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Changing Farmers' Land Management Practices in the Hills of Nepal

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ABSTRACT / This paper sheds light on changing farmers' land management practices in two mountain watersheds, with and without external assistance, in the western hills of Nepal. Information used in the analysis were obtained through a survey of 300 households, group discussion, key informant interviews, and field observation conducted during April–September 1999. Confronted with ever-decreasing landholding size due to a steadily growing population and scarcity of nonfarming employment opportunities, farmers in both watersheds have increasingly adopted assorted types of structural and biological measures to control soil erosion, landslides, gully expansion, and soil nutrient loss to maintain or even enhance land productivity. Adoption of gully control measures, construction of the retention walls, alley cropping, use of vegetative measures for landslide control, mulching, and use of green manure and chemical fertilizers are found significantly high in the project area due to the provision of technical and financial support, whereas composting is found significantly high in the nonproject area. Different from the traditionally held beliefs, population pressure on a finite land resource has brought positive change in land management. However, the experience from both watersheds indicates that there is limit to the extent that resource poor farmers can respond to land degradation without any external assistance. Required is the arrangement for appropriate polices and support services and facilities enabling farmers to adopt locationally suitable and economically attractive land management technologies.

Mountain watersheds have attracted global concern due to the threat of serious environmental and socioeconomic implications arising from natural resource degradation (Messerli and Ives 1997). They have been perceived as vast, rugged, and remote landscapes, seemingly inured to human environment (Ives and others 1997). Short-sighted policy-makers and planners find investments in conservation and development of mountains less attractive compared to the adjacent plains, as their comparative advantages are overlooked. As a result, mountain watersheds are either undergoing or are vulnerable to degradation, despite local people's efforts to prevent such adverse effects. The mountains have been the home of the poorest of the poor deprived from minimum basic needs, including adequate food and access to educational facilities and health services. In China, poverty tends to be regional, concentrated in the mountains or loess plateau and characterized by lack of transportation and communication infrastructure, and poor natural resource reserves and ecological conditions (Lo and Xing 1999). The Middle mountains, hereafter referred to as the Hills of Nepal, are not an exception.

KEY WORDS: Land management; Structural measures; Biological measures; Fertility management

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While improving Nepali hill people's socioeconomic condition was not prime concern to until the early 1990s, there has been increasing concern over environmental degradation since the 1970s. An overview of work done until the early 1980s reveals the dominance of the Malthusian view, seeing environmental degradation as a consequence of reckless exploitation of natural resources by a steadily increasing population (Enke 1971, Eckholm 1976). They have overlooked farmers' strategies to secure their livelihood on a sustainable basis through adoption of assorted types of technology evolved over a period of several centuries. Some environmentalists and development policy-makers (Enke 1971) influenced by Hardin's (1968) theory of "tragedy of commons" have gone as far as branding local people enemies of the environment, destroying forest and land resources in the pursuit of maximizing their personal benefits. Such conventional wisdom and theory based on anecdotal observations, individual perception, and vested interests have gradually lost their favor, as results of scientific work reveals quite a different picture since the late 1980s (Thompson and Warbuton 1985, Blaikie and Brookfield 1987, Ives and Messerli 1989, Bruijnzeel and Bremmer 1989, Schreier and others 1995, Guthman 1997). Contrary to the traditional line of thinking, these microlevel studies pursued in different parts of the Hills have found that, despite the steady growth of population that the condition of natural resources has gradually improved, as people innovated and practiced effective management technologies to cope with the aggravating resource scarcity (Mahat and others 1987, Gilmour 1989, Messerschmidt 1990, Fox 1993). Such experiences are in conformity with Boserup's (1970) thesis, which considers population growth as a stimulator of technological innovations.

Gradually there is growing attention to understanding location-specific natural resources situations and management systems in the Hills. However, the attention has so far been overwhelmingly focused on common land holdings in general and forest in particular. Studies have also been pursued on private property or agricultural lands, with emphasis on their use and misuse. A few studies have sheded light on Hills farmers' land management practices (Johnson and others 1982, Carson 1992), but their areas of concern have been selected aspects of management, including landslide prevention and repair measures. In view of the hill farmers facing ever more pressing socioeconomic problems arising from gradually dwindling per capita share of land resources, and scarcity of non–land-based employment and income opportunities, efforts should be initiated to enable farmers to increase land productivity through enhancement of their land management technologies built on their traditional knowledge. In this regard, the major objective of this study is to find out how hill farmers have changed their land management practices to control land degradation under the situation of steadily increasing population pressure on very small landholdings.

Methodological Approach

This study is based on information obtained through a questionnaire survey, field observations, and group discussions. The household survey was conducted from April to September 1999. The sample size for the household survey was determined using the sampling method devised by Arkin and Colton (1963). A sample size of 300 households was obtained from a total of 10,836 households in two watersheds. Cognizant that farmlands in the valley floor have relatively fewer management problems compared with farmlands on hill slopes, only settlements on hill slopes were taken into consideration for the survey. Altogether, there were 12 village development committees (VDCs) in two watersheds. One representative village located in the hill slope was chosen to conduct the survey from each VDC. Commensurate with the total number of households in respective watersheds, 155 households were surveyed in Phewatal watershed (project area) and 145 households in Yamdi-Mardi watershed (nonproject area). To control siltation in Phewa Lake, a watershed management project was implemented by the Department of Soil and Water Conservation during 1974/75–1994/95, with a total amount of investment of US$2.1 million in Phewatal watershed (Kaski district Soil and Water Conservation Office 1997). Yamdi-Mardi watershed did not receive external assistance, and farmers are managing their farmlands from their own initiative.

Simple random sampling method was employed to select households for the questionnaire survey. A list of all household heads in all villages selected for the survey was obtained from the Office of Election Commission. Households in each of the village were numbered 1 to *N*. Then each third household was picked up from the list for the interview. Households found closed during the interviewers' visit were interviewed the following day.

Detailed information on the management practices of each parcel of land owned by the sampled households were collected using a structured questionnaire. Changes in the application of fertilizer and structural and biological measures of land management have been analyzed using information of four reference years, 1975, 1985, 1995, and 1998. To evaluate change in the project area and compare it with the nonproject area, 1975 was considered the base year when a watershed management project was implemented in Phewatal watershed. Most of the information used in the analysis are derived from the household survey, discussion with farmers, and field observation.

Study Area

The study area comprising Phewatal and Yamdi-Mardi watersheds has a total population of 64,338 and 23,270 ha of land. The climate is monsoon type with average annual rainfall ranging from 3811 mm at 827 m above mean sea level (AMSL) to 5237 mm at 1740 m. AMSL. Annual mean temperature in the valley floor is 21°C, with a mean minimum of 13°C in January and mean maximum of 26°C in July. Mean temperature in the ridge is 16°C with a mean minimum of 9°C in January and maximum of 20.2°C in August.

