ENVIRONMENTAL AUDITING
Gaining Forests But Losing Ground: A GIS Evaluation in a Himalayan Watershed

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ABSTRACT / GIS overlay techniques were used to provide a quantitative historic documentation of deforestation and land-use dynamics in the Middle Mountains of Nepal between 1947 and 1990. Deforestation was most critical in the 1960s, but active afforestation programs in the 1980s have reversed the process. In spite of these trends, the degradation problem is more complex. The GIS evaluation showed that 86% of the recently afforested land is now under pine plantations located primarily at lower elevations and moderately steep slopes. In contrast, rainfed agricultural expansion is most pronounced on acidic soils and steeper, upper elevation sites, suggesting marginalization of agriculture. Agricultural expansion coupled with major losses of grazing land to pine forests are the key processes pointing towards major animal feed deficits. An alternative animal feed source is suggested through GIS using a topographically based microclimatic classification to generate a tree-planting map where the optimum ecological conditions for selective native fodder tree species are identified.

Much has been written about forest degradation and deforestation in the Third World. Unfortunately, there are few quantitative evaluations to document land—use dynamics. The topic of deforestation is particularly controversial in the Himalayas where accusations are numerous and quantitative factual information scarce. Flooding events in Bangladesh are often attributed to inappropriate management of the Nepali forests by mountain farmers. Eckholm (1975) was one of the first authors to state that the ecological integrity in Nepal has been disturbed by man to the point where landslides, devastating torrents, and floods are more frequent. International organizations such as the World Bank, FAO, Asian Development Bank and their associated consultants (World Bank 1979, FAO/World Bank 1979, Environmental Resources Ltd. 1988, Dixon and others 1988) have all claimed that the forest resources in Nepal will be completely depleted by the mid-1990s.

A few researchers have done a credible job to dispel the myth of massive deforestation in Nepal. The members of the Nepal/Australia forestry project (Griffin 1988, Mahat and others 1986a,b, 1987a,b, Gilmour and Fisher 1991) and Ives and Messerli (1989) were among the most active. However, much of their historic documentation on deforestation has been anecdotal, observational, and descriptive. The only consistent data on the national status of the forests in Nepal were provided in 1986 when the Land Resource Mapping Project (LRMP 1986) was completed. Based on an evaluation of these data and subsequent projections, it was shown by Smith and others (1993), WECS (1987), and Schreier and others (1991) that current national fuelwood production and consumption balance sheets are slightly positive and that this resource is far less critical than the overall status

KEY WORDS: Himalayas; Deforestation; Watershed; GIS

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of food and animal feed. We are not claiming that there is no deforestation, but we suggest deforestation is much less dramatic and the resource degradation much more complex.

To provide quantitative information on forest dynamics in Nepal, a watershed study was initiated in 1988. The aims of the study were to recreate the history of land use, determine the status of the resources, and assist in the management and improvement of the forest resources in the Middle Mountains of Nepal. GIS was thought to be an ideal integrating and modeling tool. The Jhikhu Khola Watershed, located in the Middle Mountains of Nepal, was selected for this investigation because it is located in a very densely populated area 40 km east of Kathmandu, access to the capital is relatively easy, demands for exports and markets are high, and it is one of the most intensively utilized basins in Nepal. It is a test site where land use intensities are some of the highest in Nepal (and probably in the world) and where the resource problems are very acute, thus reflecting worse than average conditions.

Method

The project involved the mapping of land use, a historic evaluation of land-use dynamics, an examination of the resource status, and the development of a GIS-based methodology that provides a new approach to resource planning in this part of the world.

To examine the historic land-use dynamics, two sets of surveys were carried out. First, the original 1 to 50,000 scale topographical base map produced in 1947 was digitized using the Terrasoft GIS system (Digital Resource Systems Ltd.). In addition to the topographic information, the cartographers delineated three land uses on the original base map (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 nationwide integrated survey all major land resources were mapped, based on aerial photo-interpretation and field verification, and our test area was examined as part of the overall survey in 1981. The resource information from both surveys was digitized and analyzed using the GIS overlay techniques.

The second set of data were generated by photo-interpretations of the 1972 and 1990 aerial photos (scale 1 to 20,000). The 1990 aerial photos were flown specifically for this project and, upon completion of the photo-interpretation, a very detailed field verification program was carried out in the test area. The same team was involved in both surveys and, in addition to the land-use survey, soils, forests, cropping systems, and socioeconomic resources were also evaluated. To provide a base map for the GIS evaluation, a 1 to 20,000 scale topographical map was produced using conventional photogrammetric techniques. All information was converted into the GIS system and comparative evaluations were made to discern the land-use dynamics and to document deforestation and degradation of the key resources in the watershed.

In addition to the evaluation of land-use dynamics, the GIS technique was 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.

Results

Land-Use Changes: 1947–1981

The first historical comparison was made between the available land-use classification from 1947 and 1981. Both maps were published on the same topographic base map and, as shown in Figures 1 and 2, forest, shrub, and agriculture were the only land-use classes that could be compared in a defensible manner. 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. This suggests that substantial forest deteriorations occurred during this period. Of the overall losses, 55% of the forest land deteriorated into shrub, which was defined as non-continuous tree cover, with less than 10% crown cover and less than 5 m in height. Over the same time period significant conversions of forests into agriculture took place as a result of increasing food demands.

These findings show that forest deterioration was significant, and this is in agreement with historic information published by Mahat and others (1986a,b, 1987a,b) and Griffin and others (1988).

