Understanding the Factors of Sedimentation:
A Comparison of Two Sub-basins in the Siwalik Hills of Nepal

By

Keshav Adhikari
and
Charles M. Schweik

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PART I. INTRODUCTION

There has been considerable debate in recent years over the cause of accelerated sedimentation and erosion from Himalayan watersheds. Sedimentation is considered one of the key processes related to resource sustainability in Nepal (Nakarmi et al, 1991). While there is growing evidence that much of the sediment movement in the Himalayas is due to natural forces (Carson, 1985; Ives and Messerli, 1989), human pressures on the natural resources such as forests and pasture areas do contribute to the problem (Blakie, 1988; Thapa and Weber, 1990). In watershed areas, the land-use actions taken by uplanders may have dramatic negative influences on the condition of lowland areas (Doolette and Magrath, 1991). This upland-lowland dilemma generates policy debates on how to best resolve this externality problem (Pereira, 1989; Thapa and Weber, 1990).

Recent field work in the Kair Khola watershed, East Chitwan, Nepal revealed an example of this upland-lowland sedimentation dilemma. The problem lies at the convergence of two rivers - the Shakti river, fed by the Shakti sub-basin and the Kair river, fed by the Kair sub-basin — which join to produce the Kair *Khola* IMap 1). It appears that the Shakti river, flowing from a north-west direction, has deposited material of great thickness over a widespread area, while the Kair, flowing from an east direction has not. Local farmers report that this sedimentation on the Shakti side has built up rapidly over the last fifteen years[1]. This build-up has altered the course of water flow. These changes have forced the local farmers to alter their regular cropping patterns over a large area from an initial two paddies per year (monsoon and spring seasons) to current practice of one paddy only during the monsoon season. These cropping pattern changes have dramatically affected the farmers' economic condition.

The cause of this increase sediment is puzzling. While certainly it is partially a result of major storms in the area, the question remains: why such an increase over the past fifteen years? When asked about this sediment build-up, farmers explained that in their Impression it was not a result of one or a few unusual storms to strike the area. Rather, they suggested it to be a gradual change resulting from average storms over the last fifteen years (IFRI, 1994). In their impression, it was due to land-use practices in the upland hills. This leads us to the following research questions:

[1] Some elderly local farmers reported that over roughly this fourteen year period, the river bed has widened with gravel and boulder deposits from initially less than 10-meters to more than 100 meters (IFRI, 1994).

What are the physical and social factors which have led to the increased sediment build-up in the Shakti sub-basin?

Do differences exist between the Shakti and Kair sub-basins which may explain this sediment build-up?

To investigate these questions, the paper is structured as follows: Part II describes the study area In more detail. Part III provides a theoretical framework Identifying factors that influence sediment flow. Part IV describes two data collection procedures: 1) the development of a Geographic Information System used to analyze the physical attributes of the two sub-basins, and 2) an effort to get community and institutional attributes of villages within the watershed. Part V describes the results and findings from these two efforts. Part VI provides a discussion of the results as they relate to the sediment problem described above. Finally, Part VII concludes with some final thoughts related to current Nepalese forest policy.

PART II. STUDY AREA

The study, conducted In Kair Khola watershed (refered to as "the watershed"), Chitwan, Nepal during July-December 1994, compares two sub-basins, Shakti and Kair, in terms of land use patterns, local governance, and natural physical factors influencing downstream sedimentation. The watershed spans over 68 km^3 and is a part of the southern Siwalik hills based on regional physiography. It is located in between 85°30' to 85°55' E, longitude and 27°21' to 27° 46' N, latitude and 260 m above mean sea level.

The lower part of the watershed is influenced by subtropical humid climate characterized by three distinct seasons: a hot, rainy monsoon; a warm, dry winter; and a hot, very dry winter pre-monsoon (Chaudhary, 1984). The upper part (to the higher elevation) of the watershed has cool, dry winter; a warm, humid summer; and a rainy monsoon. A diversified vegetation, landform, slope, and soil types are found in the study area. Different tropical hardwood and coniferous trees at different stages of regeneration can be seen in the natural forests within the watershed.

Moderately, steeply and very steeply sloping hills and mountains encompass the watershed. They have coarse loamy and skeletal soils characterized by relatively shallow profiles (LMRP, 1986). All these in combination reflect the land system of the area.

