Land Use Dynamics and Intensification

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1. INTRODUCTION

Population growth and rapid land use transformation are affecting the sustainable use of the bio-physical resources for the food, fuelwood, fodder, clothing and shelter. It is the aim of this paper to study the relationship between the population growth and land use changes and their impact on land degradation in the Jhikhu Khola watershed. The focus is on land use dynamics between 1972 and 1990, and evaluating causes and implications using Terrasoft (EPS Ltd.) Geographical Information System (GIS) as a integrating tool.

2. METHODS

Land use maps and aerial photographs were used to document historic land use changes. All information was digitized and changes were evaluated quantitatively using GIS overlay techniques. Three sets of surveys were conducted.

1. Changes in land use between 1947 and 1981 were evaluated using historic 1:50,000 mapping. The original 1:50,000 scale topographical base map produced in 1947 was used. In addition to the topographic information, three land uses were delineated at that time: jungle, shrub with a few scattered trees and agriculture. The Land Resource Mapping Project (LRMP) used the same topographic base for displaying the land use survey conducted in the early 1980s. In this nation-wide integrated survey all major land resources were mapped, based on aerial photo-interpretation and field verification, and the study area was examined as part of the overall survey in 1981. The resource information from both surveys was digitized and analyzed using GIS overlay techniques.

2. A second set of land use data was generated by photo-interpretation of 1972 and 1990 aerial photos (1:20,000 scale). To provide a base map for GIS evaluation, a 1:20,000 scale topographic map was produced using conventional photogrammetric techniques and 1990 aerial photos flown specifically for the project. After interpretation of the 1990 photos, a very detailed field verification program was conducted in the test area. The same team interpreted both photo sets and in addition to the land use survey, soils, forests, cropping systems and socio-economic resources were also evaluated. All information was transferred into the GIS system and comparative evaluations were made to discern the land use dynamics and to document deforestation and degradation of key resources in the watershed.

3. A detailed (1:5,000) land use evaluation was conducted for 1972 and 1990 in the Bela-Bhimsenthan region of the watershed. A detailed 1:5,000 digital base map was produced from the 1990 aerial photography using photogrammetric techniques. Enlarged aerial photos (1:5,000) from 1990 and 1972 were used for interpretation and the 1990 land use was field verified. All information was converted into GIS format for analysis.

In addition to the evaluation of land use dynamics, GIS techniques were used to identify possible causes and implications of the land use changes and provide the basis for a development plan to assist in the improvement of the forest resources within the watershed.

3.0 RESULTS AND DISCUSSION

3.1 Land Use Characteristics

The main characteristics of the hill farming system are the intensive utilization of arable land and a heavy dependence on livestock and forest inputs (Pantha, 1990). Sloping hills are cultivated under a sophisticated terrace system. In the Jhikhu Khola watershed, the cropping systems are rice-dominated (1,712 ha) on khet land and maize-dominated (4,288 ha) on bari land. The forests are heavily used for fodder, fuelwood, timber and litter collection. Grasslands are degraded due to a lack of land tenure, poor communal management, high animal stocking densities and shortages of animal feed (Carson, 1992; HMGN, 1988; Shah, 1991). Forests provide fodder and litter for livestock husbandry, while livestock provide manure and draught power for agriculture (Gilmour, 1991; Kennedy, 1989; Panday, 1992).

3.2 Land Use Changes 1947 - 1981

The first historical comparison was made between the available land use classification from 1947 and 1981. The land use dynamics covering the first historic period was restricted to three land uses: agriculture, forest and shrub (Figures 1 and 2). The land use changes over this 34 year period are summarized in Figure 3, which shows a 24% decrease in forest cover, a 10% increase in agriculture, and a 14% increase in shrub land. This suggests substantial forest deterioration over this time period which is in agreement with historic information published by Mahat et al. (1986a, b; 1987a, b) and Griffin et al. (1988). Of the overall losses, 55% of the forest land degraded into shrub, which is defined as non-continuous tree cover, with less than 10% crown closure and less than 5 m in height. Over the same time period, significant conversions of forest into agriculture occurred as a result of increasing food demands.

