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The nature and management implications of landsliding on irrigated terraces in the Middle Hills of Nepal

A.J. Gerrard[1] *and R.A.M. Gardner*[2]

[1]School of Geography and Environmental Sciences, The University of Birmingham, Edgbaston, Birmingham B15 2TT
[2]Director and Secretary, The Royal Geographical Society with the Institute of British Geographers, 1 Kensington Gore, London

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SUMMARY

In the wetter areas of theHimalaya, irrigated terraces for the growing of rice (paddy) are the mainstay of the agricultural economy. Increasing population pressure is encouraging farmers to change from a single irrigated crop to double irrigation of terraces and from rainfed (bari) terraces to irrigated terraces. This change places a premium on the efficient use of the, often dwindling, water supply. As this study in the Middle Hills of Nepal has shown, irrigated terrace risers often experience extensive slope failures. Although such failures are relatively insignificant in land degradation terms, they are labour intensive with respect to remedial measures and create management problems. The results also suggest that it is the recent conversion of bari terraces to irrigated terraces that are experiencing most problems. There is also the implication that the landscape has almost reached the point where further expansion of irrigated terraces is unsustainable. If food production is to be increased, other cropping systems will need to be considered, with more attention being paid to the sustainable use of rainfed terraces.

INTRODUCTION

The rapidly increasing population of Nepal (annual growth rate is approximately 2.6%) is placing tremendous pressure on the agricultural systems. The mainstay of food production is provided by irrigated terraces. As Ives and Messerli (1989) note, irrigation adds to yields directly, and enables much higher use of other inputs, such as inorganic fertilisers and high-yielding varieties of crops, to be used. Also, much higher cropping intensities can be obtained. The area irrigated, usually khetland for rice (paddy) cultivation, is increasing rapidly. There is also a shift from single to double irrigated khetland where possible, although in many areas this change has reached its maximum extent. These changes have major implications for land management and sustainability of production. Irrigated terraces need intensive management. Risers and retaining bunds need to be maintained on an annual basis. Risers are often cut back with the vegetation and weeds that have grown on them ploughed into the terrace soil. Cracks in

Correspondence: A.J. Gerrard, School of Geography and Environmental Sciences, The University of Birmingham, Edgbaston, Birmingham B15 2TT, UK. e-mail A.J.W.Gerrard@bham.ac.uk.