Criteria used to select this site for study include:

1) it is a compact area with typical Nepalese farming systems situated in and around the Kair Watershed.

2) Aerial photos, maps and other secondary information taken at different times were available of the area.

3) The site provides a unique combination of upland forest, rainfed upland and irrigated lowland agriculture, streams and human settlements.

4) The study area was easily accessible from the research station at the agricultural campus, Rampur, Chitwan.

PART III: A THEORETICAL FRAMEWORK

The framework presented in Figure 1 is helpful to think through the problem described above. The state of any watershed can be characterized via two main analytic categories: first the watershed's physical attributes and second, the watershed's social attributes.

Watershed Physical Attributes

This first category describes the physical state of the resource and can be further broken into two sub-categories: natural physical attributes and human-induced physical attributes. Natural physical attributes describe climatic, topographic and hydrologic characteristics within the watershed (Wilson, 1973). Human-induced physical characteristics describe the land-cover patterns of the watershed which are outcomes of human land-use.

Natural Physical Attributes:

Climate: Rainfall and runoff are the two major factors which impact the rate of sedimentation. It has been proven that these two factors have direct relationship in almost all basins studied (Morisawa, 1968). In this study however, the influence of climate should be quite similar between the two sub-basins. But the effect of a given amount of rainfall and intensity will likely differ between these sub-basins. This is due to variation in relief, vegetation cover and soil composition.

Topography (slope and elevation): The greater the steepness of the slope, other conditions being equal, the greater the runoff. As the slope increases a given sediment load will reach the stream with greater velocity. In contrast, gentler slopes will decrease runoff velocity, for they allow more opportunity for infiltration and detention storage of water. The doubling of the flow velocity enables water to move particles 64 times larger and allows it to carry 32 times more material in suspension (Brady, 1990).

The Influence of slope is greatly altered by the size and general topography of the drainage area. The larger the basins, the smaller are the seasonal or annual variations. In addition, large basins are subject to less flooding because large downpours do not usually affect all parts of the basin simultaneously.

The length of slope accompanied by soil type and land-use patterns also influence soil movement. The more dense the soil cover the more it will be protected. In addition, forests and grasses provide natural soil protection known for soil and are about equal in their effectiveness. Land-uses under various agricultural rotations can have either positive or negative influences depending on the agricultural practice.

Hydroloov: Rivers, streams and tributaries act as a conduit for sediment. Each stream is formed by particular topographical and geological obstacles encountered as it seeks the path of least resistance in its journey towards the sea (Gordon, 1992). When the river or stream reaches a lowland area it deposits much of the sediment it is carrying. First, coarser material is dropped which automatically builds up at the stream bottom. Other finer sediments are carried further (Birot, 1965). The load carrying capacity of the stream depends an climate, gradient of slope, vegetation cover, distance covered.

Flow patterns over the landscape have been particularly difficult to understand in the Himalayan context (Bruijnzeel, 1989). In Nepal, it is difficult to quantify the stream flow due to unusual physiographic settings, extreme micro-climatic conditions and intensive terracing (Nakarmi et al, 1991). River flow rates are better understood as an important factor related to the Shakti situation is referred to as the 'back-water effect." This mechanism involves blocking at the confluence of the flow in one river when the other is in spate (or has a higher discharge) leading to increased sedimentation in the affected river stretch (Anonymous, 1983). This effect slows the rate of flow in the smaller river - resulting in sediment deposition in its river bed.

Finally, the number of stream orders[2] is related to the size of the contributing area, the channel dimension and the stream discharge (Strahler, 1964). Several laws of drainage basin geometry have been developed which state that as stream orders increase: 1) the number of streams decrease, 2) the average stream length increases, 3) catchment area decreases, and 4) the average slope decreases, and these relationships are geometric (Selby, 1985). These regular relationships can help to provide a quantitative description of drainage development in a basin.

Human-Driven Physical Attributes:

In addition to the natural physical attributes of the watershed, the existing land cover patterns work in combination with the above natural features to influence sedimentation flow (ICIMOD, 1985; Gondie, 1990). Land-cover can be categorized, in general, into two components: agricultural and forest land.