Located in the northern part of Pokhara valley, the Yamdi-Mardi watershed extends from the valley bottom village of Hemja in the south to the east-west elongated ridge in the north (Figure 1). This watershed extends between 28°15′N to 28°28′N latitude and 83°50′E to 83°57′E longitude, covering 10,970 ha of land. It is drained by Yamdi *khola* (stream) in the south and Mardi *khola* in the north. The adjoining Phewatal watershed extends between 28°7′N to 28°18′N latitude and 83°47′E to 83°58′E longitude, covering 12,300 ha of land from the tail of Phewa Lake to the head of

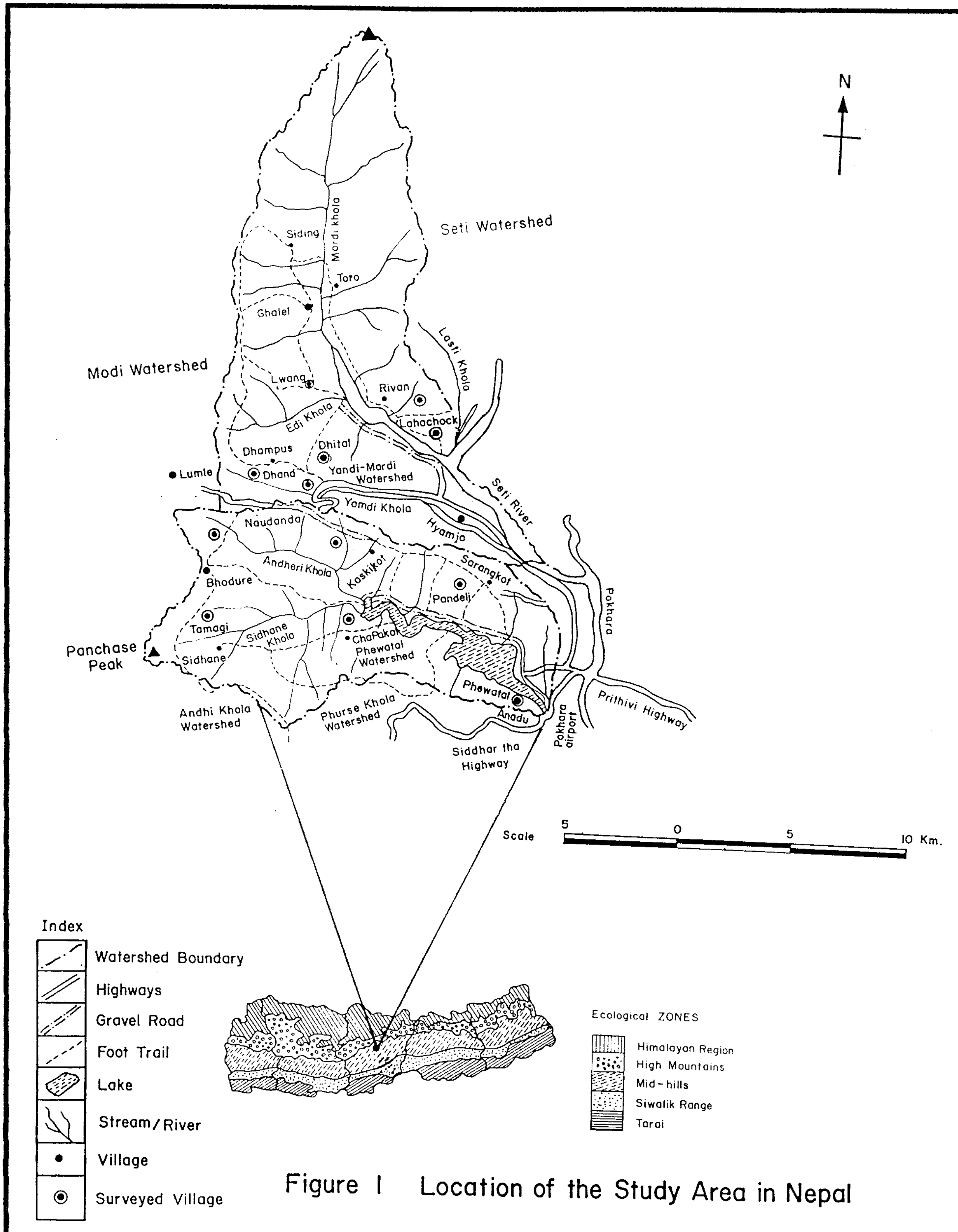

Figure 1. Location of the study area in Nepal.

Sidhane and Andheri *khola* along the east-west direction in the northwestern part of the Pokhara valley (Figure 1). Both watersheds have similar type of climate, relief, and soils.

Agricultural practices in both watersheds extend from valley bottom to the hilltop, with a variety of cropping systems and management practices. *Phantkhet*, or irrigated rice lands, are found in narrow stretches of river valleys. *Tarikhet*, or rainfed rice lands, are normally located on hill slopes. *Bari* lands cultivated with nonirrigated cereals, namely, maize, wheat, and millet, are normally found in the ridges and on hill slopes. Farm households are mostly adjacent to *gharbari*, which are utilized for fruit trees as well as maize and vegetable cultivation. Fragmented into several parcels, farmlands are being managed in different ways, to maximize benefits with the limited amount of resources available to farmers.

On average, a farm household in the project area owns 0.75 ha of land, fragmented into approximately six parcels, of which 86% is farmland and 14% is nonagricultural land. Per household farmland availability has declined substantially from 1.4 ha in 1978 (Fleming 1983) to 0.65 ha in 1998. A typical farm household in the nonproject area owns 0.90 ha of land, of which 83% is farmland and 17% is nonagricultural land. The land is fragmented into about seven parcels. As in the project area, per household farmland availability declined from 1.6 ha in 1978 (Kaski District Land Administration Office 1979) to 0.75 ha in 1998. This declining farm size has stimulated farmers to adopt improved land management practices in pursuit of controlling land degradation and maintaining farm production. The following sections of this study examine structural and biological measures of land management adopted by farmers in project and nonproject areas.

Measures of Land Management

Hill farmers have practiced different types of structural and biological measures of land management to control soil erosion and landslide and applied different types of fertilizers to maintain soil fertility as summarized in Table 1. These practices were innovated and developed by local farmers in both areas. However, in the project area, some of the measures were improved and promoted by the Watershed Management agency during 1975–95.

Result and Discussion: Structural Measures of Land Management

Terraces are narrow strips of land, carved out across the hill slopes for cultivation of cereals, including rice, maize, wheat, and millet. Regardless of land type, most terraces in both watersheds were constructed several centuries ago. Some of them were, however, constructed a few decades ago in response to increasing food demand for a steadily growing household size. Although there is no significant difference between two watersheds in terrace construction (Table 2), there have been some positive changes within watersheds. About 95% of farmers in the project area had practiced terraced farming in 1975; their relative number grew to 99% in 1998. In the nonproject area, the proportion of farmers practicing terraced farming grew from 97% in 1975 to 98% in 1998.

Leveled bench terraces are the dominant structural measures adopted by hill farmers to stabilize irrigation water required for rice cultivation in *phantkhet* and *tarikhet* (Figure 2A and B). These terraces have been maintained without any change in both areas. A remarkable change in the project area is that majority of *bari* terraces, which were normally outward facing before the implementation of the Phewatal Watershed Management Project, have been converted into inward-facing terraces under the support provided by the project (Figure 2C). *Bari* terraces in the nonproject area still have outward-facing slopes that facilitate quick drainage of water required for millet, maize, and legume crops (Figure 2D). Passage terraces located in the ridge have been maintained without any change in both areas (Figure 2E). Remarkably, sloping terraces have been abandoned gradually in both areas since the early 1980s, as farmers found it difficult to maintain due to labor shortage caused by the out-migration of adult household members and the schooling of children (Figure 2F). Some farmers with adequate labor are, however, gradually converting the steep-sloping terraces into gentle-sloping terraces to reduce the rate of soil erosion, thus increasing land productivity.

Terrace risers used to be relatively wide in the past when the population pressure on land resources was relatively low (Basnyet 1989). Farmers have sliced terrace risers to increase the area under crop production. Even the tiny fraction of land under risers has been intensively utilized for legume crops, which was not the practice until a few decades ago.

