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Land Cover Dynamics Since the 1950s in Chemoga Watershed, Blue Nile Basin, Ethiopia

This study evaluated changes in land cover in the Chemoga watershed, headwater to the Blue Nile. Two sets of aerial photographs (1957 and 1982) and a multispectral Spot image (1998) were used as inputs to produce 3 GIS-based land cover maps of the area. The results show that during the last 41 years, forest cover increased at a rate of about 11 ha per annum in the 36,400-ha watershed. Woodlands and shrublands decreased between 1957 and 1982 but increased between 1982 and 1998, approximately to their previous levels. Farmland and settled areas gained from the other cover types (13% increase) in the first period but lost around 586 ha (2% decrease) in the second. Grassland and degraded land decreased, accounting for 4.8% of the total area of the watershed in 1982 and 3.5% in 1998, as against 9.6% in 1957. Riverine trees suffered the greatest destruction, shrinking by 79% over the 4 decades; much of this decline was due to cultivation. Marshlands increased in the first period and decreased in the second. A new pond emerged amid the marshlands between 1982 and 1998. Population growth and the associated demand for land and trees was the major driving force behind the changes. This study shows that the deforestation trend was reduced and even partly reversed in the area because local people planted trees as a source of fuel and income. This trend ought to be encouraged through appropriate interventions—in particular by promoting planting of local species rather than eucalyptus—to increase not only economic but also ecological benefits. Indeed, the current state of land cover and its dynamics have environmental implications at the local scale and beyond. Hence, environmental management for sustainable development requires interregional and international cooperation.

Keywords: *Land cover changes; remote sensing; afforestation; Ethiopia.*

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Assessing land cover dynamics

Land cover dynamics—particularly deforestation—has become a global concern, with dramatic implications for human livelihood systems. It is one of the major topics in current global change studies (eg, climate change, alteration of biogeochemical cycles) jointly initiated in 1996 by the International Geosphere–Biosphere Program (IGBP) and the International Human Dimensions Program on Global Environmental Change (IHDP) (IGU 1998). In Ethiopia, accelerated deforestation has been taking place since the beginning of the 20th century (EFAP 1993). Although forests were thought to have covered nearly 40% of the country's total area at the beginning of the 20th century (Breitenbach 1961; EFAP 1993), forest cover today is estimated at only 2–3% (EFAP 1993). The rate of deforestation is calculated to be between 150,000 and 200,000 ha per annum (EFAP 1993). But estimates of original forest cover and deforestation rates differ greatly because information is derived mostly from indirect sources (eg, travelers' accounts) and less often, if at all, from quantitative studies where forest cover is measured at different time intervals. But the general consensus is that the scale of clearance in Ethiopia has been massive.

Large-scale destruction of forest resources is not the only change that has taken place at the national level. Major land cover changes have also occurred at the local level for all land types. For instance, Solomon (1994) reported rotational land cover or use involving cultivation and vegetation (forest and bush) between 1957 and 1982 in the Metu area, southwestern Ethiopia. A significant increase in cultivated land at the expense of forestland was found to have occurred between 1957 and 1995 in the Dembecha area, northwestern Ethiopia (Gete 2000). Kebrom (2000) reported increases in open areas and settlements at the expense of shrublands and forests between 1958 and 1986 in the Kalu area, north-central Ethiopia. On the other hand, increases in forestland and cultivation land at the expense of grazing land were detected in Sebat-bet Guraghe, south-central Ethiopia, (Muluneh 1994) between 1957 and 1994.

Such local-level dynamics play a significant role in determining the health of an ecosystem at the microlevel. Studies of the magnitude, rates, patterns, causes, and biophysical and socioeconomic implications of land cover dynamics at the local level can help design more effective land management strategies and policies. But investigations of land cover dynamics at this level are rare in Ethiopia, a deficiency that the present study tries to correct in the case of the Chemoga watershed. The specific objectives are to evaluate changes in land cover over a period of time on the one hand and describe the possible causes and environmental implications of these changes on the other.