Agricultural (Maize and Bice Terracing): Under indigenous agriculture systems, the farmers are the main actors closely interrelated to the watershed through their engagement in crop production, livestock raising and forestry. The agricultural system in Nepal is characterized largely by a primarily subsistence economy, small landholdings (less than one hectare per household). Intensive labor, and disparate land tenure systems (Thapa and Weber, 1990). In the sloping hills, upland crops such as maize, millet and mustard that require less water are grown whereas in the valley floor, lowland rice, wheat and potatoes are grown, The crops in the valley floor are the recipients of fertile material brought down by flood water from upstream sides.

Different support practices including tillage on the contour, contour strip cropping, terrace systems, and grassed waterways, all tend to reduce the soil loss. In hilly environments, terrace cropping controls water runoff as it reduces the flow velocity lives and Messerlli, 1989). However, in instances where these terraces slope significantly outward, increased runoff will occur.

Forest Patterns (dense and degraded forests): The existence of dense forest canopy protects the soil from direct impact from rainfall IPerira, 1989). However, forest clearing, overgrazing, poorly maintained marginal lands, and forest firing have greatly altered the natural vegetation leaving soil

[2] Stream orders are a way to identify rivers, streams and tributaries in an ecological system. Platts (1979) defined first order streams as being the first recognizable drainage on 1:31 680 scale maps. Second order streams are the next larger water source that these lead into. The order numbers continue to increase until the final river in the study area is assigned an order number.

open to degradation (ICIMOD, 1985). These open canopy areas allow the rainfall to directly hit the ground loosening the soil and starting its movement toward lowland areas (Perira, 1989).

Watershed Social Attributes

The second main analytic category shown in Figure 1 are social attributes of the watershed. Watershed social attributes can be further broken into two sub-components: (1) community attributes and (2) institutional attributes.

Community Attributes:

In regard to land-use change in the Nepalese context, the primary discussion in the literature has concerned itself with deforestation either to degraded forest areas or complete conversion to agriculture areas (Ives and Messerli, 1989; Thapa and Weber, 1990; Gilmour and Fisher, 1991). This literature has identified a number of causal factors of deforestation many of which could be classified as 'community attributes."

Population Growth/Migration: A large number of studies have reported population growth (increasing birth rates) as a significant factor in the depletion of forest resources. Increased numbers of small farmers result in land scarcities that result in conversion of forested regions to agricultural land (Hamilton, 1984; Stonich, 1989; Rowe, Sharma and Browder, 1992; Aberbathy, 1993; Messerschmidt, 1987; Shah and Schreier, 1991). Others suggest the contrary, that population pressures lead communities to crafting innovative institutional enhancements which slow, halt or even enhance environmental conditions (Fox, 1993; Boserup, 1965; Brookfield, 1984; Agrawal, 1994; Thapa and Weber, 1990). Migration flow, a variable related to population growth, has also been cited as an influential variable in the deforestation process (Haffer, 1990).

Economic Conditions (Poverty): A second explanatory variable often reported in the deforestation literature asserts that difficult economic conditions cause families who neighbor forest resources to overutilize the neighboring resources. A country's slow economic growth in may make it impossible for urban areas to absorb unemployed people in rural areas, so some turn to forest resources for their livelihood. These pressures, especially in agrarian societies, lead landless people to move into forested areas in search of arable land (Repetto and Gillis, 1988:15). One particularly salient version of this argument suggests that political and economic inequalities force the lower classes to seek a livelihood in remote forest areas (Blaikie and Brookfield, 1987; Collins, 1986;

Painter and Partridge, 1989; Redclift, 1989).

Access to Markets: Some scholars have identified the linkage of remote areas to markets as an influential factor in extreme forest consumption (Agrawal, 1994; Poffenberger, 1990). The premise here is that the ability to transport forest products swiftly to market increases the temptation to overharvest. This presumption is still open to debate. Asher (1995) suggests that this access to market does just the opposite, for it provides other income generating alternatives to community members.

Harvesting Technology: Access and use to improved forest harvesting technology has also been described as having a positive influence on the rate of deforestation in developing countries (Panayotou, 1993; Poffenberger, 1990). Engine driven machinery can greatly increase one harvester's ability to clear an area of land or to harvest additional forest products.

Agriculture Practices: The type of cultivation practices by watershed communities has also been reported as an important factor leading toward deforestation. In some of the middle hill areas of Nepal, a practice of shifting cultivation is present. In this practice, forest areas are cleared and then a rotation cultivation schedule is instituted (Thapa and Weber, 1990; Shrestha, 1993).