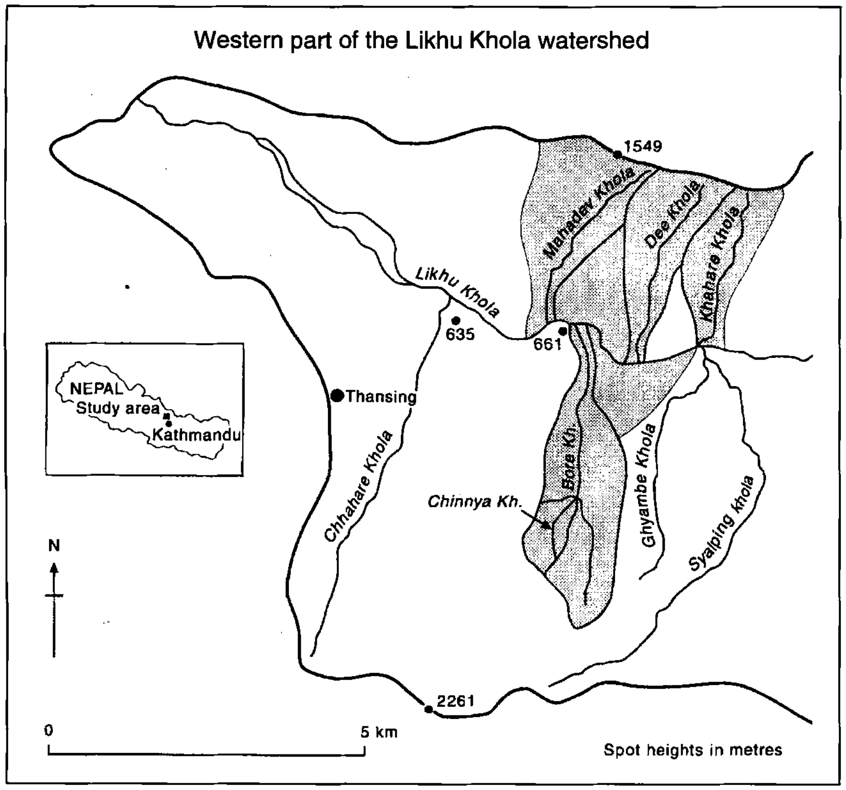

Figure 1 General location of the study area, Middle Hills, Nepal

the bunds need to be repaired to ensure that they hold the water in the terrace. Water channels need to be cleared and repaired. Added to these factors, many terrace risers suffer slumping and failure to a varying degree. These failures have to be repaired. Some of these issues are now examined using the results of an intensive study of soil conservation and water resources in the Likhu Khola basin, Middle Hills of Nepal.

STUDY AREA

The Likhu Khola basin is east–west trending and is located immediately north of the Kathmandu valley. The study has been conducted, in detail, within four well-defined subcatchments with altitudes ranging from 600 and 1850 m (Figure 1). Lithology comprises deeply weathered gneisses which has produced free-draining soils mapped, according to the US Soil Taxonomy System, as cambisols and luvisols. Surface soil textures are dominantly loams, silty loams and silty clay loams. Rainfall amounts are related to the length and intensity of the annual monsoon. The 1981–1991 average annual rainfall for the area is 2558 mm, but rainfall amounts in 1992 and 1993 (the main period of this study) were 2141 mm and 2211 mm, respectively, thus below the long-term average. The two main cultivation regimes are khet (paddy) and bari (rainfed) and there are areas of forest, grassland and scrub which vary in proportions from catchment to catchment (Table 1). Over the last 30 years, there has been an increase in the area cultivated, mostly at the expense of former grassland areas (Table 2). Wherever possible, there has been a conversion of bariland to khet. Crop rotations have shown an intensification over the last few years and farmers

Table 1 Proportions of different land uses within the four subcatchments of the study area

Land use	*Area (ha)*	*Percentage of total area*
Khet	378.66	30.6
Bari	205.5	16.6
Grassland	191.1	15.4
Forest	179.8	14.5
Scrub and abandoned land	72.5	5.8

Table 2 Percentage change in the areas of cultivated land use, 1991, as compared with 1967

Basin	*Ketland*	*Bariland*	*Total cultivated*
Khahahare	125	62	115
Mahadev	179	90	125
Dee	124	89	106
Bore	131	69	99

are constantly seeking ways to convert bari to khet. There has also been a change from single irrigated to double irrigated khet with an early monsoon crop of chaitra rice followed by a main crop of shrawan. Of the 86 fields surveyed by Blaikie (1995), 37 produced two crops of rice. It now appears as if most of the land capable of being irrigated twice is being so, although there is still conversion of bari to single irrigated paddy. There are also signs that water supply is diminishing, with springs drying up. This could put extra pressure on the irrigation process.

Blaikie (1995) has also noted that the Likhu Khola valley has a large surplus of paddy production; 56% of the farmers sell grain, of which 95% is paddy. Some farmers sell paddy and buy back cheaper grains. A quarter of the farmers sampled produced over 55 quintals of grain, mostly from khet and from terraces at lower and middle altitudes. The high-yielding farms sometimes required over 100 person-days of hired labour per year and, in one case, over 200 person-days of hired labour. The management implications of such changes in land use can be quite considerable. Many fields need constant maintenance and repair as landsliding is a problem on khetland. Farmers often have to hire labour to repair landslides.

TERRACE FAILURE

A survey of all the landslides in the four subcatchments during 1991, 1992 and 1993, has shown that the vast majority occur on khetland (Table 3). However, an analysis of size of failure scar and volume of failed material demonstrates that most failures are small (Table 4). The majority of khetland failures are small planar to slightly curved slides on terrace risers. Quite often these only affect the lower part of the riser but sometimes involve the whole riser and part of the terrace itself. Very rarely is more than one terrace involved, although sometimes more deep-seated failures involve two, three or even more terraces. Such failures are rare but they account for the failures in the largest size category noted in Table 4. Only 5.6% of failures were debris slides.