The study area: Chemoga watershed

The Chemoga watershed lies between 10°18'N and 10°39'N latitude and 37°44'E and 37°53'E longitude

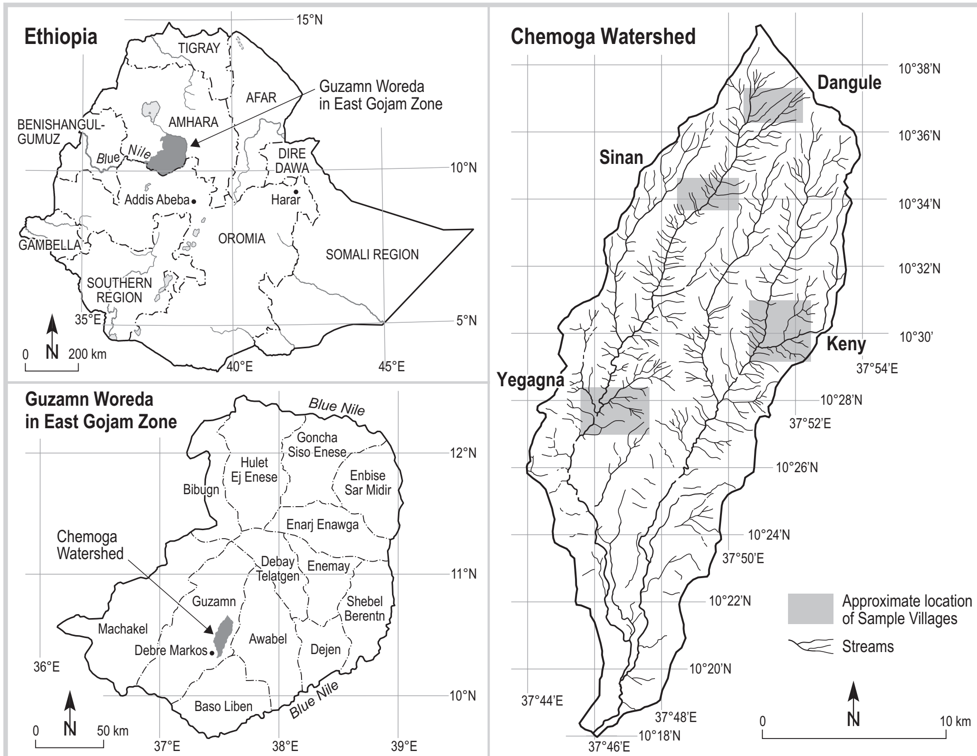


FIGURE 1 Location map of the study area. (Map by author)