Forest Products Required: The types of forest products required for the livelihood of a community is also a determinant to forest condition. Forest products in many regions of Nepal are required for cooking fuel, heating, animal feed and construction (Thapa and Weber, 1990; Shrestha, 1993; Metz, 1990;). Certainly the availability of alternative sources for these needs has an impact on how much is extracted from nearby forest stands.

Institutional Attributes:

Regardless of governance type (public, private or common property), the forested areas that exist within the watershed can be considered common pool resources (CPR). A CPR is a good that exhibits rivalrous consumption and is difficult or impossible to exclude people from its use (Gardner, Ostrom and Walker, 1990). Rivalrous consumption refers to the products of a forested area. Once one watershed resident removes a tree, a shrub, some grass, or converts the land to agriculture, that forest product or forest area cannot be utilized by someone else. Exclusion refers to the ability to restrain people from utilizing components of the resource. A review of Map 2 makes it very clear that the physical size and the terrain of the many of the forest areas within the Kair Khola watershed make it very difficult to exclude people from using the resources. The overexploitation of commons have been well articulated in the literature (Hardln, 1968; Norman, 1984; Thompson, 1977) and debate continues over the best way to counteract this problem.

Community attributes described above create pressures or incentives that lead to the desire to exploit these CPRs. But these community attributes co-exist with institutional attributes to create incentives which either encourage or discourage action in the form of land exploitation. Institutional attributes in this context refer to the set of working rules which govern watershed CPRs as well as the set of actors responsible for their development and their enforcement (Thompson, 1992) - they cover more than just who is legally the owner of the forested area. They additionally determine (1) who can access the forest area (boundary rules), (2) how the forest can be used (use rules), (3) who monitors their enforcement (monitoring practices), (4) what sanctioning mechanisms are in place (sanctioning practices), and (5) how conflicts are arbitrated (conflict resolution mechanisms), and (6) who has rights to modify these rules (collective-choice rules) (Ostrom, 1990). Each are briefly discussed below and are taken from Ostrom (1990):

Boundary rules: Boundary rules describe which individuals or households have rights to withdrawal resources from the a watershed area of interest. The right to clear a forested area for agriculture use could be described as the right to withdrawal all forest resources. Ostrom's research suggests that if individuals of a community have clearly defined rights to a resource, the CPR will be better sustained.

Use rules: Use rules define how, how much, when, and with what technology the forest CPR can be harvested. For instance, rules may exist that determine that animal grazing can only be conducted during certain times of the year. Or should someone want to convert some of the land to agriculture, they may be limited in terms of the amount of area that can be converted.

Monitoring practices: Rules are only effective if they are effectively enforced. The monitoring practices in the forest resources within each sub-basin are crucial to their acceptance and legitimation.

Sanctioning practices: Tightly coupled to monitoring practices is the capacity to punish for rule infractions. Punishment does not have to be by some governing body such as a government. In fact, Ostrom presents evidence that often successful CPR settings have sanctioning (and monitoring) that are conducted by the CPR users themselves.

Conflict resolution mechanisms: In CPR settings under institutional control, conflicts will invariably arise. Sometimes debates over rule definitions will occur. In other Instances, debates over monitoring or sanctioning will occur. In cases such as these, some type of arbitration mechanism is required. The ability for conflicts to get resolved in a expedient manner is another institutional attribute which affects the incentive structure driving resource users' actions.

Collective-choice rules: Lastly, collective-choice rules describe how the above rules and procedures are made. Few would dispute the statement that rules developed by users within the watershed would very often be different than rules devised by external government officials. The knowledge of time and place information can have a dramatic influence on what may constitute an appropriate and useful rule.

Incentives, Actions and Outcomes

The physical and social characteristics described above create the incentive structures which drive the actions by watershed residents who rely on neighboring resources. These actions - - land uses - result in changes in the land-cover patterns within the watershed over time. In instances where land-use change is prevalent, the transformed land-cover patterns then combine with the natural-physical attributes to create a continuous cycle of changing sediment flow patterns.