The total amount of material involved in irrigated terrace failures was 500.6 m^3 in 1991, 298.8 m^3 in 1992 and 392.1 m^3 in 1993. The higher amount during 1991 probably reflects the somewhat higher rainfall total. There were also more larger failures in 1991, generally late in the monsoon period. Because most terrace failures

Table 3 Frequency of slope failures on different land uses

Land use	*Numbers*	*Percentage*
Khet	250	65.6
Bari	37	9.7
Grassland	25	6.8
Old landslides	17	4.5
Sal scrub	14	3.7
Forest	10	2.6
Irrigation channel	9	2.4
River cliff	8	2.1
Path	7	1.8
Rock	2	0.5

Table 4 Size distribution of failures on khetland classified according to width of the failure scar and volume of material involved

Width of scar (m)	*Number*	*Volume (m^3)*	*Number*
0–1.9	59	0–1.9	149
2.0–3.9	115	2.0–3.9	49
4.0–5.9	59	4.0–5.9	15
6.0–7.9	10	6.0–7.9	9
8.0–9.9	3	8.0–9.9	5
10+	4	10+	23

come to rest on the terraces below, very little material leaves the terrace system. Thus, in terms of land degradation and soil loss, these failures are relatively insignificant. Soil loss and land degradation will only be a problem if the failed material leaves the terrace systems and enters the river channels. Thus, it is important to establish linkages between terrace failure and river channels. To assess such linkages, failures have been classed as having high, medium or low connectivity with the fluvial transport system. High connectivity failures leave the terrace system directly, usually falling into a ravine or river. Medium connectivity failures have the potential to be removed from the terraces but not immediately. It is this class of failure that needs immediate attention to prevent erosion and gully development. The material involved in low connectivity failures never leaves the terrace system but is reworked into lower terraces. Table 5 demonstrates that over 90% of the failures are classed as having low connectivity and only 4.4% are classed as high connectivity. If all material of high connectivity leaves the terrace system, 50% of medium connectivity and none of low connectivity, then 0.48 t ha^{-1} a^{-1} leaves the irrigated khetland and enters the river systems. This is a very small amount compared to losses from other land uses and is well within the sustainability limits. Thus the problem is not one of land degradation but one of land management.

On the basis of this analysis, it is clear that khetland is not suffering land degradation but is highly susceptible to failure. Although small, the failures do require considerable effort in remedial action. In the survey conducted by Blaikie (1995), 93% of farmers spent time repairing and maintaining fields, spending on average 14 days a year doing so. Also, 16% had experienced landslides in the 12 months previous to the survey. In addition 83% of farm households who cultivate khet spent time repairing irrigation channels.