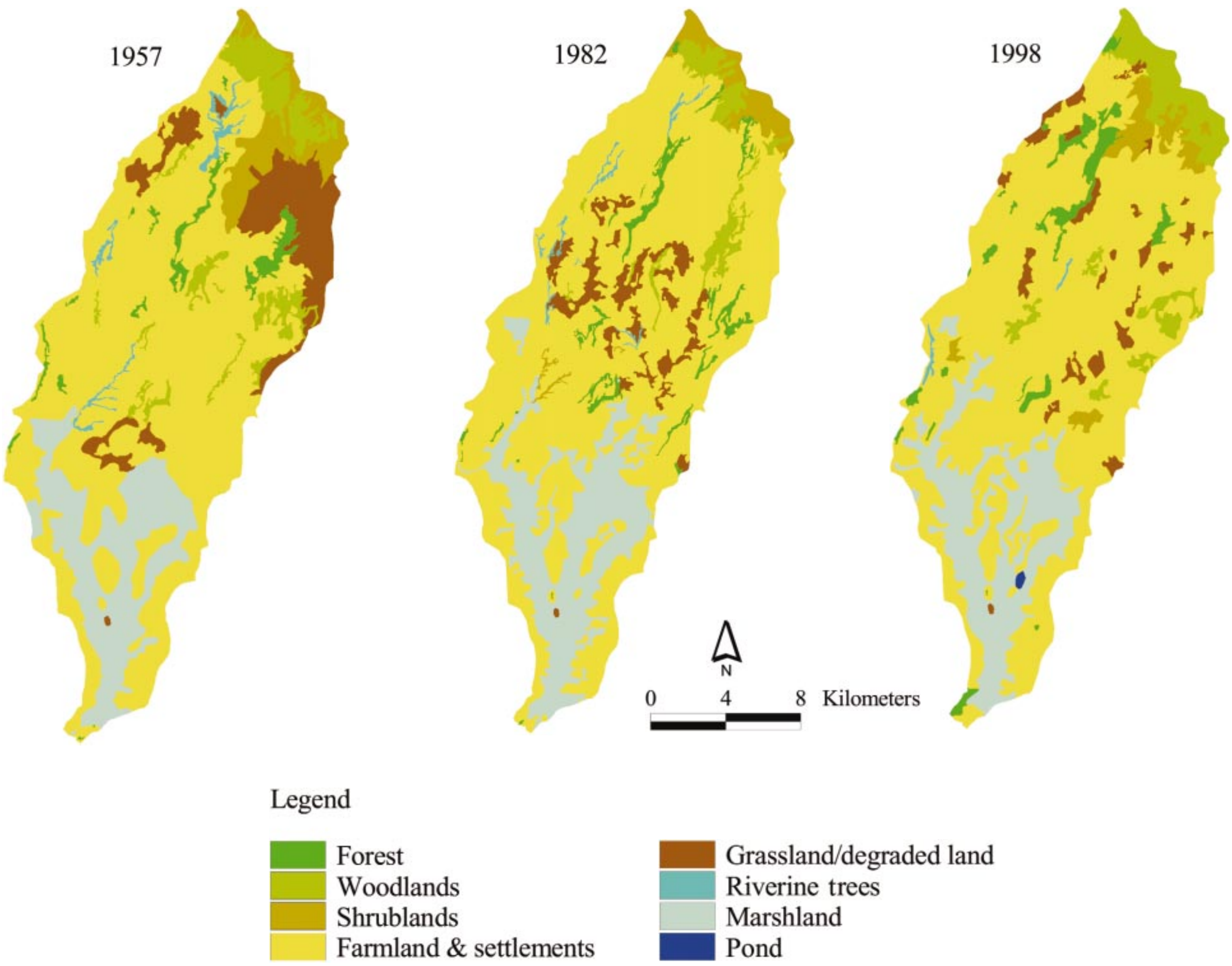
(Figure 1). It covers an area of approximately 364 km^2 and has a population of about 23,660. The Chemoga watershed is one of the headstreams of the Blue Nile. The Blue Nile is the largest tributary of the Nile, contributing around 86% of its total annual discharge (Conway 1997). In recent years, the amount of water carried downstream by the Blue Nile declined significantly (Mengistu 1997), whereas the mass of sediments transported increased (El-Swaify and Hurni 1996) because of environmental degradation in the highlands of Ethiopia. The Chemoga watershed is part of this degraded and degrading basin; it is representative of conditions in large parts of the temperate and alpine climatic and agro-ecological belts (locally known as *dega* and *wurch*) in the northwestern highlands. As measured at Debre Markos (10°20'N, 37°40'E at an elevation of 2411 m), the mean annual temperature is 14.5°C, ranging between 13.2°C in July and August and 17.3°C in March. The average annual rainfall is 1300 mm; more than 75% of the total precipitation occurs in the 4 months from June to September. Because the Chemoga watershed lies at a higher elevation than does Debre Markos (between 2420 and 4000 m), temperatures are significantly lower and rainfall is probably higher there. Average annual total potential evapotranspiration (PET), as estimated with the Thornthwaite (1948) method, is 855.7 mm, with very low monthly variation.

Materials and methods

The materials used to create the spatial database needed for this study were 2 sets of panchromatic aerial photographs taken in 1957 (December) and 1982 (January) and a multispectral (3-band) Spot image dated December 1998. Both sets of photographs have base scales of about 1:50,000 and were obtained from the Ethiopian Mapping Authority (EMA). Twenty photographs from 1957 and 19 photographs from 1982 covered the watershed studied. The use of the Spot image was necessary because recent aerial photographs were not available. On the other hand, the photographs were the only sources of information for the period predating the launch of the Spot satellites. Hence, for this study it was necessary to combine aerial photographs and a satellite picture.

The establishment of the databases involved (1) scanning the aerial photographs with a 600-dots-per-inch scanner, (2) geo-referencing the photo mosaics according to the Universal Transverse Mercator (UTM) system using 1:50,000 topographic maps, (3) geo-referencing the Spot image in the same projection using the same topographic sheets, and (4) delimiting and cutting out the study watershed by tracing it from 1:50,000 topographic maps and digitizing it in ArcView 3.1, then superimposing the view on the spatial databases created from the photographs and the satellite image.

