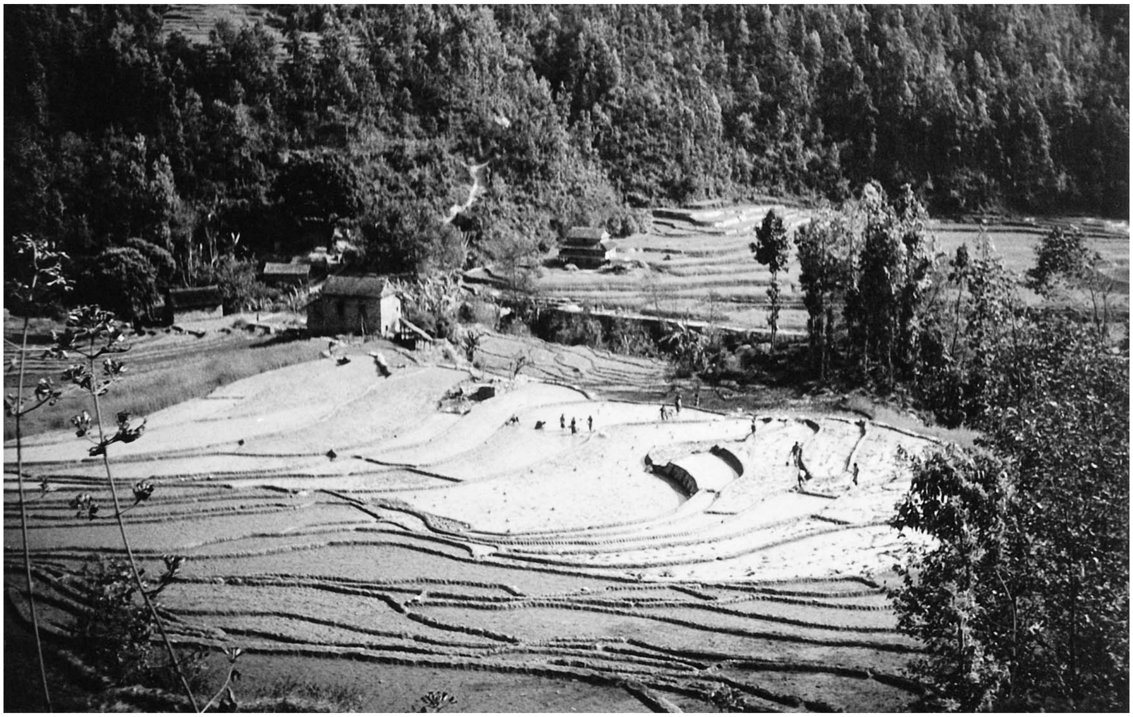

FIGURE 4 Rice transplanting on *khet* terraces low down on the valley side. Remnants of *sal* woodland in the background, in various states of degradation. (Photo by John Gerrard)

the main monsoon. Thus, these terraces are subjected to continued irrigation for a long period of time. Single-irrigated khetland is subject to natural climatic conditions during the premonsoon period and to artificial irrigation during the monsoon season.

The remaining areas of forestland are a source of fuelwood and fodder and are managed to some degree. Some areas have been planted with trees. A proportion of the land has been abandoned and taken over by shrubs and *sal* (*Shorea robusta*) scrub. This is often heavily degraded forestland that has not recovered; some of the abandoned land used to be *bari* terraces. Some of the grassland also occurs on old, degraded *bari* terraces. The proportions of land under the various land use and land cover types are shown in Table 1.

There have been changes in land use over the last 30 years. Cultivated land has increased markedly at the expense of former grassland areas; there has also been extensive conversion of bariland to khetland wherever irrigation has been possible. Bariland has expanded a bit onto the upper slopes but has also been abandoned high in the headwaters, close to the drainage divides. Some of this abandoned bariland has been forested, but some, as noted earlier, has been allowed to revert to grassland and sometimes to scrub. These changes and trends are broadly similar to those reported in the Land Resource Mapping Project overview of land use change in the Middle Hills of Nepal (LRMP 1986) and to the views expressed by the local farmers.