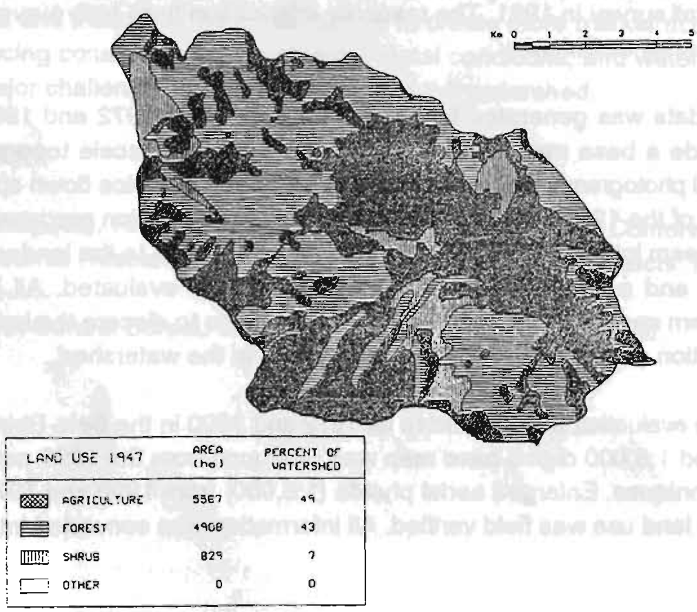
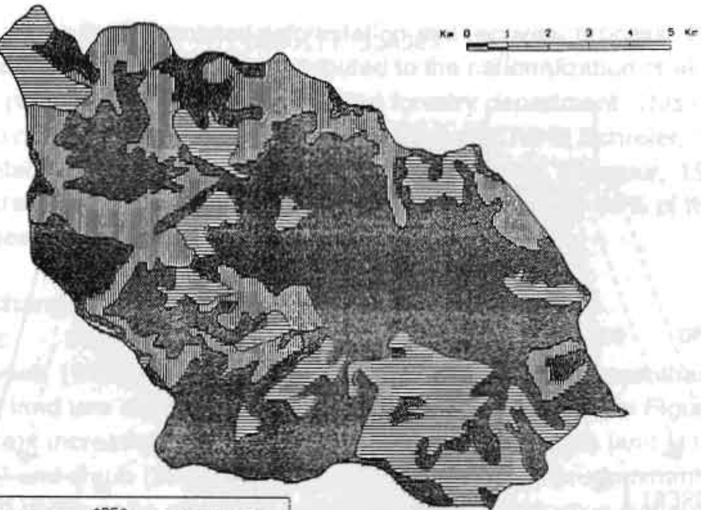


Figure 1. Land use in the Jhikhu Khola watershed in 1947.



LAND USE 1981	AREA (ha)	PERCENT OF WATERSHED
AGRICULTURE	6631	59
FOREST	2184	19
SHRUB	2481	22
OTHER	8	0

Figure 2. Land use in the Jhikhu Khola watershed in 1981.

(SCALE 1:50000)

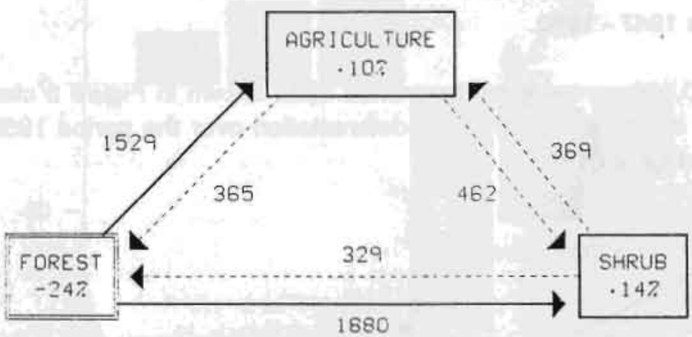


Figure 3. Land use dynamics from 1947 to 1981.

3.3 Land Use Changes 1972 - 1990

The second evaluation between 1972 and 1990 was compiled at a more detailed scale and utilized a greater number of land use categories. Six land use classes were compared including rainfed (bari) and irrigated (khet) agriculture, forest, shrub, grazing and 'other' land use (landslides, settlements, water, sand/boulders) shown in Plates 5 and 6 (Appendix I). The land use changes over the 18 year period were obtained by GIS summary and overlay techniques and the results in Figure 4 show a reversal of the forestry situation from the previous period. Forests have increased 10% and shrub decreased 9%. At the same time, arable agriculture (khet + bari) increased a further 6% while grazing lands declined by 6%. The land use gains and losses are dynamic in all categories, but the trends are far greater than inherent errors associated in data generation, data transfer and overlay techniques.