Land-Use Changes: 1972–1990

The second historic evaluation was done between 1972 and 1990. Because the data were collected at a more detailed scale (1 to 20,000), the land-use dynamics could be evaluated using a greater number of land-use categories. Six land-use classes were compared, and these included rainfed and irrigated agriculture, forests, shrub, grazing lands, and "other" land use, referring to land slides, trails, and inhabitation. The

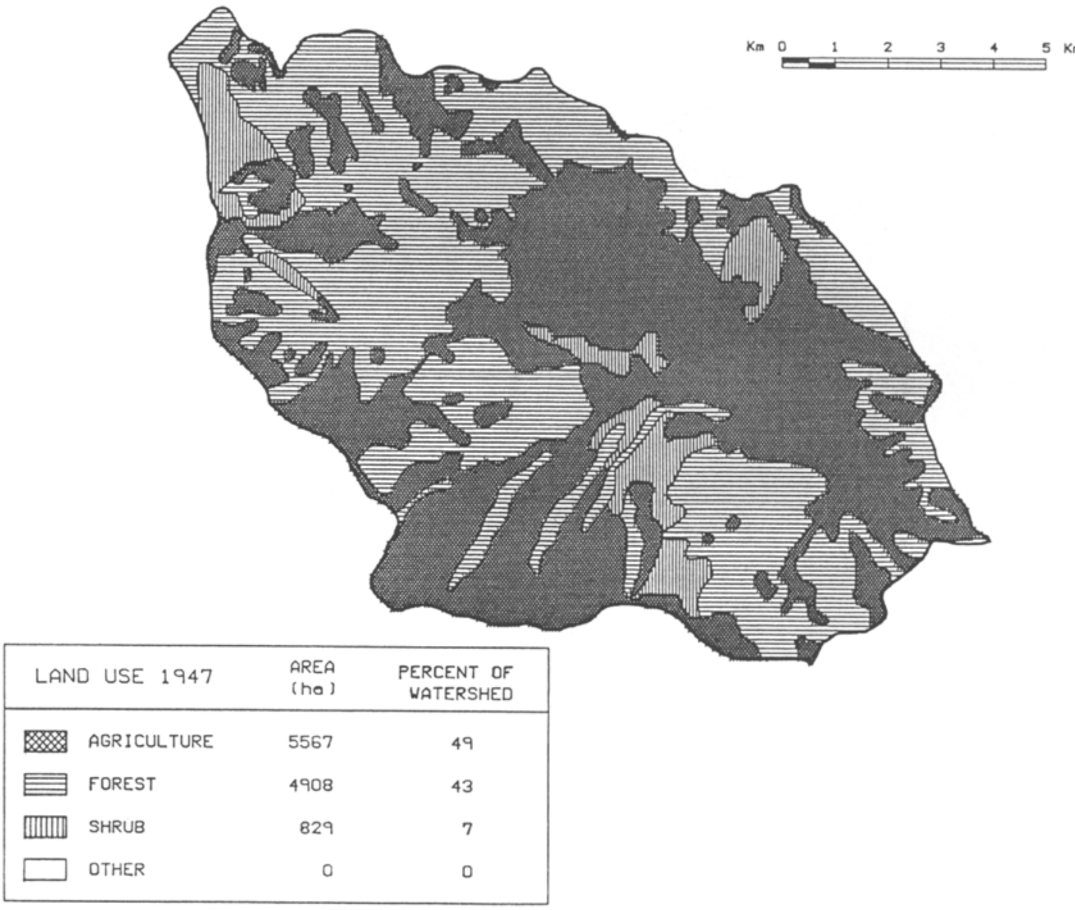


Figure 1. Land-use distribution 1947 (based on original 1 to 50,000 scale topographic map).

individual 1972 and 1990 land-use distribution maps are provided in Figures 4 and 5. The land-use changes over the 18-year period were obtained by GIS summary and overlay techniques and the results in Figure 6 show a reversal of the forestry situation shown over the previous time period. Forests have increased by 10% and shrub decreased by 6%. At the same time, arable agriculture increased by a further 6% while grazing lands declined by 9%. The actual land-use changes are very dynamic in that there are gains and losses in all land-use categories. These changes are far greater than the inherent errors associated in data generation, data transfer, and overlay techniques. In fact, it is very common in Nepal to abandon marginal terraces for a few years, particularly when the nutrients are depleted. This land then reverts back to grazing or shrub, and when food shortages are acute it is once again converted into agriculture. Additionally, a significant afforestation program came into place in the early 1980s.

Overall Land-Use Dynamics 1941–1990

Based on the above evaluations, the overall trends shown in Figure 7 clearly indicate 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. The dotted line in Figure 7 shows the interpolated deforestation and recovery process. The lowest forest cover is likely to have occurred in the late 1960s and may be attributed to the nationalization of all forests in 1957, when all forested land was placed under the jurisdiction of the forestry department. This resulted in the previous owners and local users of the forests removing large portions of the marketable forest resources. This was confirmed by Griffin and others (1988), who suggested that the worst forest conditions occurred in the early 1960s and that the nationalization in 1957 might have been a contributing factor to forest deterioration. In recent years, afforestation efforts initiated with foreign assis-