Methodology

The results presented here are for landslides that occurred in the 4 subcatchments in the years 1991, 1992, and 1993. As far as possible, all slope failures have been identified and measured. Classification of failure type has been kept as simple as possible. Two broad types, slumps and debris slides, encompass the majority of failures. Slumps are failures, often small, that occur as a relatively coherent mass on a gently curved failure surface. The commonest type was the failure of an individual agricultural terrace riser, with the material usually coming to rest on the terrace below. Debris slides break up on failure, are often quite shallow, and tend to travel further downslope. Such failures moved greater distances and sometimes reached the drainage channels.

All dimensions of the failures were measured, but the analysis presented here is in terms of the width of the failure scar and the volume of material involved. The failures have also been classified in terms of their connectivity with the overland flow pathways on the slope and the land use. Connectivity has been assessed as low, medium, and high. With high-connectivity failures, the material possesses a direct link to the drainage system and could have an immediate effect on river sediment loads. Also, in management terms, remedial measures would need to be established quickly to prevent widespread erosion and continuing instability. Low connectivity defines situations where none of the failed material is removed from the slope system. The failed mass is generally reworked into the terrace systems. Medium connectivity implies an intermediate situation where there is no immediate loss of material from the slope but where it is possible for overland flow and gullying to deliver sediment to river sources in the near future. Such failures also need immediate remedial action.

TABLE 1 Areal proportions of different land use types in the 4 subcatchments.

Land use	Area (ha)	Percentage of total area
Khet	378.7	30.6
Bari	205.5	16.6
Grassland	191.1	15.4
Forest	179.8	14.5
Scrub and abandoned	72.5	5.8

TABLE 2 Types, frequency, and size of failures in the 4 subcatchments.

Landslide type	Numbers (%)	Volume (m^3)	Average volume (m^3)
Slumps	290 (76.1)	2308.0	7.96
Debris/rock slides	87 (22.8)	30,101.3	345.99
Others	4 (1.1)	384.0	96.0

Rainfall totals for the 3 years of the study were slightly below the 1981–1991 average (2558 mm) recorded at Kakani, in the southern watershed of the Likhu basin. High-magnitude events were also not exceptional. Maximum continuous rainfall (defined as no breaks in monitored rainfall exceeding 30 minutes) from 1992 to 1993 was 102.4 mm. This magnitude in 1 day has a return period of approximately 1.7 years, using Kakani maximum 24-hour rainfall data from 1972 to 1986 as a baseline. Therefore, slope failures should reflect relatively normal rather than exceptional conditions.

Results

A total of 381 failures were recorded in the 4 subcatchments in the years 1991, 1992, and 1993, of which the vast majority were small slumps (Table 2). The number of debris slides was much lower, but the average size was considerably greater. The 4 failures in the other category were deep-seated rotational slides.

Most failures (65.6%) occurred on irrigated khetland, followed by bariland (9.7%) and grassland (6.8%). A number of failures (4.5%) occurred within the confines of old landslides. In many cases these former landslides had not completely recovered before a subsequent, albeit usually smaller, failure occurred. Fourteen failures (2.6%) were recorded on *sal* scrub and 10 (2.6%) on forested slopes. Failures are sometimes associated with irrigation channels (2.4%), usually as a result of seepage or lack of management of the channel sides. The main problem with these failures is that, until they are repaired, water escapes downslope and may initiate considerable erosion. Usually, however, such failures are repaired very quickly.

In terms of numbers, khetland appears to experience particular problems, but the vast majority of these failures involved a small volume (Table 3). The average volume of failures on khetland was 5.16 m^3, and only 5.6% of the failures were debris slides. The majority of the failures involved only a part of a terrace riser or sometimes the complete riser. Very rarely was more than one terrace involved. Of the 290 slumps recorded, 81% occurred in khetland. Only 16% of the debris slides occurred in khetland.