The sedimentation problem in the Shakti sub-basin could be due to changes in any combination of the physical or social attributes shown on the left side of Figure 1. With this theoretical foundation developed, we can now turn toward the task of identifying the physical and social factors within the Shakti and Kair sub-basins that exist and perhaps have changed over the course of the last fifteen years. This analysis may lead to a better understanding of the causes of the sediment problem in the Shakti sub-basin.

PART IV: DATA COLLECTION AND METHODOLOGY

The data collection efforts and the methodologies used for analysis in this study can be best described in two parts. First, a Geographic Information System (GIS) was developed to enhance the ability to compare physical attributes of the sub-basins. Second, data related to community attributes and institutional features were collected through a significant data gathering effort in the field. Each of these efforts will be described further below.

GIS Development

Data Collection

Topographic maps, land utilization maps, land system maps, land capability maps and two sets of black and white aerial photographs for 1978 and 1992 of the Kair Khola watershed area were obtained from Topographic Survey Branch, Department of Land Survey, Kathmandu, Nepal. These maps and photographs served as vital data sources to capture information on all spatial land features.

Definition of Land-Use Categories

Due to the small scale of the aerial photographs (1:50,000l acquired, the following general land use classifications were developed:

Agriculture: A diverse cropping systems prevail both in valley floor and rolling slopes of the watershed. Thus, agriculture was classified into two broader groups, irrigated (rice-based) and rainfed (maize/millet based). Availability of water under different terrain types was the basis of this classification. Valley floor areas and terraced areas lying in the base of the slopes were classified as irrigated rice areas, whereas hill slope cultivation without level terraces were considered as rainfed maize based crop areas.

Forest: The land use under forest areas was categorized into two categories, dense and degraded. Dense forest is defined as a plant community predominantly of trees and other woody vegetation with a closed or nearly closed canopy, canopy cover so thick in dark tone that only a little ground portion amidst the forest trees can be observed on the aerial photo prints. Degraded forest is defined as a plant community comprised predominantly of trees and other woody vegetation but exhibits a thin canopy cover. Additionally, in many cases shrubs, short trees, open forest floor, gullies, and visible lopped trees were classified as degraded areas.

Mixed land use: In the study area, there exist a number of thin forest patches where upland crops are grown underneath the natural forest trees. Here the sign of agriculture expansion into the natural forest appears to be apparent. For the practical purposes, this was classified as "mixed land use". Slash and burn practices of the forest vegetation for agriculture could be an important feature of this type of land use in these hill slopes. This category was produced in response to

field visits and hence is only used to categorize the 1992 data.

Development of Map Manuscripts for Automation

Boundary delineation and map scale: The study area was identified and the boundaries of Shakti and Kair sub-basins were delineated on the 1:63,000 scale topographic map. Geographic control points or tics were registered at four corners of the traced boundary map representing known locations on the earth surface that is also required for automation of the raw map into computer. A factor of 1.267 was used to enlarge this traced boundary map so it was compatible with the aerial photos, and the land system, land capability and land utilization maps all of which were at 1:50,000 scale.

Aerial photo interpretation: The aerial photo interpretation of both 1978 and 1992 aerial photographs at 1:50,000 scale was the foundation for the key for physical attribute component of the study. However, the photos from 1978 are of relatively poor in quality. A significant area to northern side within sub-basins are blurred. In order to ensure correct interpretation, land utilization maps developed from the same set of photographs were used to cross-check category interpretations (LMRP, 1986), A stereoscope was used to better distinguish land categories. Areas identified and classified were then doubled checked by two additional team members. As much as possible, interpretations of features lying in the centers of the photographs only as the bordering area of aerial photographs generally exhibit more inherent image distortion,

Formation of slope class: Four slope classes were formed (LMRP, 1986), <5°, <20°, <30° and >30°, which characterize moderately sloping, moderate to steeply sloping, steeply sloping and very steeply sloping hills and mountains, respectively.

Stream characteristics: The Shakti and Kair streams were classified on the basis of number and average length of stream orders according to Strahler (1964) for comparison.

GIS Development

The boundaries of forest and agriculture areas were delineated and digitized as polygon coverages in a PC Arc-Info based GIS, Other land features such as slopes (polygons), streams (lines) and settlement centroids (points) were digitized into the Arc-Info system. Partial results of this effort are shown in Maps 2 and 3.

Ground Truthing

Once the preliminary GIS coverages were developed, they were printed and taken to the field for verification. The maps were explained to local farmers who provided valuable information on where the maps ware misclassified. Modifications to land category boundaries were written directly on the maps in the field. The existing GIS coverages were then modified based on these revisions.