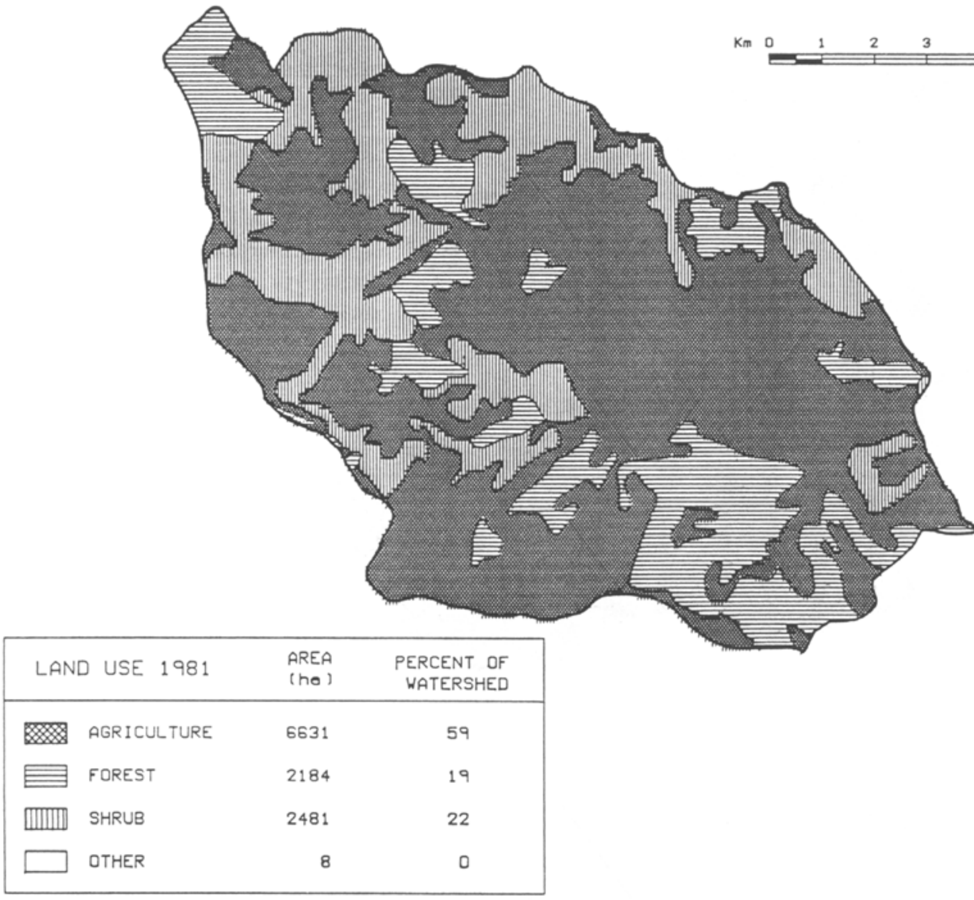


Figure 2. Land-use distribution 1981 [based on the LRMP (1985) survey at 1 to 50,000 scale].

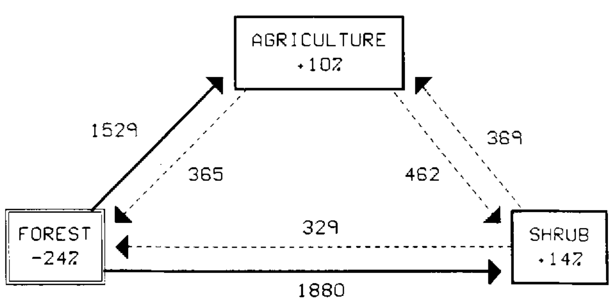
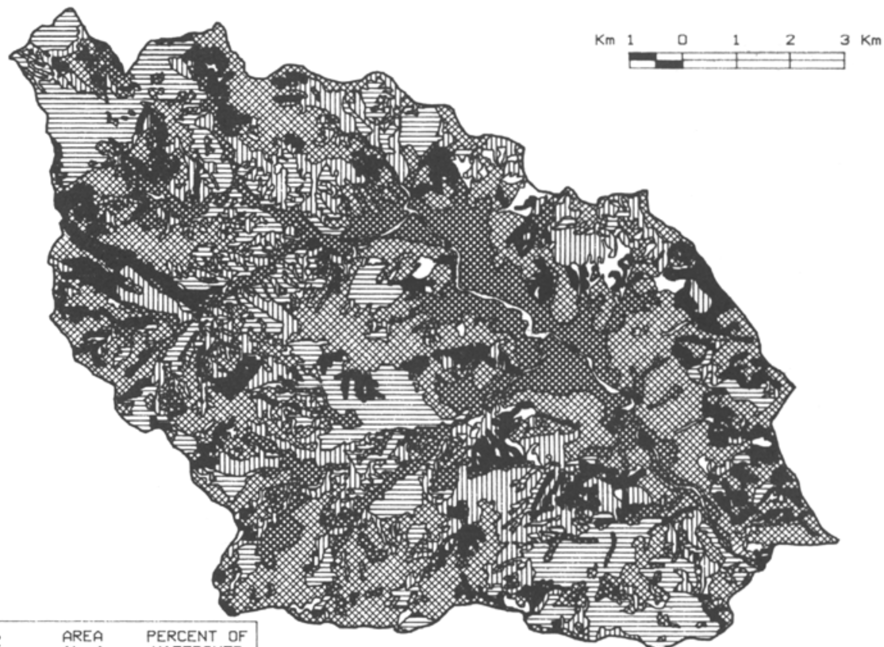


Figure 3. Land-use change 1947–1981 (numbers represent total hectares converted into or out of stated land use; scale 1 to 50,000.

tance (Gilmour and Fisher 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 and that afforestation is increasing. If this watershed is a reflection of the situation in the Middle Mountains of Nepal, then our quantitative data do not support the recent statements by many international organizations that massive deforestation is still occurring (World Bank 1979, Dixon and others 1988, Environmental Resources Ltd. 1988).