An assessment of relative landslide hazard

Table 5 Connectivity of failures on khetland

Connectivity	*Number*
High	11
Medium	12
Low	227

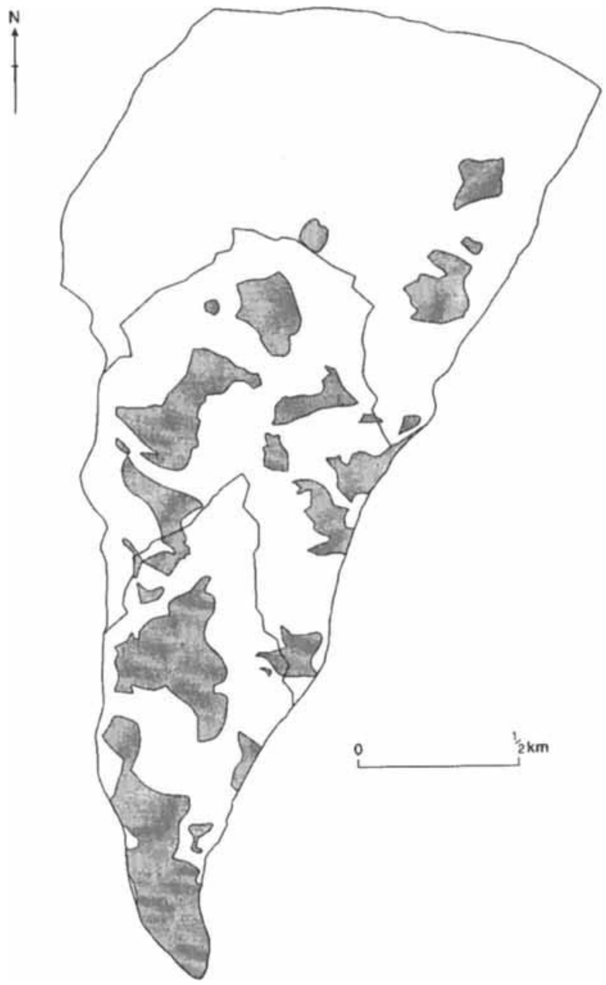

Figure 2 Landslide susceptibility map for the Dee subcatchment

within the study area suggests that khetlands on lower to middle slopes with concave morphology and slope angles of less than 20° have the greatest proportional risk or susceptibility. This enables susceptibility maps to be produced (Figure 2). But these results reflect partly the extensive amount of khet cultivation on slopes with those characteristics. All khetland combinations with other variables have a high risk factor.

Khetland failures are not randomly distributed over the areas with the most susceptible characteristics. Figures 3 and 4 show that many of the failures occur in clusters which persisted in their location during 1992 and 1993. This suggests that additional, more specific, factors are helping to promote failure. There are a number of possible explanations, not necessarily mutually exclusive, for this clustering.

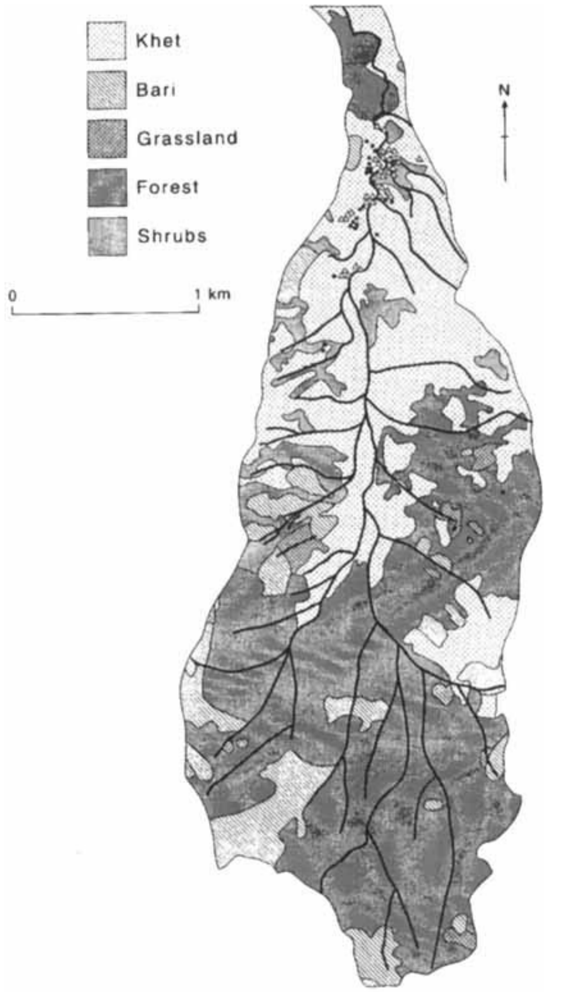

Figure 3 Map of land use and landslide distribution in the Bore Khola subcatchment; 1992 (triangles) and 1993 (small squares)

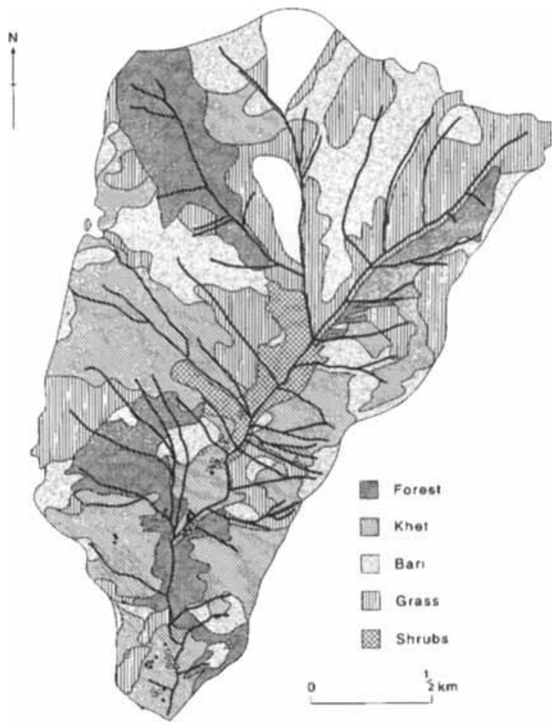

Figure 4 Map of land use and landslide distribution in the Mahadev Khola subcatchment; 1992 (triangles) and 1993 (small squares)