GIS Overlay Analysis

The Arc-Info Overlay module was utilized to develop land-use change coverages for the 1978-1992 time period. Both dense and degraded forest polygons as well as polygons for irrigated and rainfed crop lands for 1978 were overlain with similar categories of land uses for 1992. By this technique of overlay module of GIS, land dynamics between these two sets of time was easily quantified. Maps 4 and 5 provide examples of such an overlay product. A series of 16 such coverages were developed which then could easily ba queried to determine areas of land change in hectares. The results of this process are displayed in Figures 2 and 3.

Community and Institutional Data

The International Forest Resources and Institutions IIFRI) Data Collection

At the same time that the GIS data was being collected, a detailed study on forest institutions (IFRI) was conducted on a number of villages which reside within the Kair Khola watershed. The IFRI research program is a multi-country, long-term effort to monitor physical forest conditions as well as the socioeconomic, demographic and institutional factors that affect the sustainability of forest resources (Ostrom and Wertime, 1995). A common database has been developed by researchers at Indiana University in cooperation with Collaborative Research Centers (CRCs) established in Uganda, Bolivia and Nepal. Data is collected through a Participatory Research Methodology, using a set of pre-tested coding forms as a guide for each day's strategy (Ostrom, et al, 1993). Types of data collected include: information on villages of the area, neighboring forested areas, the governance structure of these forested areas, the users of the forests, the forest products used, what rules exist for forested areas and for important forest products or species, and physical measurements of the forest areas themselves (species Inventory, etc.). Community and institutional attributes are collected through participatory rural appraisal techniques, interviews and

through direct observation. In addition, information on forest rules were collected through other interested parties such as government officials in the responsible District Forest Office.

The CRC in Nepal[3] has completed ten IFRI studies over the past three years. The Kair Khola is their most recent to date.

Data Limitations

Ideally, information on the community and institutional structure of all the upland communities would be gathered. Due to limited resources, only one IFRI study could be conducted. Consequently, the IFRI study site chosen falls where the two sub-catchments meet (See Map 1). This data unfortunately cannot very easily address the question of how the two sub-watersheds differ in terms of institutional structure. However, a review of 1991 census data of the villages in this watershed reveals something quite interesting: the attributes of the communities in the upper watershed areas in both sub-basins are quite similar (Table 2). They are comprised almost entirely of people from the same ethnic group, they are almost all employed in agriculture, and they have roughly the same education level as measured by literacy rate. For this reason, IFRI data collected on two of these upland villages - Deurali and Latauli — may help us understand the social attributes driving land-use conversion in both sub-basins.

PART V: RESULTS

The results of the above two-pronged data collection will be described here. First, the results of the GIS analysis on physical attributes of each sub-basin will be described. Second, the results of the IFRI data collection will be presented.

Physical World Attributes: Results

Shakti and Kair sub-basins support a large rural community not only in the hills but also to the community and irrigated agriculture in the downstream valley of Chitwan. Kair has drainage

'The CRC in Nepal Is called NIFRIC, or the Nepal International Forest Resources and Institutions Consortium, headed by Mr. Rajendra Shrestha in Kathmandu. His team of researchers includes two social scientists, one social forester, a botanist, and a forester. This team spent nearly two months (October - November 1994) living in upland and lowland villages within the Kair Khola Watershed conducting the IFRI research.

area of approx. 3838 ha which is 73% of the entire watershed. Only 1423 ha (27%) is occupied by Shakti sub-basin. The following sections provide the results of the analysis of land use change, topographic (slope and elevation), hydrologic (stream orders and length) and the local governance for resource use in the watershed.

Land use changes: 1978-1992

Gains and Losses: The data presented in Table 1 shows that over the fourteen years, the dense forest (-32%) and maize based uplands (-2%) have lost area in Shakti sub-basin. These areas have been converted to degraded forest (+22%), mixed upland (+9%) and lowland rice land uses (+4%). Unlike Shakti, the Kair sub-basin gained areas under all land use categories except dense forest area (-22%). The majority of this conversion appears to have been into maize-based agriculture (+16%), followed by nominal changes (< +2%) in other land use categories.