FIGURE 2 Land cover types in the Chemoga watershed in 1957, 1982, and 1998.



The identification and classification of land cover types on the aerial photographs required intensive use of mirror stereoscopes for visual verification because the photographs were black and white. To avoid errors that can occur as details increase, the classification scheme was kept simple. Thus, 7 land cover classes were identified: forest, woodlands, shrublands, farmland and settlements, grassland and degraded land, riverine trees, and marshland. The 1998 land cover map contains a further class: a pond that appeared recently. The land cover classes from the Spot image were generated by on-screen digitizing, using ArcInfo 7.3 on the basis of reflectance characteristics (false color composites) of the different land cover types. This was supplemented by a number of field visits that made it possible to establish the main land cover types. For the purpose of comparison, many land cover types produced from the multispectral Spot image were synchronized to fit into the 7 classes defined from the black and white aerial photographs. In so reducing the number of classes, proper care was taken to minimize errors due to generalization.

ERDAS Imagine 8.3 and its peripheries were used to analyze the spatial databases created. Finally, 3 land cover maps were produced, corresponding to the 3 reference years, and temporal changes in land cover were determined. A few focus group interviews were also conducted in 4 sample villages in the watershed to obtain additional information.

Results and discussion

Dynamics in land cover types

Figure 2 shows the land cover maps of the watershed for the 3 reference years, and statistical summaries of the different land cover types are given in Table 1.

TABLE 1 Land cover changes in Chemoga watershed between 1957 and 1998.

Land cover type	Area in 1957 (ha)	Area in 1982 (ha)	Area in 1998 (ha)	Change between 1957 and 1982 (%)	Change between 1982 and 1998 (%)
Forest	873	1041	1321	+19	+27
Woodlands	2449	1321	2457	–46	+86
Shrublands	1860	1099	1186	–41	+8
Farmland and settlements	22,000	24,832	24,246	+13	–2
Grassland/degraded land	3508	1766	1276	–50	–28
Riverine trees	458	277	94	–40	–66
Marshland	5252	6064	5780	+15	–5
Pond	—	—	40	—	+100
Total	36,400	36,400	36,400	—	—

Forests: The area under forest cover, which includes trees planted around homesteads and which constituted only 2.4% of the total watershed in 1957, showed a slow but persistent increase over the period under study. Though this was a general trend, the rate of increase was quite small compared with the total area of the watershed. The area under forests increased by about 19% between 1957 and 1982 (7 ha/y) and by 27% between 1982 and 1998 (17 ha/y). During the entire period the increase was more than 50% (about 11 ha/y). This is attributable to the afforestation program of the *derg* regime, an initiative to preserve indigenous trees or forests and planting of trees at the household level. As in many places throughout the country, the community undertook some afforestation during the *derg*'s dictatorial rule. The small success achieved contributed to the present areal coverage by forests. Most of the tree species planted at that time were varieties of Juniper and Eucalyptus.

Area protection by the local community is another reason for the increase in forest cover, which has led to regeneration of Asta (*Erica arborea*) woodlands in forests in the upstream part of the watershed. Initiated by elders, this effective form of community forest management was established in the 1960s, as confirmed by participants in group interviews. It shows that community participation can lead to more sustainable resource use compared with a centralized system of control that strives for preservation. A centralized, top-down approach to resource conservation in Ethiopia, such as the one broadly attempted during the *derg* regime, led nowhere (Azene 1997, 2001). But the most important factor in increased areal coverage of forests is planting trees at the household level as a response to the growing scarcity of natural forests due to various reasons.

Woodlands and shrublands: The pattern of change in woodlands and shrublands is broadly similar. Both showed a decrease in the first period and then an increase in the second. The decrease in area for woodlands was 46% between 1957 and 1982; there was a recovery to a higher level by 1998. A 41% decrease in shrublands also occurred between 1957 and 1982, but here too some reemergence of this cover type occurred between 1982 and 1998. Woodlands and shrublands combined accounted for 12%, 7%, and 10% of the total area of the watershed in 1957, 1982, and 1998, respectively.