Water management

The essence of paddy cultivation on irrigated terraces is that water is led from terrace to terrace at times of flooding. As one terrace, adjacent to the water intake fills up, water overflows into successively lower terraces in quite a complex way. If the terrace risers are high, and most are higher than 0. 7 m, the water cascades down with considerable energy. It was often noted that some farmers did not prevent the formation of a backward scour of the falling water. This scour cuts into the base of the riser, locally steepens the angle of the riser and then leads to failure. Failures caused this way often involve only the lower part of the riser but, if not repaired, such failures often extend to the entire riser. Sometimes failures are seen in a downslope sequence from one terrace to the next, and so on, and this implies that cascading water is the cause. Some farmers dissipate the energy of the water by placing a large stone at the base of the riser under the water cascade. Failures caused by this process may be more prevalent on double-irrigated terraces during the first phase of irrigation when the terrace risers may be unvegetated.

Soil softening

Irrigation and infiltration of water leads to a softening of the risers. The puddling of paddy terraces leads to low infiltration rates but water will seep laterally through the retaining bunds and into the risers. This process has been demonstrated by measuring the unconfined compressive strength of the material in the risers by means of a pocket penetrometer at the moment when double irrigated terraces were about to be irrigated for the first time in the pre-monsoon period. Two groups of terraces were chosen; one group yet to be irrigated and the other group in which irrigation had just started. There was a clear difference in riser strength between the two

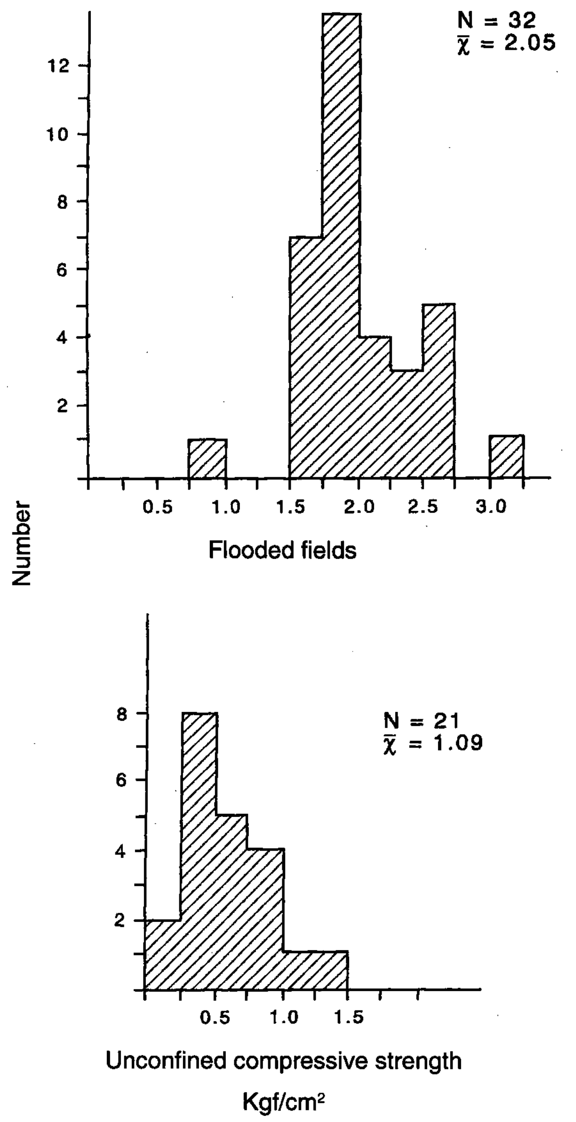

Figure 5 Frequency histograms of soil strength for wet and dry terrace risers

groups (Figure 5). The mean value of strength for the unirrigated terraces was 2.05 kg.f.cm^{-2} and for the irrigated terraces 1.09 kg.f.cm^{-2}. This shows very clearly how strength decreases as the terraces become flooded. This seepage and softening does not always lead to failure but it must be an important factor in contributing to the number of failures. Also, it will be more significant for terraces that are double-irrigated. The drop in strength will occur twice and exist for longer periods of time in double-irrigated terraces. This may explain partly why failures are more frequent on the lower slopes with angles less than 20°. These are the slopes that can be double irrigated. Unlike the poorly controlled movement of water from terrace to terrace, this process cannot be rectified by careful management. The softening of material during irrigation is part of the cultivation process and must be seen as an integral hazard. Some farmers are aware of the problem and consciously cut back the softened material on the risers each year to reveal harder material.