Bunds

Terrace bunds are small embankment constructed at the outer edge of terraces to control water flow. Terrace bunds used to be relatively wide in the past when the population pressure on land resources was relatively low. Farmers have sliced terrace bunds to increase the area under crop production. Even the tiny fraction of land under bunds has been intensively uti-

Table 1. Brief description of terminologies used in the context of the hill farming system and land management

Terminologies and measures		Description
Terminologies used in the context of the hill farming system	Hill slope	Sloping land between valley floor and ridge
	Terrace riser	Steep slope between terraces of different altitude
	Farm edge	Farm boarder
	Goth	Makeshift livestock shed constructed in farm terraces
	Slicing terrace risers	Thinly slicing of the slope between terraces by spade to remove weeds and grass
	Phantkhet	Irrigated rice field located in the valley floors and foothills
	Tarikhet	Rainfed rice field located in the hill slope
	Khet	Common local term for both *phantkhet* and *tarikhet*
	Bari	Rainfed maize and millet field
	Gharbari	Homestead used for fruits, wheat, maize, millet and vegetable production
Measures of land management	Terrace	Narrow strip of land carved out across the hill slopes for cultivation of cereals
	Terrace bund	An embankment at the outer edge of *khet* terraces made to control water flow
	Contour bund	An embankment built along the contour line to control soil erosion and siltation
	Waterway	Small canal at the inner toe of terraces made to convey runoff at a nonerosive point
	Retention wall	A reinforced wall constructed to protect terrace risers from being collapsed
	Check dam	An embankment along river and stream installed to protect farmlands from side cutting and flooding during the rainy season
	Alley cropping	Alternative rows of field crops and perennials grown in a contour pattern in sloping land
	Shrub formations in gullies	Bush formations, including bamboo, in gullies established to control gully expansion in hill slopes
	Vegetative measures of landslide control	Establishment of different shrub and tree species with extensive root systems for rehabilitation and control of landslide
	Mulching	The practice of covering the plowed land by crop residues and leaf litters for moisture and soil conservation
	Farmyard manure	Dung mixed with leaf litter and crop residues used for fertilizing land
	Green manure	Plant species containing soil nutrients
	Compost	Decomposed mixture of organic materials, including manure, utilized for fertilizing land

lized for legume crops, which was not the practice until a few decades ago.

Farmers have also constructed contourbunds across the farm edges (Figure 3). Mostly made from stone, these bunds control soil erosion and siltation. Besides, contourbunds prevent stray livestock from sneaking into farmlands. These bunds are a common feature in the project area, as farmers were provided financial support for their construction. In the nonproject area, where such support was not provided, contourbunds are rare.

Construction and Maintenance of Waterways

Waterways have been an integral part of the terraced farming system in the mountains of Nepal (Ojha 1995). The main purpose of waterways in land management systems is to convey runoff at a non-erosive point (Morgan 1995). Uncontrolled surface runoff moving down slope across hill slopes destroys terrace risers and removes soil from the farmlands, eventually decreasing crop yields and increasing the cost of terrace maintenance. To cope with this problem, farmers in both watersheds have constructed waterways (Figure 3) and there is no significant variation between two watersheds in terms of percentage of farmers who have constructed them (Table 2). About one-fifth of farmlands in the project area and one-tenth in the nonproject area are protected by waterways.

According to their location, waterways in the study area can be categorized into three types. Interterrace waterways are constructed across the inner toe of *bari* terraces. A narrow waterway is constructed across terraces for the diversion of surface runoff, which is channeled through waterways and drained into either gul-

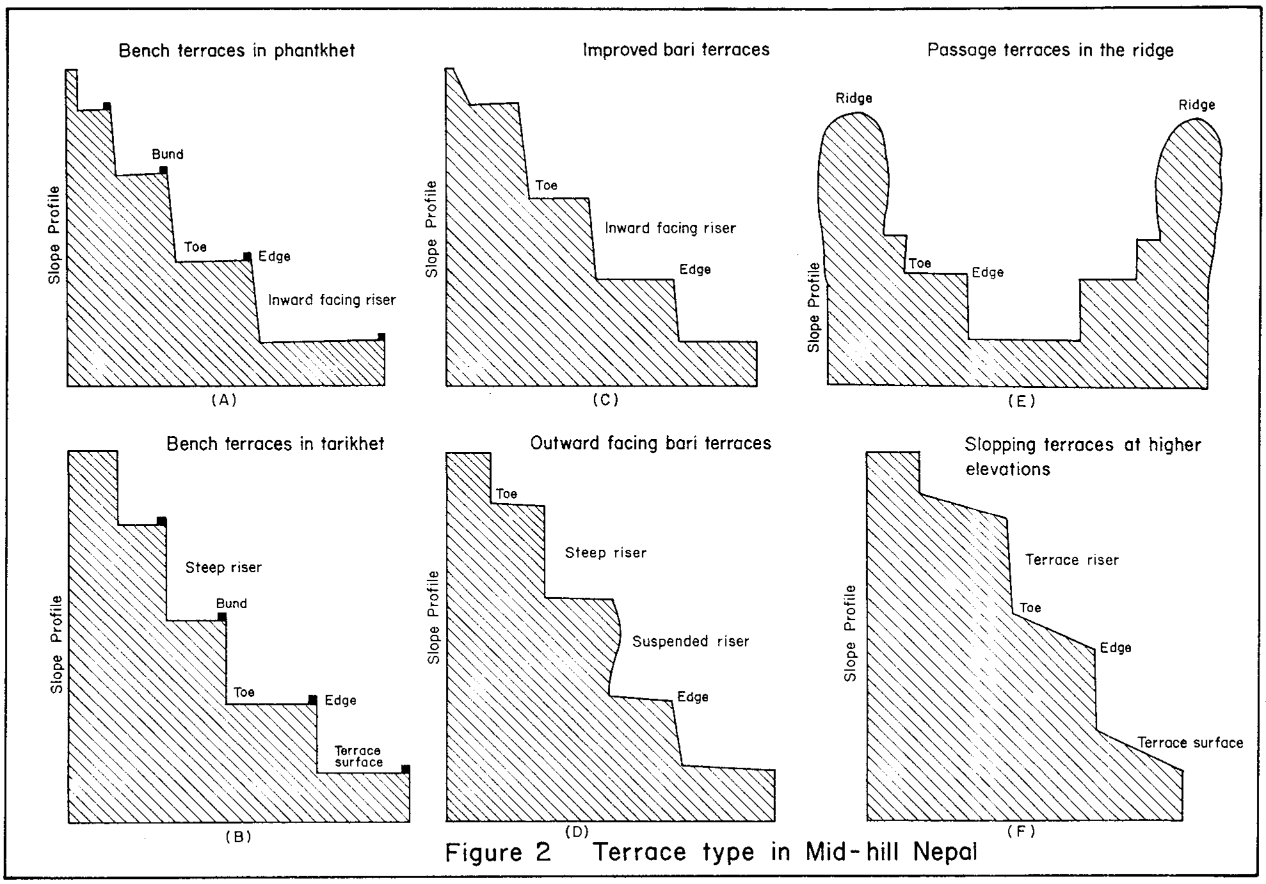

Figure 2. Terrace type in mid-hill Nepal.

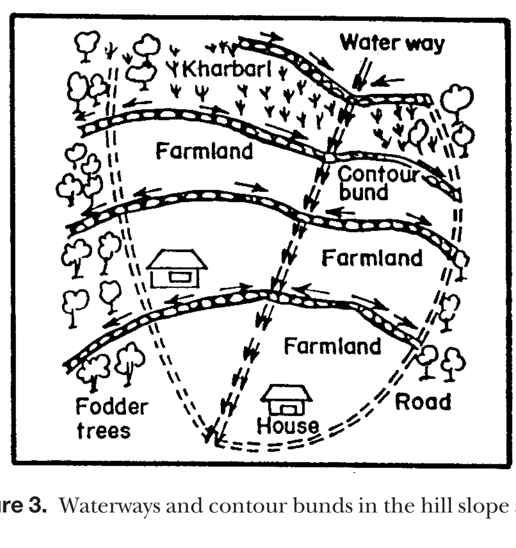

Figure 3. Waterways and contour bunds in the hill slope area.

lies or grassways. This type of practice is relatively intensive in the project area, as watershed management officials had made farmers aware of the advantages of this technology. Confronted with the damage to farmlands caused by surface runoff, farmers in the nonproject area have also constructed waterways across *bari* terraces by observing the practice in the project area.