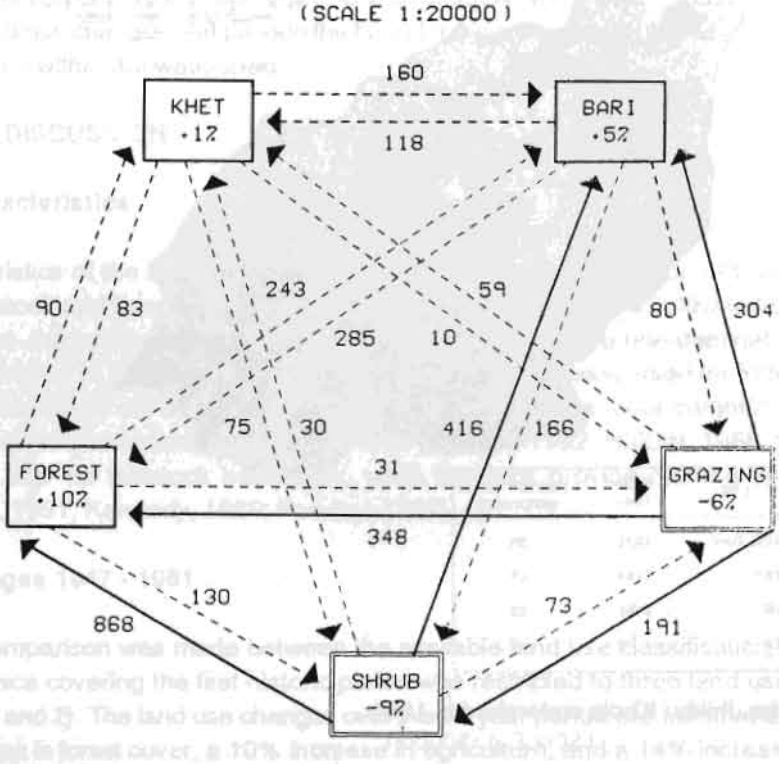


Figure 4. Land use dynamics from 1972 to 1990.

3.4 Overall Land Use Dynamics 1947 - 1990

Based on the 1:50,000 and 1:20,000 evaluations, the overall trend shown in Figure 5 clearly indicates a reversal in forest land use with a pronounced trend in deforestation over the period 1950 - 1960 and a subsequent increase in the period 1972 - 1990.

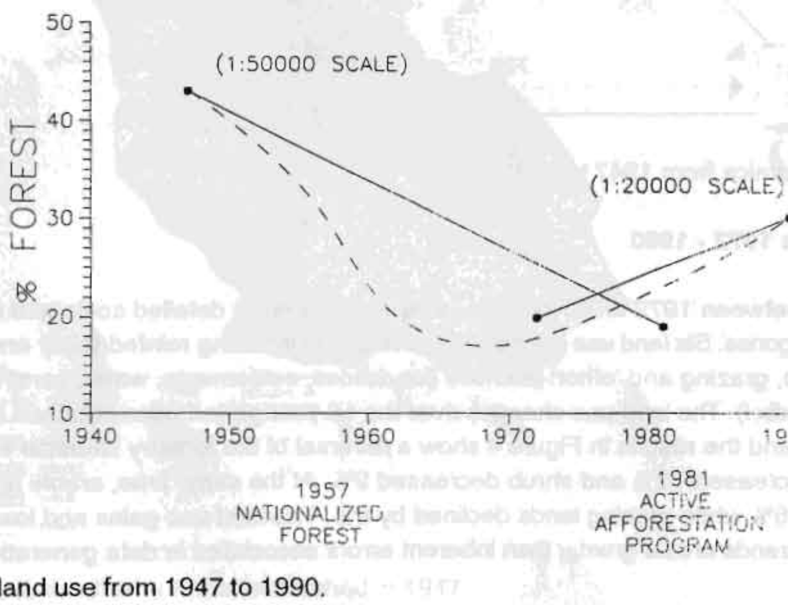


Figure 5. Overall land use from 1947 to 1990.

The dotted line in Figure 5 shows the interpolated deforestation and recovery process. The lowest forest cover is likely to have occur in the late 1960s and may be attributed to the nationalization of all forests in 1957, when all non-cultivated land was placed under the jurisdiction of the forestry department. This resulted in the clearing of forest land by villagers to maintain ownership (Feigl, 1989; Mahat, 1987a, b; Schreier, 1993). In recent years, afforestation efforts initiated by the Nepal-Australia Forestry Program (Gilmour, 1991) have resulted in significant increases in forest cover. The results suggest that approximately 50% of the area previously lost from the forest has now been reclaimed.