There are three key problems associated with this analysis. First, within the 34- and the 18-year time periods, there are internal land-use dynamics, and with the available data we can only show the overall trend. Second, caution is needed in the evaluation of the data since the first data set was examined at a much more general scale than the second (1 to 50,000 vs 1 to 20,000 scale). Third, there are potential errors in data collection, transformation, and processing. Their cumulative effect is difficult to ascertain.

While these are valid criticisms, it is nevertheless interesting that the trends obtained from the GIS analysis confirm the impressions of foresters working in the test area for the past 10 years (Griffin and others 1988, Gilmour and Fisher 1991). In addition, an independent dataset supports the results. Schmidt (1992) and Wymann (1991) carried out very detailed



LAND USE 1972	AREA (ha)	PERCENT OF WATERSHED
KHET	1653	15
BARI	3843	34
FOREST	2182	20
GRAZING	1184	10
SHRUB	1857	17
OTHER	422	4

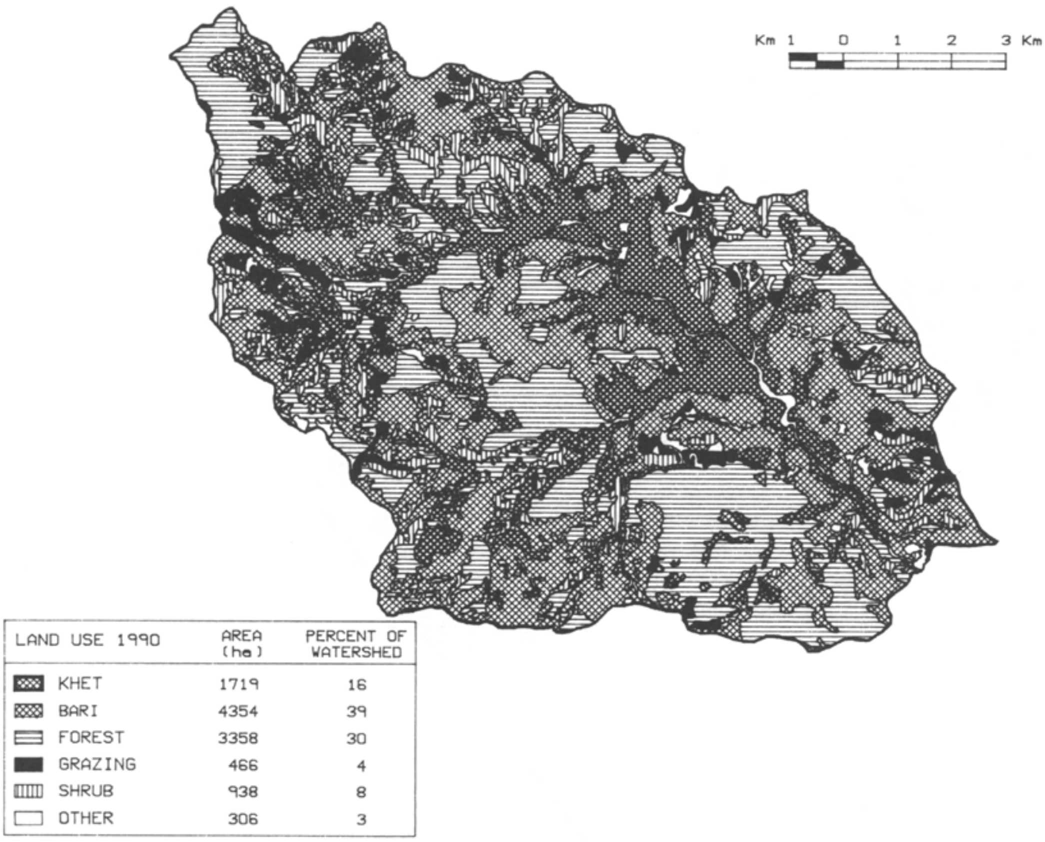
Figure 4. Land-use distribution 1972 (based on 1 to 20,000 scale aerial photo interpretation).

forest and agricultural surveys for the period 1972–1990 in the upper portion of the watershed (approximately 10% of the area, referred to as the Dhulikhel subwatershed). The same interpretation and GIS techniques were used, but all information from the aerial photos was transferred directly into GIS using the AP-190 analytical plotter. Every mapped polygon was verified in the field, and soil and foliar samples were collected in 80% of forest units and 60% of agricultural units. The overall survey included the Dhulikhel portion of the watersheds, but data were collected independently. A comparison of these two surveys can be used to confirm the land-use trends and show that the potential cumulative errors associated with combinational accuracy is not influencing the end results. Table 1 shows that not only are the trends the same but they are in remarkable agreement. In spite of differences in the areas and topographic conditions, the data show that the increases in forest cover are virtually the same and the losses of grazing lands and shrub follow the same directional trends. The increases in rainfed agriculture (bari) and the losses in grazing land and shrub were proportionally higher in the subwatershed. This is to be expected since more frequent conversions are expected in rainfed agriculture on more marginal areas where soil fertility maintenance is more difficult. The Dhulikhel subwatershed is in the headwaters of the Jhikhu Khola watershed and has proportionally more marginal and steeper land. This comparison gives us confidence to state that the trends are realistic.