Intraterrace waterways are constructed to prevent land from getting oversaturated, because this adversely affects the yield of some crops. Such waterways are also utilized to uniformly distribute water in farm plots during the dry season. Especially in the project area, farm edge waterways are constructed about 10–50 m above the farm boarder. Waterways, especially in high-erosion-prone areas, have been paved with stones to prevent gully formation. These types of waterways are extremely limited in the nonproject area due to lack of external assistance.

Gully Control

Gullies are relatively permanent steep-sided watercourses with momentary flows during rainstorms (Morgan 1995). According to farmers, gully formation was high during the 1960s and 1970s when forests on hill slopes were cleared for the expansion of farm and grazing lands. Once gullies were formed, they started

Table 2. Changes in the structural measures of land management

	Project area (n = 155)				Nonproject area (n = 145)			
Measures	1975 (f')	1985 (f')	1995 (f')	1998 (f')	1975 (f')	1985 (f')	1995 (f')	1998 (f')
Terraces	95.0#	98.0#	98.0#	99.0#	97.0#	98.0#	98.0#	98.0#
Waterways	61.0#	90.0#	91.0#	92.0#	69.0#	85.0#	89.0#	92.0#
Gully control	7.0#	27.0**	28.0**	30.0**	10.0#	14.0**	18.0**	20.0**
Retention walls	10.0*	26.0*	41.0*	42.0*	3.0*	8.0*	10.0*	12.0*
Check dams	6.0#	11.0#	14.0#	14.0#	3.0#	12.0#	15.0#	15.0#

f' = Proportion of n.

*Significantly different at 0.01 confidence level (t test, $P \leq 0.01$).

**Significantly different at 0.05 confidence level (t test, $P \leq 0.05$).

#Not significantly different at 0.05 confidence level (t test, $P > 0.05$).

Source: Field survey, 1999.

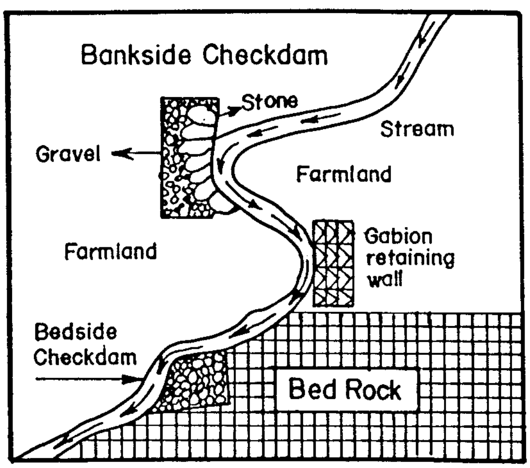

Figure 4. Check dams protecting farmlands from flood.

expanding both vertically and laterally, eventually engulfing adjacent farmlands. Farmers in the project area started making contributions to the gully control program during the 1980s under the technical and financial support provided by the Phewatal Watershed Management Project. In this regard, check dams were constructed along the vertical axes of gullies, and gabion retaining walls were installed at critical points where the small stones used in check dams could be washed away during floods (Figure 4). Altogether, 261 gullies covering an area of 123 km^2 were stabilized through joint efforts of local people and the watershed management agency. This explains why farmers' participation is significantly high in the project area compared with the nonproject area (Table 2). More than two-fifths of the surveyed farmlands in the project area and one-fifth in the nonproject area have been protected by these control measures.

In the project area, only 7% of the farmers had participated in gully control in 1975. The proportion of participants grew substantially over the successive years (Table 2). Farmers in the nonproject area have not been able to control large gullies due to lack of technical and financial resources. They controlled the expansion of small gullies using resources at their disposal. About one-tenth of farmers had contributed to gully control in 1975, with the proportion reaching one-fifth by 1998.

Landslide Repair and Prevention

The study area receives highest amount of rainfall in Nepal. Heavy rain accompanied by thunderstorm is a common phenomenon during the premonsoon and monsoon seasons. According to farmers, lands are highly susceptible to landslide, especially during days with continuous rain over 24 h accompanied by thunder. Rainfall data recorded in six stations in and around the study area over the last 21 years (1977–97) confirmed that there are at least five such events in a year. The rainwater percolates through porous soil and reaches bedrock comprised of slate and phylite, eventually saturating rocks and weakening their load-bearing strength. In this type of situation, repeated occurrence of thunder creates vibration in saturated soils and triggers landslips, especially in areas with steep slopes. Thus, even well-managed farmlands are vulnerable to landslides. As explained by farmers, occasional shocks caused by earthquakes and heavy extreme rainfall events aggravate landslide hazards as happened in 1833, 1933, 1957, 1971, and 1989.

Landslide occurrence is a natural process. However, its magnitude depends on slope gradient and the height of terrace risers and the nature of bedrock materials. More than 60% of landslides occur in areas with slope gradients over 20%. Most of the landslides

Table 3. Landslide density and management

Landslide occurrence (in single year 1998)	Project area					Nonproject area				
	PK	TK	*Bari*	*Gharbari*	Total	PK	TK	*Bari*	*Gharbari*	Total
Surveyed area (ha)	10.6	66	8.3	15.7	100.6	28.2	47.5	17.3	15	108
Number of landslides	89	752	147	225	1213	35	654	186	128	1003
Mean density/ha	8.4*	11.4#	17.7*	14.3**	12#	1.2*	13.8#	10.8*	8.5**	9.3#
Labor workdays/ha for landslide treatment	4.2**	1.4*	21.3*	14.3#	13.3#	1.8**	16.5*	16.2*	12.0#	12.1#
% of land affected by landslide	36.0	60.0	59.0	47.0	56.0	6.0	52.0	41.0	35.0	36.0

PK = Phantkhet. TK = Tarikhet

*Significantly different at 0.01 confidence level (*t* test, $P \leq 0.01$).

**Significantly different at 0.05 confidence level (*t* test, $P \leq 0.05$).

#Not significantly different at 0.05 confidence level (*t* test, $P > 0.05$).

Source: Filed survey, 1999.

are small in scale ranging from 2 to 150 m^2, with an average size of 10 m^2. According to farmers, landslides affect about 10% of their farmlands each year, and it takes 10–15 years to rehabilitate terraces and restore soil fertility affected by landslides.

The occurrence of landslide in all types of land except *tarikhet* is significantly high in the project area (Table 3). On average 9.3 landslides are reported per ha of land per year in the nonproject area and 12 per ha in the project area (Table 3). This clearly indicates that, despite the substantial investments, the watershed management project could not control landslide effectively. *Bari* lands are more vulnerable to landslide, owing to high terrace risers and their location on steep slopes. On average about 18 landslides are recorded per ha of land in the project area and 11 in the nonproject area. In *tarikhet*, landslide density per ha of land is 11.4 in the project area and 13.8 in the nonproject area (Table 3). Even *gharbari* and *phantkhet* have been affected by landslide, though a lot attention has been paid to their management.

Contrary to traditionally held beliefs, farmers in the study area are seriously concerned about the management of their landholdings, as any negligence would make them vulnerable to severe food shortages. In the past, availability of relatively abundant "open-access" lands provided an opportunity to expand farmlands if existing farmlands were badly damaged by landslides. With the steady growth of population and increasing state as well as local community control over open-access lands, currently it is virtually impossible to expand agricultural lands. Nonfarming activities that offer alternative employment opportunities are still rare. Farmers therefore have to pay serious attention to the management of their small landholdings. In this regard, on average, farm households in both areas spend 13 man days of labor per ha of land on maintenance and repairing farmlands affected by landslides (Table 3). They normally reclaim affected parcels of land during the winter or spring season. In this pursuit, rocks are removed from terraces and soil is leveled uniformly. Farmers cannot do anything other than wait for 10–15 years to reclaim farmlands naturally, in case large landslides affect farmlands (Dhital and others 1993).