Soil texture

The clustering of failures may indicate areas where soil and regolith texture is conducive to failure or requires more careful management. High clay contents may lead to greater water retention and greater differences in dry and wet strengths. However, textural differences at the scale required to test this idea were not investigated in the soil mapping programme, thus the relevance of this hypothesis still awaits investigation. Some farmers have mentioned piping as a cause of failure and some signs of piping have been seen on a few terraces. Piping will develop in soils rich in silt and also in soils with specific clay mineralogys and those prone to desiccation cracking. Piping may be responsible for some failures but it does not appear to be a widespread process.

Slow reactivation of old landslides

The entire landscape of the Likhu Khola drainage basin shows clear evidence of an extensive history of large-scale landsliding. It is this landsliding which is responsible for the essential concave nature of the slope morphology. Large bowl-shaped depressions, often in lower and middle slope positions, have been created. It is these depressions that have been extensively terraced and irrigated, often with double irrigation. In some of these hollows slow subsidence and creep along old deep-seated rotational failure planes is occurring. This movement usually affects suites of terraces. In the lower Mahadev Khola, 12 terraces have been affected by a gentle slide creating a bulging in a downslope direction. The failure plane is estimated to be approximately 5 m below the surface. Slight differential subsidence can also be seen which produces discontinuities in riser height within individual terraces, as well as cracking. Slow movement may occur preferentially along lines of deep subsurface water drainage and where small former natural surface drainage routes have been terraced over.

These appear to be the main factors leading to khetland failure and to the spatial clustering. Some farmers have suggested that the small holes made by infestations of khumre may be responsible for failure but there is little evidence to substantiate this.

Table 6 Numbers of khetland failures in the four subcatchments

Subcatchment	*Number of failures*
Bore	75
Dee	62
Khahare	36
Mahadev	81

CONCLUSIONS

It is clear from these results and deliberations that intensive rice cultivation on irrigated terraces in the Middle Hills of Nepal often results in significant management problems. Although the results presented here only relate to four subcatchments, a more general study within the Likhu Khola, as a whole, indicates that the results are typical of the wider region. The major problem appears to be the failure of individual terrace risers. The failure is most commonly of a single riser but there are significant clusters of failures where more multiple risers are involved, suggesting more deep-seated problems. Although little material leaves the terrace systems, indicating that land degradation is not a major problem, the failures do require a considerable input of labour for remedial action. Most failures appear to be the result of a certain lack of care in managing the water flow through the terrace systems.

These problems may be increasing as single irrigated terraces are changed to double irrigation and rainfed bari terraces are changed to irrigated terraces. These changes are placing increased pressure on the available water supply, especially as there is good evidence that a significant number of natural springs are experiencing reduced flow or have dried up completely. Extension of irrigated terraces is now occurring in the less favourable, drier and more degraded south-facing catchments. It was seen in Table 2 that the most significant recent change to irrigated terraces has occurred in the Mahadev Khola drainage basin. This is also the basin with the highest incidence of terrace failure (Table 6) and the one in which significant clusters of terrace failures were observed. These failures have probably occurred as a result of a combination of inexperience on the part of the farmers, inappropriate soil and topographical characteristics and pressure on the water supply.

These results demonstrate the problems involved in attempting to increase food production in areas where intense cultivation appears to have reached its sustainable limits. In the study area there appears little scope for further expansion of irrigated terrace cultivation either from single to double irrigated terraces or from the change from rainfed terraces to irrigated terraces. Further expansion of irrigation seems likely to lead to major management problems with perhaps environmental consequences. At the present time, the failures are being repaired in a generally efficient way but there may come a time when this is not possible.

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