Commonalities and contrasts: The multi-directional patterns of land use changes found in Shakti and Kair sub-basins have been illustrated in Figures 2 and 3, respectively. A careful look at these Figures and Table 1, suggests that the Shakti sub-basin has undergone land transformations of larger scale as compared to the Kair sub-basin. In both sub-basins (61 % area in Shakti and 63% in Kair) dense forest stood as the largest single land use type in 1978 and in 1992 these resources have been dramatically converted to other land uses. The striking land-use change common to both sub-basins is that the dense forest have been exclusively a single source for expanded areas in other land use types. The major contrast between the two sub-basins is that the deforestation has been conducted for different purposes: the dense forest in Kair sub-basin that have disappeared overtime appear to have converted solely into maize based upland agriculture, whereas in Shakti sub-basin it has changed mainly Into degraded forest. The Shakti sub-basin also displays considerable parcels of dense forest has been converted to mixed upland and lowland rice land use categories.

Topography (slope, and elevation)

Based on the severity of local topographic features, the sub-basin areas have been categorized into slope classes: flat to moderately sloping (<5°), moderate to steeply sloping (<20°) hills and mountains, moderate to steeply sloping (<30°) mountain terrains and steep to very steeply sloping (>30°) mountain terrains (Table 3).
Unlike the Kair side where at least 3.97% of land area is flat, the Shakti basin exhibits no such

areas (<5°). Similarly a significant area (23.76%) in Kair side is below 20° slope which is also almost non existent (1.31%) in Shakti side. Compared to Kair, Shakti side offers progressively larger areas exposed to steeper slopes. This is apparent in Table 3 where 34.98% and 63.71 % land area of Shakti fall under higher (<30° and >30°) slope classes.

Table 4 shows the major elevation ranges exhibited by the two sub-basins for the basin floors, middle hills and mountain areas. The average elevations in the valley and middle part of the basin are quite similar between the two basins. However, their highland areas vary significantly. The upper part of Shakti raises up to 6155 feet, whereas Kair does not extend beyond 5400 feet. In addition, few areas in the Shakti sub-basin exhibit less than a 20° slope, but yet the sub-basin exceeds the maximum elevation of Kair sub-basin at least by 750ft. This suggests that the slope gradient of the Shakti sub-basin is much greater than in Kair sub-basin.

Hydrology (stream orders and length)

The Shakti and Kair sub-basins both exhibit the presence of perennial streams (Table 5), named Shakti (a 3rd order stream) and the Kair (a 4th order stream). These streams are fed by rain and from the reserves in the local basin. Given the basin area (Table 3), it seems natural to have shorter and less number of stream orders in Shakti compared to the Kair sub-basin. In terms of water catchment, the Kair stream receives water from as much as three times the area of Shakti and exhibits at least eighteen first order streams compared to Shakti which is fed by only eight. The Kair stream orders have minimum length of 1010m to a maximum of 1368m. Table 3 also shows that third order Shakti streams and fourth order Kair streams travel almost the same distance (Shakti 975m and Kair 1010m) before they converge at their common outlet.

This GIS analysis provides clear evidence that significant human-driven physical changes to dense forests - deforestation - has occurred in both sub-basins. This analysis does provide secondary evidence that the increase in sedimentation in the Shakti side is due at least in part to these human-driven land cover changes of forest land coupled with the topological characteristics of the Shakti subbasin.

But referring back to Figure 1, our analysis has only addressed the physical attributes, natural and human-driven, that have lead to the outcome of sediment deposition. What about the lower half of Figure 1: What are the community and institutional attributes that have led to this deforestation? In addition, why are the land-conversion practices so different between the two sub-catchments?

An Analytic Problem: Scale

The incentives faced by watershed resource users are thus a function of both the attributes of the community these users find themselves in as well as the governance arrangements of neighboring forested areas. It is at this point that we run into a difficult analytic problem related to the scale of analysis. To get a clear understanding of community attributes and institutional data -• to really understand the working rules - we must move from the macro analysis used in GIS to a micro analysis of the upland communities.

Community Attributes: Results

The IFRI study along with supplementary documentation provide much insight into the community attributes of these upland communities. Everything that follows has been taken from the IFRI data collection effort[4] unless it is otherwise cited.