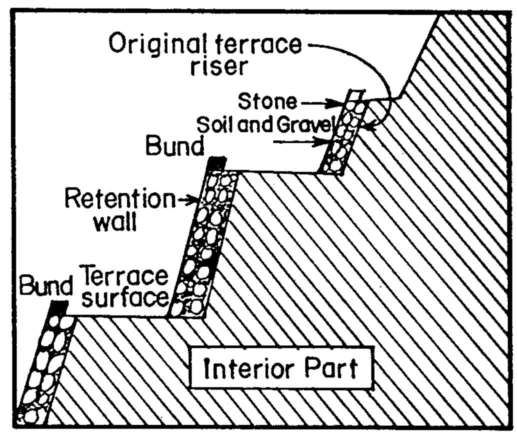

Figure 5. Reinforced terrace walls.

Reinforced Terrace Walls

A landslide, depending on its size, may affect several farmers. Where there is a possibility of several farmers' landholdings being affected by a landslide, concerned farmers jointly construct reinforcement walls to protect terrace risers from collapsing (Figure 5). The upper edge of the retention wall is slightly tilted toward the upper slope to reinforce the load-bearing capacity of the wall. The percentage of farmers who constructed retention walls is significantly high in the project area compared to the nonproject area (Table 2). In the project area, only 10% of farmers had constructed retention walls at the outset of the project in 1975; they accounted for 42% in 1998 (Table 2), 3 years after the termination of the project. In the nonproject area, participation of farmers in construction of reinforcement walls had increased marginally from 3% in 1975 to 12% in 1998 due primarily to lack of external support.

Check Dams

To protect their farmlands from landslides and flood related damages farmers have made substantial amounts of labor investment in the construction of check dams since the 1960s. In the valley floor, river level and route keep changing every year, which sometimes inflicts severe damage on fertile *phantkhet*. Even farmlands on hill slopes are destroyed through the process of gully expansion and associated landslides. Stabilizing riverways, particularly large streams, on a permanent basis is beyond farmers' capability. However, they are pursuing small-scale works to protect lands from possible damage. In this regard, they have constructed gabion retaining walls and spurs with launching aprons to control land cutting by streams (Figure 4). These structures are protected by vegetational cover, comprising a mixed formation of trees and shrubs. Overall there is no significant variation between two watersheds in involvement of farmers in check dams construction (Table 2). The farmers who had adopted this measure in the project area accounted for 6% in 1975 and 14% in 1998; the situation was similar in the nonproject area.

Biological Measures of Land Management

Farmers in both watersheds are also practicing several types of biological measures of land management. These practices evolved from the past have contributed to control land degradation at relatively low cost. They also played an important complementary role in supporting farm household economies by providing fuelwood, fodder, and food (Ya 1998, Denholm 1991).

Alley Cropping

As in the case of other mountain areas of Nepal, traditional alley cropping being practiced by farmers in the study area is different from alley cropping developed and promoted by agricultural research centers in which alternative rows of field crops and perennials are grown in a contour pattern (Ya 1998, Denholm 1991). Until a few decades ago, trees and shrubs used to be grown mostly in *kharbari* (private pasture) together with *Typha angustata*, which is used as fodder as well as thatching material. With the dwindling forest fodder supply caused by deforestation and restrictions on free access to forests, farmers started planting fodder trees and shrubs on the edges of terrace risers, including palatable fodder species like *Artocarpus lakoocha*, *Ficus auriculata*, *Ficus locor*, *Ficus nemoralis*, and *Ficus glamberrima*. During the 1980s large tree species were gradually replaced by nitrogen fixing and high fodder–yielding shrub species, including *Bahuhinia variegata*, *Leucaneia leucocephala*, and *Morus indica*, as crop yield under the shade of tall trees gradually declined. Farmers found farm edges, foot trails, gullies, and terrace risers at higher elevations suitable for tall species. In the project area, some exotic species, including *B. variegata*, *L. leucocephala* are promoted (Shah 1980), while in the nonproject area mostly indigenous species, like *F. locar*, *A. lakoocha*, and *F. glamberrima* are found.

Confronted with shrinking landholdings and dwindling forest fodder and fuel-wood supply, farmers in both areas have increasingly resorted to alley cropping as an alternative means of fulfilling subsistence requirements. Overall the percentage of farmers practicing alley cropping is low in both areas. However, it is significantly high in the project area (Table 4). In the project area, only 2% of the surveyed households had practiced alley cropping in 1975, 28% in 1995 and 30% in 1998. In the absence of an effective extension service, alley cropping was being practiced by 17% of the total households of the nonproject area in 1998.

Bamboo Species Plantation in Gullies

Establishing bamboo species, including *Bambussa balloca*, *Dendrocalanus hamiltonii*, *Bambussa* spp. and *Arundinaria raccam* in deep gullies and along stream banks is a recent practice adopted to minimize soil erosion, river bank erosion, and gully expansion. These species propagate rapidly and have fibrous root systems with excellent soil-binding capacity. Leaves of these species are used as fodder, stems as thatching and handicraft materials, and branches as fencing materials. Bamboo species planted in gullies at the valley bottom occasionally block surface runoff and flood farmlands. To protect land from this hazard, farmers have filled in gaps between bamboo clumps with stone walls. There is no significant difference between the project and nonproject areas in adoption of this measure (Table 4). However, there have been considerable positive changes over the past 23 years. About two-fifths of farmers in the project area had established bamboo species in gullies as of 1975. Their relative number had nearly quadrupled two decades later, and a similar type of change was experienced even in the nonproject area.

Table 4. Change in the adoption of biological measures of land management

	Project area (n = 155)				Nonproject area (n = 145)			
Measures	1975 (f')	1985 (f')	1995 (f')	1998 (f')	1975 (f')	1985 (f')	1995 (f')	1998 (f')
Alley cropping	2.0*	5.0#	28.0*	30.0*	0.0*	3.0#	12.0*	17.0*
Bamboo species plantation in gullies	37.0**	44.0#	86.0#	87.0#	19.0**	40.0#	79.0#	83.0#
Establishment of vegetation for landslide control	39.0**	45.0**	88.0**	88.0**	17.0**	24.0**	51.0**	55.0**
Mulching	37.0#	40.0#	68.0*	70.0*	37.0#	40.0#	46.0*	47.0*

f' = Proportion of n.

*Significantly different at 0.01 confidence level (t test, $P \leq 0.01$).

**Significantly different at 0.05 confidence level (t test, $P \leq 0.05$).

#Not significantly different at 0.05 confidence level (t test, $P > 0.05$).

Source: Field survey, 1999.

Table 5. Farmers applying fertilizers

	Project area (n = 155)				Nonproject area (n = 145)			
Type of fertilizer	1975 (f')	1985 (f')	1995 (f')	1998 (f')	1975 (f')	1985 (f')	1995 (f')	1998 (f')
Farmyard manure	81.0#	85.0#	89.0#	90.0#	86.0#	88.0#	91.0#	93.0#
Compost	2.0#	10.0**	12.0**	12.0**	1.0#	4.0**	26.0**	34.0**
Green manure	27.0*	30.0*	40.0*	40.0*	5.0*	7.0*	13.0*	13.0*
Legume	15.0#	19.0#	33.0#	34.0#	22.0#	25.0#	34.0#	38.0#
Chemical fertilizer	10.0**	65.0*	85.0*	96.0*	2.0**	19.0*	50.0*	59.0*

f' = Proportion of n.

*Significantly different at 0.01 confidence level (t test, $P \leq 0.01$).