Farmland and settlements: This category includes cultivated land and settlements. These 2 land cover types were combined into 1 category because it was difficult to identify the dispersed rural settlements as a separate land cover type. Also, cultivated land exists around homesteads and would have to be recognized as such. Hence, for practical reasons, the 2 cover types were merged into 1 category. Farmland and settlements gained area between 1957 and 1982 (13% increase) but lost around 586 ha (2% decrease) between 1982 and 1998. The increase between 1957 and 1982 corresponds to the population growth and is also possibly due to the 1975 national-level land reform, which allocated much of the grazing land to landless peasants for cultivation; this was also observed in the most recent land redistribution of 1997 undertaken in the Amhara Regional State (Yigremew 1997). The decrease in the latter 16-year period, though very small, might seem to contradict expectations, given the increase in population. But this decrease is attributable to increased tree planting at the household level, which has led to the formation of clustered plantations around homesteads. These were classified as forest cover because that is how they appeared on the images.

Grassland and degraded land: Grassland and degraded land includes both open grazing lands and exposed

TABLE 2 Population growth in 4 villages in the Chemoga watershed between 1984 and 1994.

	Population		Growth between 1984 and 1994	Rate of growth (%)[a]	Number of years after which the population will have doubled (after 1994)
	1984[b]	1994[c]			
Dangule	3469	5121	1652	3.89	18
Keny	3025	4102	1077	3.05	23
Sinan	2865	3990	1125	3.31	21
Yegagna	3268	3570	302	0.88	78
Total	12,627	16,783	4156	2.85	24

[a]The growth rates were calculated assuming an exponential increase: $P_t = P_0 e^{rn}$. Hence, $r = 1/n \ln(P_t/P_0)$; the doubling period in years is given as ln 2/r.
[b]Source: OPHCC (1990).
[c]Source: OPHCC (1995).

badlands. Because it was difficult to distinguish open badlands from grazing lands, which are heavily degraded in the area, they were classified together. In 1957, grassland and degraded land covered around 9.6% of the total area of the watershed. This was reduced to 4.8% by 1982 and further diminished to 3.5% by 1998. According to the group interviews, the major reason for the decrease in the areal extent of grassland and degraded land was population pressure, which caused much of the open grazing land to be transformed into cropland. The remaining area now consists largely of bare ground, which is overgrazed and characterized by exposed rocks.

Riverine trees: Most destruction of vegetation cover occurred in areas with riverine trees. The width of these strips of vegetation-covered lands along the rivers shrank continuously. In 1957 the area under riverine trees was about 458 ha. It was reduced to 277 ha by 1982 and further dwindled to 94 ha by 1998. This constitutes a 40% rate of decrease for this type between 1957 and 1982 and a 66% rate of decrease between 1982 and 1998. During the 41-year period, the area covered by riverine trees decreased by around 79%, much of it lost due to cultivation.

Marshlands: The pattern of change for this land cover type is one of increase in the first period and decrease in the second. Marshland covered 14% of the total area of the watershed in 1957, 17% in 1982, and 16% in 1998. These dynamics may be due to the decrease in woodlands and shrublands and the increase in farmland and settlements between 1957 and 1982 and the increased vegetative cover (forest) between 1982 and 1998. Indeed, decrease in vegetation in a catchment can lead to increase in water yield due to decreases in transpiration losses. Such an increase in water yield can cause a greater area to be subject to wet conditions, thus expanding the marshland. By the same reasoning, increased vegetative cover by 1998 may have caused increased transpiration losses and reduced catchment yields, thereby leading to shrinkage of the marshland. The increased water yield was probably the cause of the formation of a new pond amid the marshland by 1998. Indeed, the pond is unlikely to have been caused by a change in the rainfall pattern. This pond may have also provided an inlet for the water in nearby marshland, causing the surrounding area to dry up, resulting in a gain for farmlands and settlements.

Causes of land cover dynamics

Land cover changes are caused by a number of natural and human driving forces (Meyer and Turner 1994). Whereas natural effects such as climate change are felt only over a long period of time, the effects of human activities are immediate and often radical. Population growth is the most important of the human factors in Ethiopia (Hurni 1993), as it generally is in underdeveloped countries (Hurni 1993; Mortimore 1993). It was not possible to obtain overall demographic data for the watershed studied here because such data are compiled according to administrative structures (peasant associations, districts and provinces; data do not correspond to watershed boundaries). But changes in population in 4 sample villages in the watershed between 1984 and 1994 are given below, making it possible to gain insight into the magnitude and rate at which the population has been increasing (Table 2).