Although failures on bariland were fewer in number, they tended to be larger, with a higher percentage of debris slides. The average volume of a failure on bariland was 59.34 m^3. The average failure size on grassland was 224.42 m^3, with 56% being of the debris slide type. The percentage of debris slides on *sal* scrub was 86%, with an average volume of 766.67 m^3 for all failures. All the failures in old landslides were debris slides with an average volume of 376.6 m^3, and 50% of the failures in forests were debris slides with an average volume of 128.8 m^3 for all failures.

The large number of failures on khetland might suggest a possible problem with water management and the labor involved in repairing the failures; but the small size of failures would mean that khetland contributes little sediment to the drainage systems and has minimal denudation rates from landsliding. This tends to be substantiated when the connectivity of the failures with the drainage system is examined (Table 4). A very large percentage (90.8%) of the failures in khetland were in the low-connectivity group, and only 4.4% were assessed as possessing high connectivity. In contrast, 10.8% on bariland, 21.4% on *sal* scrub, 24.0% on grass-

TABLE 3 Number of slope failures on different land use types classified by volume.

Volume (m^3)	*Khet*	*Bari*	Grassland	Landslide	*Sal* scrub	Forest
0–1.9	149	7	6	0	0	0
2.0–3.9	49	8	3	1	0	1
4.0–5.9	15	5	1	0	0	0
6.0–7.9	9	3	0	0	0	0
8.0–9.9	5	2	1	1	0	1
10.0+	21	12	14	15	14	8

TABLE 4 Number of failures on different land use types classified by connectivity.

Connectivity	*Khet*	*Bari*	Grassland	Landslide	*Sal* scrub	Forest
Low	227	31	12	9	6	3
Medium	12	2	7	3	5	2
High	11	4	6	5	3	5

land, 29.4% in old landslides, and 50% in forests were in the high-connectivity category. This would imply that sediment yield and denudation rates are considerably higher in these categories, especially as it has been shown that the slope failures associated with these land uses are considerably larger than those on khetland.

In order to assess sediment yield, it is necessary to make some assumptions about the proportion of material reaching the drainage systems and to know the total areas under the respective land uses. Unfortunately, only the areas under khetland, bariland, grassland, and forest are known with any degree of accuracy. *Sal* scrub is very difficult to define because it generally occurs on small parcels of land and is sometimes classed as abandoned land. But it was possible to estimate the total area under this land use. With respect to sediment delivery ratio, the assumption made is that 100% of the failed material with high connectivity exits the system, whereas 50% of the failed material with moderate connectivity, and none of the failed material with low connectivity, leaves the slopes. Using these assumptions, the average figures are 0.48 ton/ha/y for khetland, 3.65 ton/ha/y for bariland, 1.86 ton/ha/y for grassland, 0.80 ton/ha/y for forested land, and a massive 23.95 ton/ha/y for *sal* scrub and abandoned land. In terms of average annual surface lowering, these figures become 0.039 mm for khetland, 0.29 mm for bariland, 0.15 mm for grassland, 0.064 mm for forested land, and 1.92 mm for *sal* scrub and abandoned land. These figures are probably on the high side because it is unlikely that all the failed material with high connectivity leaves the slope in the first year, and the figure of 50% for medium connectivity is also probably high. However, although the figures are probably on the high side, they do give some indication of the relative importance of landsliding on specific land uses. The average denudation rate per year for the 3 years in the 4 subcatchments, taking into account all the landslides on all land uses, was 5.56 ton/ha, producing a surface lowering of 0.44 mm/y.

This average figure of 0.44 mm/y is based on 3 relatively degraded south-facing catchments and 1 relatively nondegraded north-facing catchment. If it is assumed that the entire drainage basin is composed half of homogeneous north-facing and half of homogeneous south-facing catchments, the average denudation rate becomes approximately 0.325 mm/y. This figure compares favorably with previous estimates for denudation from landsliding in the Himalaya, such as 2.5 mm/y (Ramsay 1986), 1.7 mm/y (Bartarya 1988), and 0.5–5 mm/y (Starkel 1972).