3.5 Detailed Land Use Changes 1972 - 1990

The third evaluation between 1972 and 1990 was compiled for the Bela-Bhimsenthan region using 1:5000 photo enlargements. Net land use changes for this detailed study are shown in Figure 6. Over the 18 year period there were significant increases in forest cover (47%), khet (irrigated) land (11%) and bari (4%) and decreases in grazing (38%) and shrub (20%). Increases in khet land were predominantly converted from bari land (90% of the increase) and may be attributed to the expansion of irrigation systems within the region.

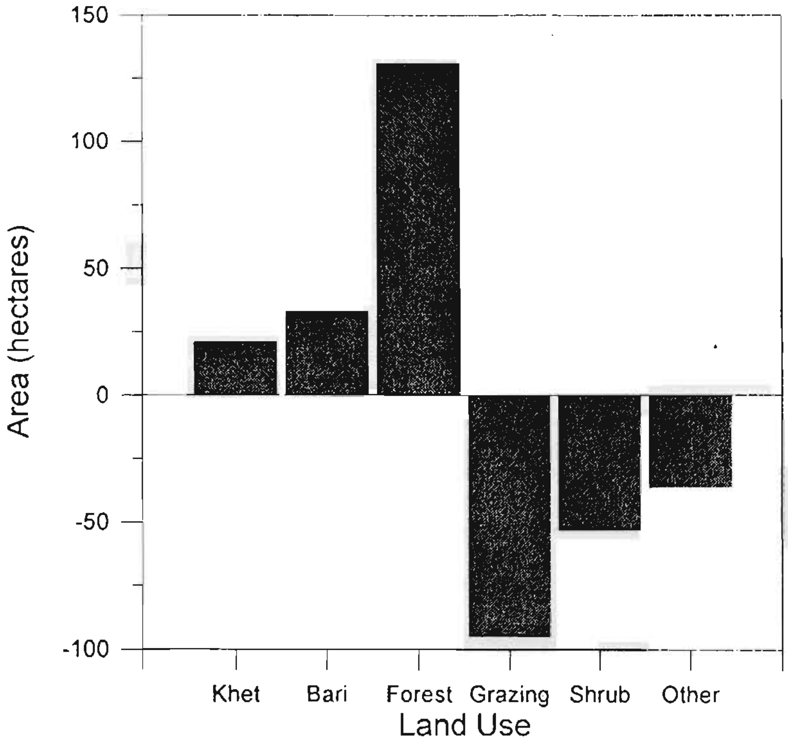


Figure 6. Net land use changes between 1972 and 1990.

3.6 Spatial Relationships between Land Use and Site Conditions

A historical representation of the land use trends has been developed using GIS techniques. These techniques may be used more fully to examine resource quality, determine possible causes, predict future consequences and provide alternatives to resource management. GIS was used to determine spatial relationships between land use and other resource data for the 1972 - 1990 1:20,000 scale surveys. Gains and losses of land uses in relation to site conditions were examined to evaluate the implications of: (1) forest expansion; (2) agricultural expansion; and (3) losses of grazing and shrub land.

3.6.1 FOREST EXPANSION

The key forestry question was to determine where forest expansion occurred and what type of forests have been created. The forests were classified into four main forest types (coniferous, hardwood, mixed and shrub) and several subclasses (crown closure, maturity and dominant species) (Table 1). Between 1972 and 1990 the gains in forest area from shrub (868 ha) significantly exceeds the losses (130 ha) suggesting a general improvement in the status of the forest (Figure 4). Crown cover has also improved. Table 2 shows a substantial decrease in forests and shrub with less than 10% crown cover and an increase in forests with crown cover in the 10-50% category. The areas under mature forest have also increased pointing towards a general improvement in forest resources. However, there are trends to suggest the situation has not improved as much as first perceived. A significant portion of the forest gains have come at the expense of grazing lands (386 ha).

Table 1. Forest classification used in the field survey.

Forest Type	Crown Cover (%)	Maturity Class	Dominant Species
Coniferous[a]	<10	Mature	*Pinus roxburghii*
Hardwood	10-30	Immature	Sal (*Shorea robusta*)
Mixed	30-50	Reproductive	Mixed hardwoods
Shrub	50-70		Mixed broadleaf
	>70		

[a]More than 75% of tree species

Table 2. Land use dynamics in relation to type and condition of forests.