So far we have used GIS to produce a historical representation of the land-use dynamics and trends. The next step is to use more fully GIS techniques to examine the resource quality, determine possible causes, predict future consequences, and provide alternatives to resource management. This was done by examining the GIS data base selectively and combining the land use information with other GIS-based resource information.

Spatial Relationships between Land Use and Site Conditions

In examining the spatial relationships between land use and other GIS-based resource data, only the detailed survey (1972–1990) was used. The first eval-



LAND USE 1990	AREA (ha)	PERCENT OF WATERSHED
KHET	1719	16
BARI	4354	39
FOREST	3358	30
GRAZING	466	4
SHRUB	938	8
OTHER	306	3

Figure 5. Land-use distribution 1990 (based on 1 to 20,000 scale aerial photo interpretation and field verification).

uation focused on the gains and losses of land uses in relation to site conditions. The three key issues are: (1) implications of forest expansion, (2) implications of agricultural expansion, and (3) implications of losses of grazing and shrub land.

The key forestry question was to determine where the forest expansion took place and what type of forests have been created. The forests were classified into five main forest types and several subclasses (Table 2). Comparing the land-use dynamics to the forest type and quality (Table 3) yields some very positve relationships. There are substantial net gains in forest cover. Between 1972 and 1990 the gains of forest cover from shrub exceeds the losses by more than six times (868 ha), suggesting a general improvement in the status of the forest. Forest losses to shrub and grazing lands were small and losses and gains into and out of agriculture were more or less the same. Finally, crown cover has also improved in that there is a substantial decrease in forests and shrub with less than 10% crown cover and an increase of forests with crown cover in the 10%–50% cover category. From Table 3 it is evident that the areas under mature forests have also increased. All these findings point towards a general improvement of the forest resources.

In contrast, there are trends that suggest the overall situation has not improved as much as first perceived. A significant portion of the forest gains have come at the expense of grazing lands. A net of 386 ha of grazing land was lost to forestry and the total grazing land has declined to 718 ha. This represents a loss of 61% of all grazing lands present in 1972. Feed resource deficits have been identified by Schreier and others (1991) as reaching critical proportions in Nepal as a whole and, coupled with the loss of shrubland, is creating an even more precarious feed resource problem in this area.

In addition, the most significant changes in the forests were due to pine plantations. Of the 1176 ha of overall forest expansion, 743 ha (63%) were in the form of pine plantations. This suggests that historic forest cover has not increased dramatically except for the introduction of pine plantations. This is evident by the figures for sal (*Shorea robusta*) -dominated forests, which have declined slightly over the same time period (Table 3). This change in species dominance is

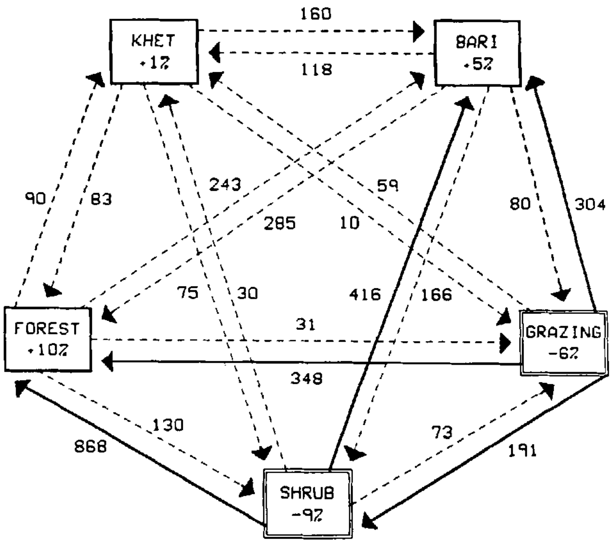


Figure 6. Land-use changes 1972–1990 (numbers represent total hectares converted into or out of stated land use. Khet = irrigated land with cropping systems dominated by rice, bari = rainfed agriculture with cropping systems dominated by maize). Does not include category labeled "infrastructure," which includes rivers, roads, villages, and landslides. (Scale 1 to 20,000.)

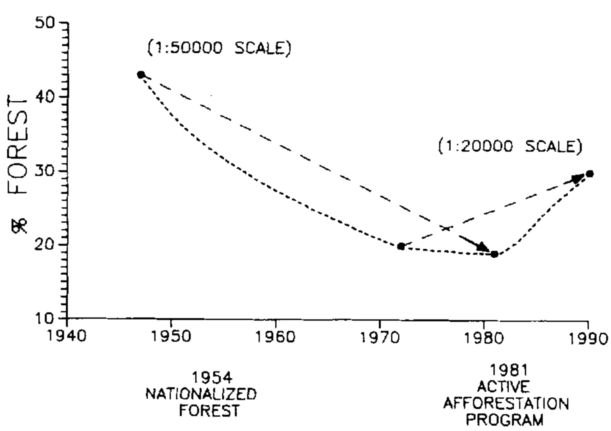


Figure 7. Overall historic trends in forest cover in the Jhikhu Khola watershed 1947–1990. The dotted line reflects inferred changes interpreted from historic events.

not necessarily of great immediate benefit to the people. Although pine trees are useful in stabilizing soils and improving future timber production, they are not very 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, which is collected during the dry season as input to maintain nutrients in agriculture, is likely acidifying soils over the long run.