The denudation rates for landsliding can be compared with those for soil erosion by overland flow. In the Dee subcatchment the average soil losses per monsoon for the years 1991–1993 were 5.5 ton/ha from bariland, 0.5 ton/ha from grassland, 0.5 ton/ha from little-degraded forest, 10.0 ton/ha from moderately degraded *sal* forest, and 20.0 ton/ha from highly degraded *sal* forest (Gardner et al 1995). Thus, bariland is more susceptible to the effects of overland flow, but grassland is more susceptible to landsliding. Soil loss figures for highly degraded *sal* forest are high, both from landsliding and from erosion by overland flow. This implies that the management of forestland is a more critical factor in land degradation than the change from forest to agriculture.

Discussion

Khetland

Small slumps in khetland, usually involving only 1 terrace, are by far the most frequent of the slope failures. Although the failures are small, they result in large costs for the farming community, and few farmers escape the experience of such failures. In a survey of farmers, 16% said that they had experienced landslides on their land in the past year (Blaikie 1995). The average person days spent repairing and maintaining fields was 14 days.

Khetland failures are not randomly distributed but tend to cluster in specific locations. There appear to be several possible explanations for this clustering. Some failures were clearly the result of water mismanagement. The essence of the system of irrigated terraces is that water passes through the system from terrace to terrace. Some farmers did not prevent the backward scour of water, which then cut into the base of the riser as water flowed from one terrace to the next one below. Scour is facilitated on high, unvegetated risers and was generally seen to occur on groups of terraces. The softening of material in the risers as a result of irrigation may also be a factor (Gerrard and Gardner 2000). Both these factors will be more important where the terraces are double irrigated, and there is some evidence to suggest that most of the single-terrace failures occur on double-irrigated khetland. Some of the clustering of failures on lower slopes probably reflects this because these lower terraces are capable of being double irrigated. Terraces that are irrigated twice per year require more attention to ensure efficient water management.

Bariland

The number of failures on bariland was comparatively small, but these failures were often larger and exhibited higher connectivity. There appear to be a number of reasons for this. *Bari* terraces are not susceptible to the small riser failures found on khetland because management techniques and possibly soil texture are different. There is not the same "softening" process or movement of water from terrace to terrace. Outward-sloping terraces with a rear drainage ditch are efficient at moving surface flow off the terraces, preventing a buildup of water at depth. Also, *bari* terraces tend to be on the higher slope areas with well-drained soils.

However, failures do occur, and they tend to be debris slides. Because of the system of deeply incised ravines that form the main drainage system of the subcatchments, debris slides on bariland often have direct access to the river systems. Management is also a significant factor. Many of the larger failures were on bariland that had been temporarily abandoned. Also, the majority of the abandoned *bari* terraces occur on the south-facing catchments where lack of water may be a problem.

Grassland

Much of the area classed as grassland is old *bari* terraces, some of which have been left uncultivated to allow grass to grow for grazing or thatching. But most of the *bari* terraces now covered by sparse grassland have been abandoned. They tend to be on the steeper upper slopes with thin soils, and there is little doubt that these areas are now susceptible to slope failures and that the failure is most likely to be a debris slide. The only relatively deep-seated rotational failures occurred on abandoned *bari* terraces.

Sal scrub and forestland

The type of failure on *sal* scrub is similar to that on grassland but with an even higher proportion of debris slides and with a higher connectivity. Failures on forestland were few but tended to be larger. This seems to accord with the view expressed by Ives and Messerli (1989) that forested slopes may merely postpone the occurrence of a major landslide cycle and, by facilitating the production of a deeper debris mantle, ensure large-scale events with longer recurrence intervals. Also, Upadhyay (1977) has argued that the most numerous and most spectacular landslides are often under forest cover.

Old landslides

The comparatively large number of failures in old landslides is significant; it emphasizes the potential continuing instability if landslides are not repaired. It is likely that many of the larger failures will not recover sufficiently by natural processes before failing again. Also, old landslides are prime locations for the occurrence of overland flow and gullying.