Land Use	1972 Total (ha)	1990 Total (ha)	Net Increase / Decrease (ha) 1972-1990
Agriculture	5496	6073	+577
Forest	2182	3358	+1176
Grazing Land	1184	466	-718
Shrub	1857	938	-919
Others	422	306	-116
Pine Dominated[a]	681	1588	+907
Sal Dominated	897	826	-71
Pine Plantations	268	1012	+744
Mature Forest Total	180	386	+206
Crown Cover >50%	0	19	+19
10-50%	2008	2878	+870
<10%[b]	2031	1399	-632

[a] Includes pine plantations
[b] Includes shrub

Animal feed resource deficits have been identified by Schreier et al (1991) as critical in the Middle Mountains, and combined with the loss of shrub land is creating more pressure on feed resources. In addition, their has been a marked change in species distribution, with 63% of the increase in forest cover due to pine plantations (Table 2). Although pine trees are useful in stabilizing soils and improving future timber production, they are not useful multipurpose trees in the short run. The needles cannot be used as animal fodder, pine is not a desirable firewood, and pine-dominated forest litter used as input to agriculture during the dry season is reducing soil cations and base saturation (Shah, 1995).

GIS allows us to examine further the resource situation by comparing the land use dynamics in relation to elevation and slope. Table 3 illustrates the expansion in pine plantations in relation to elevation and slope. Pine plantations dominantly occur on gentle to moderately sloping terrain.

Table 3. Land use dynamics in relation to slope angle and elevation.

Overall Distribution		Gains in Pine Forests Plantation		Losses of Grazing Land		Gains in Rainfed Agriculture	
Slope (%)	Area (ha)	Area (ha)	% of slope class	Area (ha)	% of slope class	Area (ha)	% of slope class
0-4	1675	96	5.7	78	4.6	114	6.8
5-19	2655	245	9.2	179	6.6	301	11.3
20-35	2813	314	11.2	242	8.6	332	11.8
36-49	2730	255	8.2	257	9.4	340	12.8
50-155	1268	132	10.4	190	15	137	10.8
Elevation (m)	Area (ha)	Area (ha)	% of elev. class	Area (ha)	% of elev. class	Area (ha)	% of elev. class
750-999	4558	476	10.4	358	7.9	452	9.9
1000-1199	3056	371	12.1	214	7	405	13.3
1200-1399	2027	120	5.9	248	12.3	258	12.7
1400-1599	1014	41	4	105	10.4	86	8.5
1600-2099	486	4	0.8	21	4.3	23	4.7

Sixty-five percent of all pine plantations are on slopes less than 35% with the largest area in the 20-35% slope range. In addition, 84% of the plantations are below 1200 m elevation. The intention of the afforestation program was mainly to produce a source of wood products, but afforestation in Nepal should also consider stabilizing steeper upper elevation slopes, and provide biomass that can readily be used by local farmers for animal feed, fuelwood and food. The slope stabilization component has not been addressed since high elevation and steep slopes, where erosion concerns are greatest, have minimal afforestation. The concern for feed, fuelwood and food resources has also not been addressed since pine dominated forests produce few products that are directly beneficial to farmers.

3.6.2 AGRICULTURAL EXPANSION

Dryland (bari) agriculture increased by 511 ha over the period 1972 to 1990. Evaluating this expansion in relation to topographic position and slope (Table 3) indicates that 66% of all sites converted into rainfed agriculture occurred on slopes great than 20%, and the highest land conversion occurred in the 36-49% slope category. In the upper elevations (>1200 m), agricultural expansion covers twice the area that has been converted into pine plantations (Table 3), and occurred on steeper slopes than forest expansion. The increase in agriculture on the upper slopes has largely been at the expense of shrub (losses 351 ha) and grazing lands (losses 255 ha) which have poor soil fertility (Shah, 1995). This clearly points towards agricultural marginalization. Slope stability and soil erosion is of concern in this monsoon climate on steeply sloping upper elevation cultivated slopes, yet conversion into agriculture rather than afforestation is the dominant trend on these sites.

In addition to agricultural marginalization there has been agricultural intensification. The cropping intensity is defined as the number of crops harvested each year from a parcel of land, with relay crops counted as 100% of the area. Hagen (1980) reported that under rainfed agriculture, the national average annual cropping intensity was 1.3. Pantha and Gautam (1987) indicated an average of 1.6 crops / year. Riley (1991) reported averages of 2.0 to 2.45 crops / year in villages examined as part of the National Hill Crops Programme. From socio-economic and land use surveys in the Jhikhu Khola watershed the average annual cropping intensity ranges from 2.2 to 2.7 crops (Table 4) and four crops per year are currently grown by 13% of the households surveyed in the Bela region.

Table 4. Cropping intensity.