Table 1. Comparisons of land use changes between 1972 and 1990: Dhulikhel vs Jhikhu Khola watershed

Land use type	Dhulikhel watershed[a] ha	Dhulikhel watershed[a] % total	Total watershed change 1972–1990 ha	Total watershed change 1972–1990 % of total
Khet (Irrigated)	+23	+1.8	+66	+0.6
Bari (Rainfed)	+115	+9.0	+511	+4.6
Forest	+132	+10.4	+1176	+10.5
Grazing	−127	−10.0	−719	−6.5
Shrub	−156	−12.3	−919	−8.2
Others	+13	+1.0	−116	−1.0
Total area		1267 ha		11,141 ha

[a]From a detailed study by Schmidt (1992) and Wymann (1991).

Table 2. 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 Wood	30–50	Reproduction	Mixed hardwoods
Shrub	50–70		Mixed broadleaf
	>70		

[a]More than 75% of tree species.

The dominance of pine (*Pinus roxburghii*) is exemplified in Table 3. Pine is now dominant in 48% of all forests, which represents a dramatic increase from the 31% dominance in 1972. While there are increases in three maturities and crown cover, these increases are small and suggest that the improvements are small. Only 19 ha of forests were classified as having crown cover of more than 50%. The fact that the area of sal forests is declining is of additional concern since this species provides very valuable fodder and composting material.

The pine planting effort has occurred mostly on land previously under forest (36%), shrub (25%), and grazing (24%), and the remaining 15% occurred at the expense of agriculture and other uses.

These findings show a general increase in forest cover, a slight improvement in standing biomass, and a marked change in the species distribution. In the short run, this latter trend is of questionable benefit to the local farmers since it significantly reduces feed supplies, reduces biodiversity, and produces an undesirable compost. We are not condoning the use of forest litter for agriculture, since this ultimately re-

Table 3. Land use dynamics in relation to type and conditions of forests

Land use	1972 total (ha)	1990 total (ha)	Net increases or decreases (ha) 1972–1990
Agriculture	5496	6073	+577
Forests	2182	3356	+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	+743
Mature forest total	180	386	+209
crown density %			
>50	0	19	+19
10–50	2008	2878	+870
<10[b]	2031	1399	−632

[a]Includes pine plantations.
[b]Includes shrub.

duces the forest productivity, but the long-term implication of using pine litter as a soil amendment for agriculture can lead to significant acidification and cation losses, both of which are detrimental to productivity.

GIS allows us to examine further the resource situation by comparing the land-use dynamics in relation to elevation and slope. The first evaluation provided in Table 4 illustrates the major forest expansions in relation to elevation and slope. Since pine plantations make up the bulk of the expansion, we limited the forestry analysis to the recently planted pine plantations. As can be seen from Figure 4, the expansion of pine plantations occurred mostly on gentle to moderately sloping terrain (65% of all pine plantations are on slopes less than 35%), with the largest area in the 20%–35% slope range. In addition, 84% of all pine plantations are on sites below 1200 m elevation. The intent of the afforestation was mainly to produce a source of wood products, but afforestation in Nepal should give equal considerations to stabilizing the steeply sloping upper elevation slopes. In addition, improving biomass products that can readily be used by the local farmers for feed, fuelwood, and food should also be given high priority. The slope stabilization component as shown by the slope/elevation statistics has not been addressed, since high elevation and steep slopes, where erosion concerns are highest, have not been subject to much afforestation. The concern for providing more feed, fuelwood, and food resources from the forest has also not been met since pine-dominated forests produce fewer products that are directly beneficial to the farmer in the short run.

Since the forests play an intricate role in the lives of Nepali farmers, it is not very fruitful to look at the forest situation in isolation from the other resources. The impact of the forest dynamics on agriculture can be shown by further GIS-based analysis.

To meet the increasing food needs of the population, which is growing at a 2.8% rate in the test area, agricultural intensification has occurred in two ways. Double and triple annual crop rotations were introduced in the early 1980s, and marginal lands are continuously being converted into agriculture. If irrigation water is available, triple crop rotations dominated by rice (khet) are the preferred cropping system. However, such intensification has now reached a state where water availability is limited, hence the only other option to the poor farmers is converting marginal land. This is happening and can be documented by the GIS analysis in Table 4.

Figure 6 shows that the overall increases in irrigated land (khet) are insignificant over the period 1972–1990, suggesting that insufficient water supplies are limiting this generally preferred option. Dryland agriculture was evaluated in terms of topographic position and slope angles using a 10 × 10-m raster size. The results in Table 4 indicate that 66% of all sites converted into rainfed agriculture occurred on slopes greater than 20% and the highest land conversion occurred in the 36%–49% slope category. In addition, the agricultural expansion in the upper elevations (above 1200 m) covers twice the area that has been converted into pine plantations. This clearly points towards more marginalization of agriculture. This trend is consistent in all land (forests, shrubs, and grazing lands) converted into rainfed agriculture.