**Significantly different at 0.05 confidence level (t test, $P \leq 0.05$).

#Not significantly different at 0.05 confidence level (t test, $P > 0.05$).

Source: Field survey, 1999.

Establishment of Vegetation for Landslide Control

Farmers in both areas use 50–80-cm-long logs of fast-propagating tree species, including *Erythrina strica*, *Vitex negundo*, *Alstonia scholaris*, and *Salix babylonica* for the construction of terrace risers, retention walls, and check dams. They are staked on a stone foundation. Roots and shoots sprout out of these logs (Figure 6). Roots growing vertically and horizontally on the ground reinforce the foundations of terrace risers, retention walls, and check dams. Besides providing fodder, leaves and canopies intercept the rain and control erosion of the structure made for soil conservation. Lands affected by landslides are planted with several tree and shrub species as they facilitate speedy recovery (Figure 7). Being aware of its importance for land conservation and fulfilling other household requirements of fodder and fencing materials, farmers in both areas have been increasingly practicing this measure, though the percentage of farmers in the project area is significantly higher (Table 4). About two-fifths of farmers in the project area had employed this measure in 1975, growing to nine-tenths in 1998. In the nonproject area, the proportion of farmers practicing vegetative

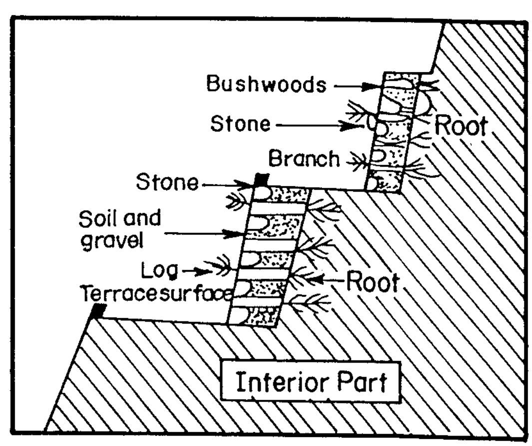

Figure 6. Use of live materials in terrace construction.

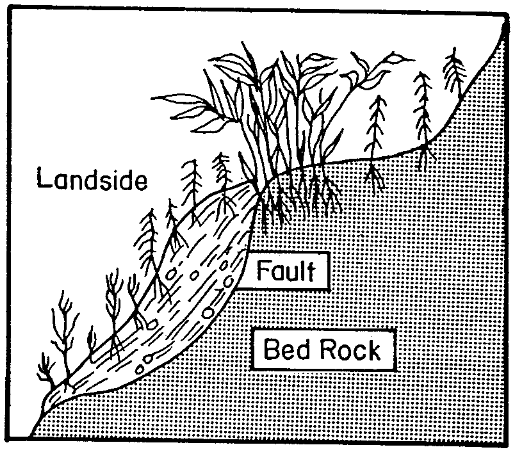

Figure 7. Shrub and tree established to reclaim lands affected by landslide.

measures for landslide control grew from 17% in 1975 to 55% in 1998.

Mulching

Farmers considered mulching an effective means of moisture conservation in farmlands, which are vulnerable to a lot of moisture loss during the winter and early spring seasons. To prevent this, farmers with a relatively large household size and small land holdings cover the plowed land with crop residues, leaves, and twigs. Mulching is also practiced to prevent seedbeds from getting exposed to the sun and rain and to protect seedlings from hailstones, which occur every year. Farmers observe the weather conditions and remove mulch from seedbeds when they feel that seedlings can tolerate the rain.

About one-third of farmers in the project area were practicing mulching in 1975; their relative number grew to over two-thirds in 1998 (Table 4). In the nonproject area, the proportion of farmers employing this technology grew from 37% in 1975 to 47% in 1998. Notably, there was no significant variation between two areas in terms of percentage of farmers practicing mulching in 1975 and 1985. Due partly to the external intervention in the project area, the difference had become significant by 1995 and it continued until 1998 (Table 4).

Soil Fertility Management

Besides adoption of structural and biological measures, farmers in both areas apply different types of organic and chemical fertilizers to improve land productivity. This section analyzes the variation in application of fertilizers between different types of lands in project and nonproject areas.

Farmyard Manure

Farmyard manure (FYM), comprising mainly manure and livestock bedding, is the major source of fertilizer in both areas. Livestock beds, consisting of waste fodder, tree leaves, and crop weeds, and manure are cleared twice a day to keep the *goth* clean. These materials are normally dumped in front of the *goth* in a 3–4-foot-deep pit and remain exposed to the sun, rain, and wind for several weeks until their transfer to the field.

The amount of FYM applied to all types of land is significantly high in the project area (Table 6), though the percentage of farmers applying this type of fertilizer is not significantly different between two areas (Table 5). Overall, farmlands in the project area receive FYM at the rate of 9300 kg/ha/year, compared to 6000 kg/ha/year in the nonproject area (Table 6). In both areas, priority is given to *gharbari* followed by *bari* for application of FYM. Though it is a major source of fertilizer, the supply of FYM is steadily declining in both areas as farmers have reduced their livestock herd size to cope with shortage of labor and gradually shrinking grazing-lands and landholdings.

Compost

The practice of compost making began in the study area during the 1960s to cope with declining FYM supply. By 1998, one-third of farm households in the nonproject area were applying compost to their farmlands, compared to one-tenth in the project area (Table 5), though the amount of compost used was very low and not significantly different between two areas (Table 6). In both locations, first priority is given to *gharbari* followed by *bari. phantkhet*, and *tarikhet* for compost application. Significantly low involvement of the project farmers in compost-making is primarily attributed to the provision of subsidized chemical fertilizers ever since the implementation of the project in 1975 (Table 5). Being unable to receive such assistance, farmers in the nonproject area had no alternative for increasing the supply of fertilizer other than compost-making.

Chemical Fertilizers

According to farmers, they did not apply chemical fertilizers until the mid-1970s. Confronted with declining FYM supply, a considerable proportion of farmers in the project area started using chemical fertilizers provided at highly subsidized rate by the watershed management agency and Lumle Agricultural Center

Table 6. Application of fertilizer by land type

Fertilizer	Project Area (n = 155)					Non-project Area (n = 145)				
	PK	TK	BA	GH	Mean	PK	TK	BA	GH	Mean
FYM (kg/ha)	5800*	4200*	19,200*	27,400*	9300*	2300*	3400*	10,100*	16,300*	6000*
Compost (kg/ha)	743*	108#	352*	916**	321#	48*	145#	925*	1580**	444#
Green manure (kg/ha)	35*	56#	121*	253**	90*	0*	42#	15*	97**	34*
Mineral fertilizer (kg/ha)	42**	30**	51*	51*	37**	63**	20**	2.0*	7.0*	26**
Wrapping land by flood water (% of total land)	36.0*	25.0#	0.0	0.0	20.0#	25*	20#	0.0	0.0	15.0#

Note: PK = *Phantkhet*; TK = *Tarikhet*; BA = *Bari*; GH = *Gharbari*.

*Significantly different at 0.01 confidence level (t test, $P \leq 0.01$).

**Significantly different at 0.05 confidence level (t test, $P \leq 0.05$).

#Not significantly different at 0.05 confidence level (t test, $P > 0.05$).

Source: Field survey, 1999.

since the late 1970s. Initially chemical fertilizers were used for millet and paddy seedbeds; since the early 1980s, they have also been applied to wheat, rice, and maize fields.

Farmers are fully aware that the regular use of chemical fertilizers accelerates soil acidity. Still, the percentage of farmers using chemical fertilizers has gradually increased over the years. Particularly in the project area, nearly all farm households used chemical fertilizers in 1998 compared to only 10% in 1975 (Table 5). Farmers in the nonproject area had started using chemical fertilizers only during the late 1980s because they could not receive any external assistance. By 1998, nearly 60% of the farmers were using fertilizers, though the intensity of use was significantly lower than the project area (Table 6).