Date	Cropping Intensity	Source
1980	1.3	Hagen (1980)
1987	1.6	Pantha & Gautam (1987)
1990	2.5-2.6	Jhikhu Khola Survey
1991	2.0-2.4	National Hill Crops, Riley (1991)
1991	2.5-2.7	Dhulikhel Survey
1994	2.3-2.6	Bela-Bhimsenthan Survey

3.6.3 FOREST DYNAMICS 1989 - 1994

The forest dynamics over the past five years has been evaluated with plot studies. Twelve forest plots 20 by 20 m in size were established in 1989. The plots include government, community and private forests. Soil nutrients, foliar nutrients and biomass were determined. Individual trees were marked and these demarcations were maintained yearly. In 1994, changes in tree losses, soil and foliar nutrients and biomass over the five-year period were determined. Between 1989 and 1994, the standing biomass diminished from 614 trees to 386 trees which represents a loss of 37% of the forest stand (Figure 7). The losses varied greatly between plots and reflect different degrees of protection. The majority of trees lost to cutting were Sal trees (Shorea robusta) as they are more valuable as construction material and for brick making than other species. Few pine trees were removed. This indicates that the recent optimism about forest conservation and increasing forest biomass production from the forest (Gilmour, 1991) may not be substantiated. Recent community based afforestation efforts facilitated by ICIMOD may see short term improvements for local forests within the watershed.

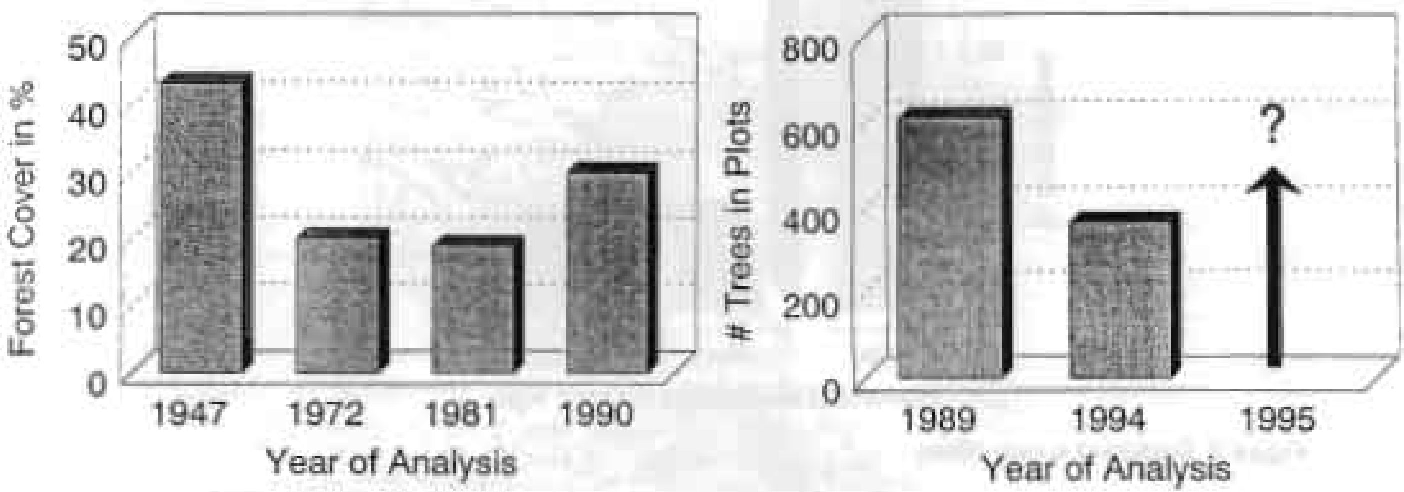


Figure 7. Forest cover and dynamics.

It appears that the expansion of the forest occurs in cycles. The conceptual historic framework indicates at least two cycles of deforestation followed by efforts of rehabilitation. Large losses of forest cover occurred in the 1950s. Afforestation resulted in significant increases in forest cover but only about 50% of the losses were recovered by the 1990s. Renewed losses have been observed in the 1990s due to the increased demand of firewood for brick making and timber for house construction. Recent community based afforestation programs may improve the situation but the rehabilitation of degraded forests after a period of deforestation is insufficient to establish the conditions prior to the degradation cycle. Hence the overall trend of cyclic changes is in a decreasing direction and the long term sustainability of the forests is in question. Forest quantity and quality must both be assessed to evaluate changes as the implications of the type of forest (pine versus fodder trees) may be as important as the quantity of trees.