The total population of the watershed at the time fieldwork for this study was carried out (2000) was around 23,660. Assuming that the average rate of population increase in the 4 sample villages (2.85%) remained constant in the whole watershed, the population of the watershed would have been around half its current size about 25 years ago. By the same reasoning it will double within less than 25 years from now. Thus, population growth was certainly the most important factor causing change in the observed land cover dynamics because demand for land for cultivation and settlement and trees for fuel and construction purposes was greater. As mentioned above, the scarcity of trees motivated the local population to plant and protect trees.

Implications of land cover dynamics

Implications for soil degradation: Land cover is one of the factors that determine the rate of soil loss due to erosion. It influences both the erosivity of the eroding agents and the erodibility of the eroding subject (Morgan 1995). From the point of view of exposure of the land to erosive storms, which are typical in the area, the land cover types in the watershed can be classified into 2 classes: (1) land that is bare when the erosive rains occur, and (2) land under good vegetative cover when the rains begin, which is protected from the threat of erosion. Cultivated fields and part of the grassland and degraded land constitute the first category, whereas the rest of the land cover types can be included in the second. Accordingly, the part of the watershed subject to possible maximum soil loss accounted for 70%, 73%, and 70% of the total area in 1957, 1982, and 1998, respectively. Thus the total area exposed to major erosion remained almost constant between 1957 and 1998. The slight increase in forest cover in the watershed does not imply less severe erosion because most of the newly forested areas consist of eucalyptus trees, and their areal cover is limited to the vicinity of homesteads. Therefore, they do not contribute to soil and water conservation in this most vulnerable landscape, especially because the nonindigenous eucalyptus plantations hardly reduce erosion because of sparse canopies (FAO 1988).

Implications for the hydrological balance in the watershed: Land cover changes interfere with the land phase of the hydrological cycle. As is well known, land under little vegetative cover is subject to high surface runoff and low water retention. The increased runoff causes sheet erosion to intensify and rills and gullies to widen and deepen. The masses of sedimentary materials removed from hillslopes accumulate in low-lying areas downstream, where they create problems of water pollution, reservoir siltation, and problematical sediment deposition on important agricultural lands. These problems have already emerged in the study watershed, as was clearly stated by the local population during focus group interviews and also observed in the field. Extensive flooding and sedimentation problems occur in the watershed's vast downstream marshland area. According to local informants, this has become a major problem because valuable grassland is "buried," which makes it unusable for grazing.

According to the above grouping of land cover types into 2 classes, the total area of possible maximum runoff remained more or less the same between 1957 and 1998. Also, the observed increase in afforested areas did not improve the hydrological balance in the watershed because most of the eucalyptus trees planted are known to absorb a great amount of water.

Conclusions

Land cover changes have occurred in the Chemoga watershed during the 41 years considered here. But agriculture is still the main type of land use, leading to increased runoff, erosion, flooding, and sedimentation. A general trend toward "more people more trees" was observed, contrary to the findings of other studies (eg, EFAP 1993; Gete 2000; Kebrom 2000). This is the result of community afforestation, a local initiative to preserve indigenous forests and plant trees at the household level. This is a commendable initiative because it can have economic as well as ecological benefits, provided the main species of tree is not eucalyptus, which has many negative ecological effects (FAO 1988). Planting of trees at the household level should therefore be encouraged by providing farmers with ecologically friendly multipurpose species. Local initiative to preserve indigenous forests also requires important policy adaptations because it is necessary to involve local people and exploit the influence of village elders to implement efficient resource management in the country. Finally, the status of land cover and its dynamics have environmental implications at the local level as well as beyond because the consequences of degradation know no boundaries. For instance, downstream sedimentation caused by upstream degradation is already a problem in the study watershed. There is, therefore, an urgent need for interregional and international cooperation to improve environmental management. A logical framework for such cooperation is to use watersheds as regional constructs and to pursue an integrated watershed management approach for conservation planning and development of resources.

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