Farmers in the nonproject area use highest amount of fertilizers in *phantkhet*, as there is prospect for increasing crop yield considerably due to good-quality soils and the availability of irrigation water. This is not the case in the project area, where most *phantkhet* are owned by land speculators pursuing business in the regional town of Pokhara. Therefore, *gharbari* and *bari* received relatively high amounts of fertilizers.

Green Manure

Applying green manure species, namely, *Adhatoda vasica*, *Euphorbia roylena*, *Artemisiia vulgaris*, *Albizia* spp., *Trichilia connoroides*, and *Stirum insigne*, to vegetable and paddy seedbeds has been a traditional practice of small percentage of farm households in both areas. Because of the promotional efforts made by the watershed management agency, the percentage farmers using green manure as well as the intensity of use are significantly higher in the project area (Tables 5, 6). Mostly found in the wild, these plant species contain more than double amounts of NPK compared to FYM (Subedi and Gurung 1991, Joshi 1997). Some of these species are also considered useful for controlling weeds and pests. Despite their awareness of the usefulness of green manure, farmers have not been able to apply it intensively because of the scarcity caused by lack of conservation and promotional efforts.

In response to dwindling availability of green manure, farmers are using leaves of *Schima wallichi* and *Castanopsis* spp. especially for paddy cultivation. These species, according to farmers, have low nutrient contents and still help prevent soils from becoming acidic. In some instances, weeds grown in the field are also being utilized as green manure, specifically for millet.

Overall Application of NPK

Different types of fertilizers, including farmyard manure, compost, green manure, and chemical fertilizers, applied to farmlands were converted into nitrogen (N), phosphorous (P_2O_5) and potassium (K_2O), known as NPK, using standard conversion factors to examine overall variation in NPK application. The supply of N is significantly high in all types of land in the project area (Table 7). Regarding the amounts of P applied to *phantkhet* and *tarikhet*, there are no significant variations between two areas, but *bari* and *gharbari* in the project area receive significantly high amounts of P. With the exception of *tarikhet*, the application of K is also significantly high in all types of land in the project area. Obviously lands in the project area are in better condition in terms of fertility compared to lands in the nonproject area.

Table 7. Average amounts of NPK application by type of land

Land type	Project area N (kg/ha)	Project area P (kg/ha)	Project area K (kg/ha)	Nonproject area N (kg/ha)	Nonproject area P (kg/ha)	Nonproject area K (kg/ha)
Phantkhet	57*	13#	40*	35*	17#	14*
Tarikhet	40*	11#	28#	31*	9.0#	23#
Bari	124*	33*	121*	67*	14*	66*
Gharbari	198*	47*	178*	114*	23*	110*

*Significantly different at 0.05 confidence level (t test, $P \leq 0.05$).

#Not significantly different at 0.05 confidence level (t test, $P \leq 0.05$).

Source: Field survey, 1999.

Goth System

Keeping livestock under a makeshift shed built on a parcel of land relatively far from the farmhouse is locally known as the *goth* system. As practiced in other mountain areas of Nepal (Metz 1994), this system has been adopted by farmers since the 1950s to cope with the labor shortage. Carrying FYM to distant farm plots is a labor-intensive task. Therefore, farmers build a makeshift livestock shed on a farm plot and one of their household members stays there with livestock during the months of December–April. Livestock are fed on crop residues stocked on the shed. During the daytime livestock graze on the farm plot and are kept under the shed at night. The manure mixed with bedding materials is dumped in front of the shed and applied to puddled *khet* during rice transplantation. Farmers demolish *goth* and bring the livestock back to the farmhouse when the stock of crop residues is finished. This type of system is gradually declining because of the cultivation of winter crops in some of the *khet*, and shortage of the labor force required for taking care of livestock and for fodder as well as bedding material collection. About 12% percent of farm households in the project area and 15% of those in the nonproject area are practicing this system.

Wrapping Farmlands by First Flood Water

The first flood of the rainy season, according to farmers, brings dung dropped by livestock on grazing lands, fallen leaves, decomposed organic materials, and other fine and coarse inorganic materials from the catchment area (Zifieng 1997). Farmers are well aware that these materials contain high amounts of plant nutrients. Therefore, they channel the first flood water into particularly *phantkhet* and *tarikhet* through canals and ditches. To facilitate the uniform flow of water throughout the farm plot, farmers make waterways by cutting terrace bunds and let the water flow into the farm plot as long as considerable amounts of nutrient-rich materials are coming with water. The water is diverted back to canals and streams as soon as the flow of such materials starts dwindling. Reportedly, 36% of the *phantkhet* and 25% of the *tarikhet* in the project area are fertilized in this way, which is significantly higher than the area fertilized in the nonproject area (Table 6). However, as mentioned by farmers, not much nutritious material comes with the flood water these days due to shrinking forests and grazing lands, diminishing livestock grazing, and growing numbers of irrigation canals in the upstream areas.

Legume Cultivation

The need for increasing cropping intensity coupled with maintaining land fertility has increasingly attracted farmers in both areas to legume cultivation, which was not a typical practice until recently (Subedi and Gurung, 1991). Major legumes being cultivated in both areas are *Vigna ungiculata*, *Vigna mungo*, *Vicia feba*, *Dolichas lablah*, *Glycine max*, and *Arachis hypogea*. Grown in terrace risers of *khet* and intercropped with maize and millet in *bari* and *gharbari* (Figure 8), legumes are consumed with meals and residues are fed to livestock.

There is an increasing tendency toward legume cultivation in both areas (Table 5). In 1975, only 15% of households in the project area had cultivated legume crops; this grew to 34% in 1998. During the same period, legume cultivation in the nonproject area grew from 22% of farm households to 38% which is not significantly different from the project area. Still, the area under legume cultivation accounts for less than 5% of farmlands in both areas.

Crop Residue and Weed Burning

Burning crop residues and weeds is a traditional method of fertilizing particularly *bari* land in both areas. During the dry summer season, farmers collect maize and millet stubble, leftover wheat straw, dried

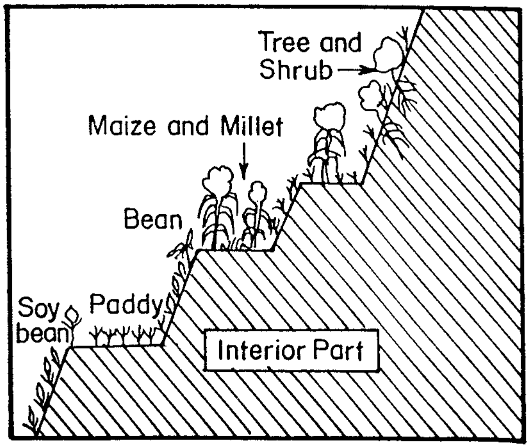

Figure 8. Effective use of terrace risers for legume cultivation.

weeds, and woody plants grown in *bari* terraces. The collected biomass is burned when signs of rainfall appear so as to allow the ash to get mixed well with the soil after the rain as well as to control the fire from spreading into other farm plots. Farmers spread the ash all over the farm plot to enhance soil fertility and to control some pests. This practice is being abandoned gradually in both areas; as mentioned by farmers, most crop residues are used as fuel-wood and forage.