Further evidence of the marginalization of agriculture can be shown by the overall 6% loss of grazing land to forestry. Comparing grazing lands that remained under grazing (1972–1990) with those converted into forests (Table 4), it is evident that a proportionally larger amount of less steeply sloping land was converted into forests than remained under grazing (314 ha on 20%–35% slope vs 340 ha on 36%–49% slope). In addition, the grazing land losses above 1200 m were more than twice the land area that was placed under pine plantation. On a proportional basis, the higher amount of land lost from grazing was in the 1200 to 1400-m elevation class, while the largest proportional gains in forests took place in the 1000 to 1200-m elevation zone. Slope stability and soil erosion is of critical concern in this monsoon climate on steeply sloping upper elevation cultivated slopes, yet

Table 4. Land use dynamics in relation to slope angles and elevation

Overall distribution in watershed		Gains in pine forests (plantations)		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	225	8.2	257	9.4	340	12.8
50–155	1268	132	10.4	190	15.0	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	7.0	405	13.3
1200–1399	2027	120	5.9	248	12.3	258	12.7
1400–1599	1014	41	4.0	105	10.4	86	8.5
1600–2099	486	4	0.8	21	4.3	23	4.7

Table 5. Soil pH distribution in relation to elevation

Elevation classes (m)	Area (ha)	No. of samples	Percent of soil samples with pH		
			>4.8	4.3–4.8	<4.3
750–999	4558	64	39	50	11
1000–1199	3056	81	33	52	15
1200–1399	2027	78	29	53	18
1400–1599	1014	49	8	63	29
1600–2099	486	12	12	50	33

conversion into agriculture rather than afforestation is the dominant trend on these sites.

Given the interdependence of the resources, the overall increases in forest cover, and the intensification in agriculture, it will become increasingly difficult to sustain the prevailing land use systems. This is evident by the very dynamic nature of land-use changes and the conversions of upper elevation, steeper lands into agriculture. The increasing use of acid-generating fertilizers on rainfed agricultural fields encouraged through aid programs has resulted in crop intensification in the last 7–10 years. The concern of using pine litter as a soil amendment is expected to further increase the acidity.

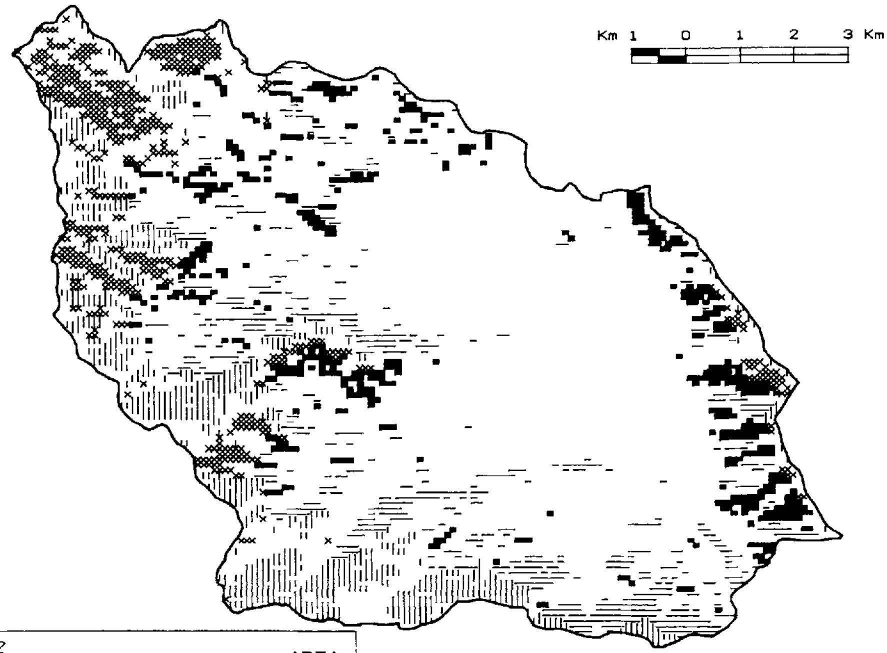
The problems associated with this potential acidification can be shown by a GIS overlay of elevation classes with the pH of 284 soil samples. Overall, 18% of all samples had soil pH (in $CaCl_2$) values in the very acidic class and, as shown in Table 5, there is a higher portion of very acid soils in the higher elevation sites and a clear trend of increasing acidity with elevation (ranging from 11% to 33%). This is in part a result of natural leaching effects, but might also reflect the more frequent use of acid-producing fertilizers and pine litter in dryland agriculture, which dominates the upper elevation slopes.

The effects of these practices have yet to be documented in detail. Given the inherent variability and the recent introduction of these practices, it will be challenging to show direct cause-and-effect relationships. Table 5 indicates that the higher elevation slopes have predominantly more acidic conditions and that the overall pH levels are very low. Coupled with the fact that forests are losing nutrients through litter collection, it is clear that gaining forest cover has not improved the overall resource condition.

GIS: A Tool for Forest Improvements

The problems and complexities of the resource management issues in Nepal are easy to identify, but it is challenging to provide possible alternatives to improve the resource status. GIS can play a key role in this process. An alternative forest practice illustrates the potential of GIS in resource management (Figure 8 and Table 6).