The results of the socio-economic survey were used to relate the information on forest use and perceptions to the biophysical data on forest dynamics. The fuelwood situation within the Bela-Bhimsenthan region illustrated in Figure 8 showed that fuelwood sources include private trees (35%), crop residue (34%), forest (24%), bought fuelwood (4%) and kerosene (3%). Of the 85 households surveyed, 52% were not sufficient in fuelwood. About 71% of families responded that it was significantly easier to obtain fuelwood five years ago. Possible reasons for the increased demand in forest products over the last five years include:

1) Population increases, and the construction of new houses (Shrestha, 1995);
2) Greater demand of Sal wood for construction and brick making;
3) Increased demand for animal feed due to losses in grazing and shrub lands; and
4) Land tenure issues, specifically government, community or private management.

Limited data is available for the historic use of forest litter, but since the introduction of multiple annual cropping systems, the demand for forest litter as a substitute for traditional organic matter (manure) has increased steadily.

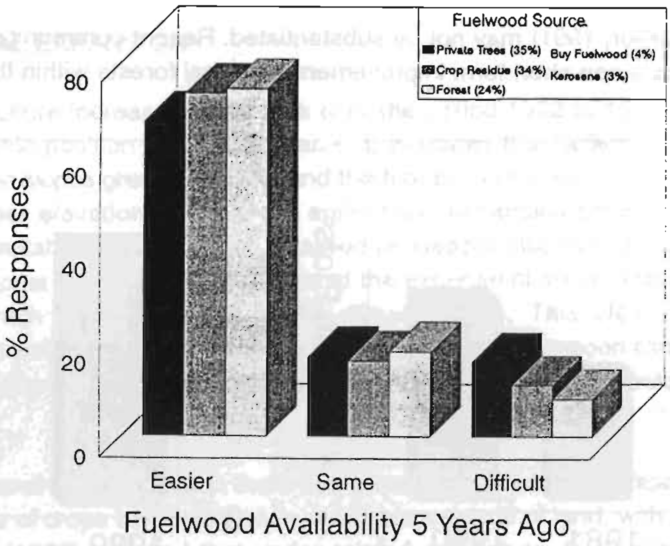


Figure 8. Fuelwood supply (Bela).

3.6.4 FOREST IMPROVEMENTS

The complexity of resource management issues in the Middle Mountains are easy to identify, but management alternatives which improve the resource status are challenging. An alternative forest practice illustrates the potential of GIS combined with resource data in resource management. The watershed was divided into two elevation zones (± 1200 m) representing a climatic break evident by a change in the natural vegetation. The watershed was further divided into dominantly south- versus dominantly north-facing aspects. This is an important subdivision as south-facing aspects are significantly drier than north-facing slopes. The combined aspect elevation classification divides the watershed into four microclimatic conditions which are reflected in the soil conditions. Analysis of the carbon content in surface soils showed a doubling of carbon between low-elevation, south facing and high-elevation north-facing sites (Wymann, 1991, Schmidt, 1992). Given the importance of agricultural production, only slopes >35% were used in the forest evaluation. The four site classes displayed in Figure 9 represent microclimatic site conditions useful for afforestation. The high-elevation, north-facing sites are considered to be cool and moist, while the low-elevation, south-facing sites are considered hot and dry. The climate has been monitored at five stations in the watershed since 1989 and the GIS-generated microclimatic site conditions will be calibrated more thoroughly in the future.

Nepal has a wealth of fodder trees that are native to the region and many have the capacity to fix nitrogen. A list of indicator species was produced that shows the optimum climatic conditions (Panday, 1982; Panday, 1991), and these were linked to the GIS-generated micro-climatic classification (Table 5). Combining Table 5 and Figure 9 provides an ecological plantation map which matches species to site conditions. Native trees can be planted to stabilize steep slopes, provide fodder and fuelwood, improve soil fertility (N-fixers), and match species with optimum site conditions. These tree species are increasingly difficult to obtain since heavy lopping prevents seed production.

To convert these findings into practical action, it was necessary to create a tree nursery, determine germination and propagation methods and assure a plentiful and diverse supply of highly valuable native species. The nursery supplies fodder tree seedlings for the rehabilitation project and for wider distribution to the farmers (Shah, 1995). Individual farmers and community forestry groups may then set priorities in the choice of species and where they could be planted.