Conclusion

Agriculture being the major source of their food supply, most farmers in the study area have pursued efforts to enhance land productivity to cope with shrinking landholdings caused by population growth. In this regard, they have improved terraces, intensified agroforestry practices and participated in gully control, landslide stabilization, and waterway construction activities. They also have adopted alley cropping and mulching and applied chemical fertilizers, farmyard manure, compost, and green manure to improve land productivity. The overall change in land management practices has been positive in both areas. The project farmers have experienced a significantly high degree of change in the construction of retention walls, application of gully control measures, stabilization of landslides, alley cropping, mulching, and application of chemical fertilizers and green manure due primarily to the promotion of land management technologies by the watershed management agency. Similar kinds of change could not be experienced in the nonproject area in the absence of required assistance. Consistent with findings of studies carried out elsewhere (Bilsborrow 1987, Fox 1993, Tiffen and others 1994), the findings of this study justify Boserup's postulate (Boserup 1970) that farmers devise alternative technologies for increasing land productivity, as they are exposed to the risk of food scarcity due to shrinking per capita landholdings. However, the findings also indicate that farmers' efforts alone, especially in a situation where people have been struggling to secure just two meals every day and are deprived from basic services and facilities required for production promotion, are not adequate to manage land resources effectively.

During a discussion held in the project area in September 1999, farmers explicitly mentioned that they are doing their best using very limited resources available at their disposal and knowledge passed on to them by their forefathers. They could still not be able to manage and utilize their lands effectively, owing to unawareness of alternative production potentials and unavailability of efficient support services and facilities, including extension service. It should be noted that whatever technical services were being provided to the project farmers were withdrawn following the termination of the project. Therefore, they demanded particularly the provision of very efficient technical assistance, providing information about locationally suitable alternative agricultural enterprises, improved land and crop management technologies, and services like treatment of livestock and crop diseases. These concerns clearly indicate the type of policies and programs required for effective management of land resources in the study area.

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Literature Cited

Arkin, H., and Colton, R., 1963. Table for Statistics. Barnes and Noble, New York.

Basnyet, S. K. 1989. Micro-level Environmental Management: Observations on Public and Private Responses in Kakani Panchayat. ICIMOD Occasional Paper No. 12, Kathmandu, Nepal.

Bilsborrow, R. E. 1987. Population pressures and agricultural development in developing countries: a conceptual framework and recent evidence. *World Development* 15(2):183–203.

Blaikie, P., and H. Brookfield. 1987. Land Degradation and Society. Methuen, London and New York.

Boserup, E. 1970. The Condition for Agricultural Growth. George Allen and Unwin, London.

Bruijnzeel, L. A., and C. N. Bremmer. 1989. Highland Lowland Interaction in the Ganges Bramaputra River Basin: A Review of Published Literature. ICIMOD Occasional Paper No. 11, Kathmandu, Nepal.

Carson, B. 1992. The Land, The Farmers and Future: A Soil Fertility Management Strategy for Nepal. ICIMOD Occasional Paper No. 21, Kathmandu, Nepal.

Denholm, J. 1991. Agroforestry in Mountain Areas of the Hindu Kush Himalayan Region. ICIMOD Occasional Paper No. 17, Kathmandu, Nepal.

Dhital, M., N. Khanal, K. B. Thapa. 1993. The Role of Extreme Weather Events, Mass Movements, and Land Use Changes in Increasing Natural Hazards. ICIMOD Kathmandu, Nepal.

Eckholm, E. P. 1976. Loosing Ground: Environmental Stress and World Food Prospects. World Watch Institute and UNEP, Norton Company, New York.

Enke, S. 1971. Projected cost and benefit of population control. Population and Development CIDA Seminar Paper No 2. Kathmandu, Nepal: 17–22

Fleming, W. M. 1983. Phewatal catchment management program: benefits and costs of forestry and soil conservation in Nepal. Pages 217–288 *in* S. H. Lawrence, ed., Forest and Watershed Development and Conservation in Asia and the Pacific. East-West Centre, Honolulu, HI.

Fox, J. M. 1993. Forest resources in a Nepali village in 1980–1990: the positive influence of population growth. *Mountain Research and Development* 13(1):89–98

Gilmour, D. A. 1989. Forest Resources and Indigenous Management in Nepal. Working Paper No. 17, East-West Center, Honolulu, HI.

Guthman, J. 1997. Representing crisis the theory of Himalayan environmental degradation and project of development in post Rana period. *Development and Change* 28:45–69.

Hardin, G. 1968. The tragedy of commons. *Science* 162(3859): 1243–1248.

Ives, J. D., and B. Messerli. 1989. The Himalayan Dilemma Reconciling Development and Conservation. United Nations University, Routledge, London and New York.

Ives, J. D., B. Messerli, B. and E. Spiess, E. 1997. Mountains of the world: A global priority. Pages 1–15 *in* B. Messerli and J. D. Ives, eds., Mountains of the World: A Global Priority. The Parthenon Publishing Group, New York.

Johnson, K., E. A. Olson, and S. Manandhar. 1982. Environmental knowledge and response to natural hazards in mountainous Nepal. *Mountain Research and Development* 2(2):157–188.

Joshi, D. 1997. Indigenous technical knowledge in Nepal. Pages 45–61 *in* R. Lesile, ed., Issues on Sustainable Land Management No. 3. International Board for Soil Research and Management (IBSRAM). Bangkok, Thailand.

Kaski District Soil and Water Conservation Office. 1997. Efforts on Watershed Management in Kaski District. Pokhara, Nepal.

Kaski District Land Administration Office. 1979. Unpublished Land Survey Data. Pokhara, Nepal.

Lo, F. C., and Y. Xing, eds., 1999. China's Sustainable Development Framework: Summary Report. United Nations University/Institute of Advanced Studies, Tokyo.

Mahat, T. B. S., D. M. Griffin, and K. R. Sheperd. 1987. Human impacts on some forests of the middle hills Nepal: part 3 forest in subsistence economy of Sindhu Planchok and Kavre Palanchok. *Mountain Research and Development* 7(1):53–70.

Metz, J. F. 1994. Forest product use at an upper elevation village in Nepal. *Journal of Environmental Management* 18(3): 371–390.

Messerschmidt, D. 1990. Indigenous environmental management and adaptation: An introduction to four case studies from Nepal. *Mountain Research and Development* 10(1):3–4.

Messerli, B., and J. D. Ives, eds., 1997. Mountains of the World: A Global Priority. Parthenon Publishing Group, New York.

Morgan, R. P. C. 1995. Soil Erosion and Conservation. Longman Group Limited, Malaysia.

Ojha, E. R. 1995. Ecosystem Dynamic Analysis: The Case of the Hills in Far Western Nepal. AIT Dissertation No. HS. 95–3, Bangkok, Thailand.

Schreier, H., S. Brown, and P. B. Shah. 1995. Identification of key resource issues: discussions and recommendations. Pages 247–252 *in* H. Scheier, P. B. Shah, and S. Brown, eds., Challenges in Mountain Resource Management in Nepal Processes Trends and Dynamics in Middle Mountain Watersheds. Proceeding of a Workshop held in Kathmandu Nepal, ICIMOD/IDRC/UBC, Kathmandu, Nepal.

Shah, S. G. 1980. Husbandry and Feed Resources Survey Result and Recommendation. HMG/N and UNDP, Project Field Document No. 16, Kathmandu, Nepal.

Subedi, K. D., and G. Gurung. 1991. Soil Fertility Thrusts towards Sustainable Agriculture: Experiences of Lumle Agriculture Research Center. Lumle Agriculture Research Center, Technical Paper No. 4/91, Pokhara, Nepal.

Tiffen, M., M. Mortimore, and F. Gichuki. 1994. More People, Less Erosion: Environmental Recovery in Kenya. Wiley, New York.

Thompson, M., and M. Warbuton. 1985. Uncertainties on a Himalayan scale. *Mountain Research and Development* 5(2): 41–73.

Ya, T. 1998. Soil conservation and soil fertility improvement through counter hedgerow. *ICIMOD Newsletter* 32:8–11.

Zifeing, B. 1997. Diverting flood for wrapping farmland. *Asian WATMANT Newsletter* 13:5–6.