The watershed was divided into two elevation zones (above and below 1200 m). This represents a natural climatic break evident by a change in the native vegetation. The watershed was then further divided into dominantly south- vs dominantly north-facing aspects. This is a critical subdivision since south-facing slopes are significantly drier than north-facing slopes. These climatic breaks are reflected in the soil conditions. The combined aspect/elevation classification enabled us to divide the watershed into four microclimatic conditions. Analysis of the carbon content in the surface soils showed a doubling of carbon between low-elevation, south-facing and high-



SLOPE >35% ASPECT	ELEV.	CLIMATE	AREA (ha)
■ SOUTH	≤1200m	HOT DRY	598
▩ SOUTH	>1200m	WARM DRY	549
☰ NORTH	≤1200m	WARM MOIST	835
▥ NORTH	>1200m	COOL MOIST	894

Figure 8. GIS-generated forest planting map based on a combination of slope, aspect, and elevation. The four categories represent microclimatic conditions above or below 1200 m elevation, predominantly north- vs south-facing slopes, and slopes steeper than 35%. The appropriate fodder tree species that best match these categories are provided in Table 6.

elevation, north-facing sites (Wymann 1991, Schmidt 1992). Considering the importance of agricultural production, we excluded all lands with slopes <35% from our evaluation. The four site classes displayed in Figure 8 thus 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 to be hot and dry. The climate has been monitored at five stations in the watershed since 1989 and, once sufficiently long-term records have been collected, the GIS-generated site conditions will be calibrated.

Nepal has a wealth of fodder trees that are native to the region and many have the capacity to fix nitrogen. These tree species are increasingly difficult to obtain since heavy lopping prevents seed production. However, there is sufficient data in the literature (Panday 1982, Panday and others 1991) to produce a list of indicator species and their optimum climatic conditions in relation to the GIS-generated microclimatic classification. Combining Table 6 with Figure 8 produces an ecological plantation map that matches species to site conditions. This represents a prescription to plant native trees that can stabilize the most critical slopes, provide desirable fodder and fuelwood to the local people, improve soil fertility (N-fixers), and match species with their optimum site conditions. Additional GIS data on soil conditions could be added to further refine the GIS analysis. The community forestry group can then set priorities in the choice of species and where they should be planted.

Conclusions

This GIS-based evaluation has shown that forest degradation was most critical in the Middle Mountains of Nepal in the late 1950s and early 1960s when more than 24% of the forest land was lost to agricultural conversions and forest degradation to shrub. In the early 1980s, as a result of afforestation programs, a significant forest expansion took place, resulting in an overall 10% increase in forest cover between 1972 and 1990. These findings do not support published claims of massive recent losses in forest cover in the

Table 6. Optimum site conditions for different fodder tree species

Moist-humid conditions	Dry condition
Environmental conditions: above 1200 m asl	
North aspect	
Brassaipsis hainla	*Betula alnoides*
Machilus gamblei	*Castanopsis tribuloides*
Machilus gamblei	*Sarauia napaulensis*
	Ficus nemoralis
	Quercus glauca
South aspect	
Ficus lacor	*Ficus nemoralis*
Ficus roxburghii	*Grewia tiliefolia*
Bauhinia variegata	*Litsea polyantha*
	Ficus cunia
Environmental conditions: below 1200 asl	
North aspect	
Artocarpus lakoocha	*Ficus cunia*
Ficus lacor	*Erythrina variegata*
Terminalia tomentosa	*Artocarpus integra*
Bauhinia variegata	*Bassia butyracea*
Boehmeria rugulosa	*Bauhinia purpurea*
South aspect	
Garuga pinnata	*Ficus clavata*
Artocarpus lakoocha	*Bauhinia purpurea*
Terminalia tomentosa	*Shorea robusta*

hills of Nepal. This suggests that the afforestation efforts spearheaded by the Nepal–Australia forestry project have had considerable success.

With the GIS analysis it was possible to identify causes and consequences of afforestion and increasing agricultural expansions by comparing the forest and agricultural land expansions and the grazing land losses in relation to slopes and elevation. The forest expansion has come primarily at the expense of converting grazing land and shrubland into pine plantations. While this expansion has contributed to soil stabilization, the improvements are questioned since much of the conversion has occurred on low elevation sites and on moderately steep slopes. In addition, pine does not provide fodder, its fuelwood is less desirable, and the pine litter is likely increasing soil acidity in agriculture since forest litter is regularly used during the dry season to supplement nutrients in intensive agriculture. The agricultural marginalization is further shown by the fact that the proportion of acid soils shows a very marked increase with elevation.

This analysis demonstrates the complexity and interdependence of resource managment. Major afforestation programs have resulted in significant increases in forest cover. Unfortunately, the population pressure has resulted in more land-use intensification and the afforestation has caused a reduction in species diversity, a decline in fodder production, and a likely increase in the soil acidification process. The combined effect may lead to serious long-terms consequences for sustainable development unless the pine plantations can be converted into more diverse forests. The GIS-based evaluation indicates that we are gaining forests but losing ground in the Middle Mountains of Nepal.

Finally, GIS has the capacity to assist development by facilitating the production of afforestation plans that are more effective than the currently prevailing program of planting pine. The method subdivides the key areas in need of afforestation by highlighting where the steep slopes and topographically induced microclimatic conditions are. The native tree species that are most appropriate is generating fodder, providing desirable fuelwood, and improving soil nutrients by nitrogen fixation are then matched to their optimum site conditions are generated by GIS. This map can assist local community groups in diversifying their afforestation efforts. GIS thus becomes a powerful analytical resource management and planning tool.

Acknowledgments

Financial support for this research was provided by the International Development Research Centre (IDRC). The assistance of Dr. N. Mateo (IDRC), Dr. K. Riley (IDRC), Dr. E. Rached (IDRC), Mary Beaussart (IDRC), R. M. Tamrakar (ISS), K. Subba Jabegu (ISS), and Dr. K. K. Panday (ICIMOD) is gratefully acknowledged.

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