Conclusions

The following specific conclusions can be made:

1. Although the number of slope failures in the 4 subcatchments appears large, most failures were small and had little or no impact on land degradation in general.
2. Most of the failures that occurred on irrigated khetland were probably the result of water movement from terrace to terrace. These were small and easily repaired, but they did have labor cost implications.
3. Failures on cultivated *bari* terraces were rare but more frequent when terraces became abandoned.
4. Abandoned land, whether now grassland or *sal* scrub, possessed by far the highest landslide denudation rates.
5. Failures within old landslides also contributed significantly to the overall denudation.

These results substantiate those of previous researchers. Sarkar et al (1995) found that in the Alaknanda Valley, Garhwal Himalaya, the highest percentage of landslides occurred on barren lands, followed by sparsely vegetated, moderately vegetated, managed agricultural, and thickly vegetated lands. Similar results were obtained by Bartarya and Valdiya (1989) in the Kumaun Himalaya. Caine and Mool (1982) also noted that terracing and irrigation increase the likelihood of failure above that of unmodified slopes. But there is also a counterbalance, a tendency toward stabilization as a result of farmers' efforts to repair the damage (Kienholz et al 1984).

These results have implications for the continuing sustainability of the agricultural systems. Increasing the area under khetland at the expense of bariland will lead to more failures that will require careful management. As noted by Ives and Messerli (1989), labor required to repair the more valuable khetland might lead to the neglect of *bari* terraces. The upper limit of irrigated terraces is being pushed slowly further up the slopes where water supply becomes more uncertain. This change may also have an impact on the number of failures on bariland. However, as Wu and Thornes (1996) have shown, converting an identical slope from *bari* to *khet* does not necessarily produce a higher risk of failure if the original *bari* slope was not at risk of failure.

Bariland appears, in general, to be comparatively stable unless it becomes abandoned, or new *bari* terraces are created on unstable slopes. Abandoned land poses the greatest risk for continuing land degradation and may need to be controlled in some way. Certainly, the proportion of abandoned land should be kept as low as possible. This is in accord with Laban's (1979) view that some of the most densely populated and extensively terraced areas possessed the smallest frequency of significant landslides. The input of human effort maintains a quasi-stability. Whether this quasi-stability can be maintained if the land comes under even greater pressure is difficult to say. Blaikie (1995) has noted that badly eroded land tended to move from private to open access land when owners could no longer cope with the erosion, and management responsibility lapsed. This process may have important consequences for medium-term sustainability.

What implications do these results have for assessing the landsliding component of the Theory of Himalayan Environmental Degradation? At the simplest level, if one assumes that the whole area was originally forested, then deforestation has led to an increase in the number of slope failures but not necessarily to a significant increase in denudation rates. The annual denudation rate of 0.80 ton/ha/y for forested land can be taken as the base. However, the value of 0.48 ton/ha/y for khetland is below this value. Values of 3.65 ton/ha/y for bariland and 1.86 ton/ha/y for grassland are higher but not excessively so, and there is little indication that such land is becoming severely degraded. The high value of 23.95 ton/ha/y for *sal* scrub and abandoned land is of more concern. Fortunately, the proportion of such land in the study area is low. But this may not be so in other areas. The general conclusion is that deforestation does not necessarily lead to land degradation; much depends on the nature of the deforestation, the subsequent land uses, and the labor input to repair landslide damage.

Deforestation is probably too ambiguous a term to be used in an unspecific manner. As Hamilton and Pearce (1988) have noted, deforestation can be used to describe fuelwood cutting, commercial logging, shifting cultivation, and forest clearance for continuous annual cropping or for grazing. The subsequent land use is vitally important, as is the specific location where the change is taking place. Thus, Jackson et al (1998) noted that in 2 Middle Hill districts of Nepal, to the east of the Kathmandu valley, shrubland and grassland at lower altitudes are being converted to forestland but that on the upper slopes the forest cover is being denuded, and shrubland and grassland are increasing in extent. If the land is managed carefully with coordinated communal effort, serious land degradation from landsliding need not occur.

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