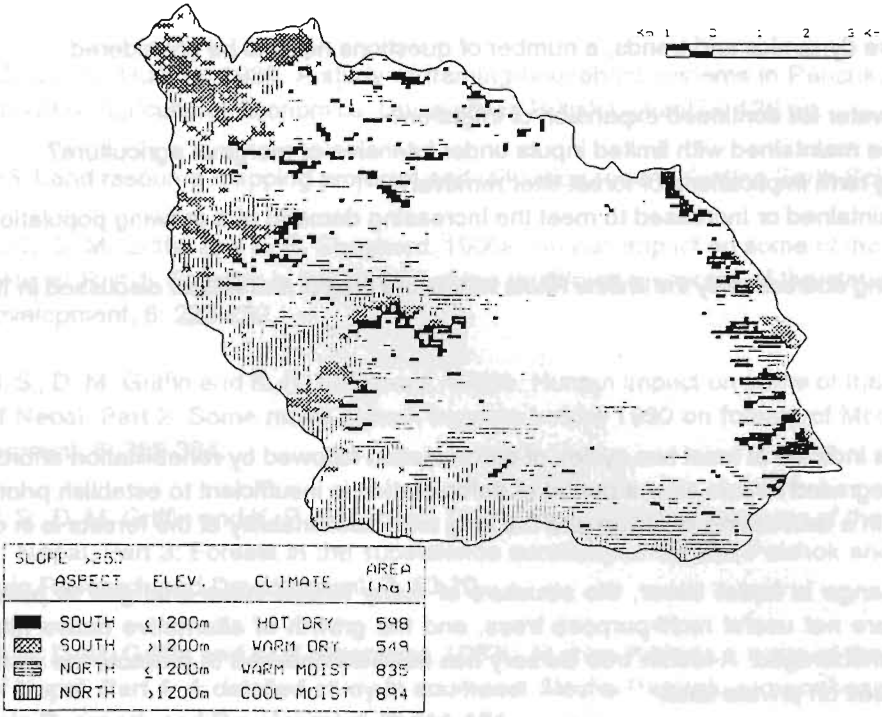


Figure 9. Microclimatic site conditions.

Table 5. Optimum site conditions for selected fodder tree species.

Above 1200 m		Below 1200 m	
Moist-Humid	Dry	Moist-Humid	Dry
North Aspect		North Aspect	
Brassaipsis hainla	*Betula alnoides*	*Artocarpus lakoocha*	*Ficus cunia*
Machilus gamblie	*Castanopsis tribuloides*	*Ficus lacor*	*Erythrina variegata*
	Sarauis napaulensis	*Terminalia tomentosa*	*Artocarpus integra*
	Ficus nemoralis	*Bauhinia variegata*	*Bassia butyracea*
	Quercus glauca	*Boehmeria rugulosa*	*Bauhinia purpurea*
South Aspect		South Aspect	
Ficus lacor	*Ficus nemoralis*	*Garuga pinnata*	*Ficus clavata*
Ficus roxburghii	*Grewia tiliefolia*	*Artocarpu lakoocha*	*Bauhinia purpurea*
Bauhinia variegata	*Litsea polyantha*	*Terminalia tomentosa*	*Shorea robusta*
	Ficus cunia		

3.6.5 ISSUES

Given these land use dynamics and trends, a number of questions need to be considered:

1) Is there enough water for continued expansion of irrigation?
2) Can soil fertility be maintained with limited inputs under intensive or marginal agriculture?
3) What are the long term implications of forest litter removal?
4) Can yields be maintained or increased to meet the increasing demand of a growing population?

These issues are being addressed by the Jhikhu Khola watershed project and will be discussed in the following papers.

4. CONCLUSIONS

Historic forest trends indicate at least two cycles of deforestation followed by rehabilitation efforts. However, the rehabilitation of degraded forests after a period of deforestation is insufficient to establish prior conditions. The overall trend is in a decreasing direction and the long term sustainability of the forests is in question.

In addition to a change in forest cover, the structure of many forests have changed to pine-dominated plantations. Pines are not useful multi-purpose trees, and the growth of alternative native nitrogen-fixing species should be encouraged. A fodder tree nursery has been established to promote the distribution and planting of fodder trees on private land.

Agricultural changes have occurred in two directions: expansion on marginal land and crop intensification. A substantial expansion of agriculture has occurred onto steep upper elevation shrub and grass lands and is likely leading to a marginalization of agriculture. These lands have a greater erosion risk, soil nutrient conditions are poor, and the production potential is limited. In contrast to agricultural marginalization, there has been a significant increase in cropping intensities from 1.3 to 2.7 crops/year between 1989 and 1994. The concern in this area is the maintenance of the nutrient pool with the limited availability of inputs.

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