Population Growth and Migration Influences:

The upland communities are comprised almost entirely by one ethnic group: the Chepangs. These people were indigenous to the Chitwan District but were considered low in the Nepalese social hierarchy (Shrestha and Singh, 1992). After malaria was eradicated in the area, they and were driven up into the hills as a result of significant migration of wealthier castes looking for valuable agriculture land in lowland areas (Bahadur K.C., 1986; Rajbhandari, 1989). Table 6 presents a summary of the ethnic composition of eighteen upland and lowland villages within the watershed and provides additional support to this statement. All of the upland villages are comprised of a significant majority of people from the Chapang caste. Our IFRI upland villages, Deurali and Latauli, are no exception. Over the past fifteen years, the population of Deurali has increased significantly. The availability of a water tap by an NGO appears to have been the motivation for much of this migration. Villagers report that this shifting of population has resulted in slash and burn practices in part to clear new agricultural areas for these new residents.

[4]The analysis here was developed from interpreting many of the IFRI questions supplied on the IFRI coding forms. For a specific list of questions supplied on the forms, please contact the Workshop in Political Theory and Policy Analysis, Indiana University.

Household population Increases between 1978 and 1992 for selected upland villages are presented in Tables 7 and 8. During the map ground truthing efforts, watershed residents were asked to report household[5] increase estimates for their villages over the past fifteen years. It is apparent from these estimates that population increases are a fairly high rate of growth. Some Increases are rather dramatic, such as in the case of the Chherewang village that shows a doubling in households over this period.

Economic Conditions:

Subsistence farming was reported in both villages to be the main source of economic activity. Most residents rely on their own food crops for a majority of the year. The neighboring CPR resources are critical to their survival. In the Latauli and Derauli villages over four-hundred buffalo and four-hundred goats graze in a 32 hectare forest commons nearly year-round. Tree products provide daily fuelwood for SO households (520 individuals) in these two villages and timber supplies input for all agriculture and housing construction requirements. Fruits, herbs and wildlife are collected or hunted within the CPR for either personal consumption of for sale in the markets.

Villagers define wealth in this area by the amount of land and livestock a household owns. In the Derauli and Latauli villages combined, the difference between the haves and the have-nots is dramatic. Nearly 30% of the households are reported as owning very little or no land, while only 6% are considered wealthy. Over 50% of the households report that they do not own enough land to satisfy their subsistence requirements. Most of the landless villagers assist neighbors in farming practices for meager wages or a few engage in some supporting business such as charcoal making, carpentry or craft construction for their earnings.

One significant problem directly observed by the IFRI team while residing in the villages was that of alcoholism. Many villagers, primarily men, spent the evenings drinking maize wine they or someone in the village produced and they must purchase. While no one reported this drinking as something that contributed to the economic hardship these villagers face, it is undoubtedly a significant problem. The women and children who gather forest products and tend to the livestock appear to take most of the burden from this addition.

[6]A household is defined as a group of family members who live and eat together. Typical households in the Latauli and Derauli villages include grandparents, parents and children.

Access to markets:

The nearest market in the area is roughly sixteen kilometers away from both villages. This market is in fact the nearest center for all the villages within the Kair Khola watershed. The Shakti river separates the villages from the nearest road, but the river is usually crossable (thanks in part to the sediment that is our problem) throughout the year. Bus access is available, and villagers report that at least once a week some individual from the household will travel to this market. Some residents of the watershed were observed carrying forest products such as fruit away from their village and toward the market area. They often would barter these goods with residents of neighboring villagers they encountered along their trek.

Harvesting technologies:

The harvesting technologies appear to not have changed in recent years. Hand axes, saws and sickles are the primary harvesting instruments.

Agriculture Practices:

The residents of these villages plant maize as their staple crop. Rice is the most economically beneficial crop, but these villages are upland and lack sufficient water resources for this endeavor. Terraces exist everywhere along the slope, and in many areas only the steepest of terrain was home to forest vegetation. Shifting cultivation - rotation planting - is a practice widely used by these villagers. This practice, coupled with the lack of ownership of land by many of the residents, leads villagers themselves to report that continued encroachment of the forest for conversion to agriculture land was the most significant problem facing them in the future. Forest sampling conducted as a part of the IFRI program confirmed this activity for many forest plots contained signs of recent slash and burn practices.

Institutional Attributes: Results

The forested area which encompasses the Latauli and Durauli villages is under the jurisdiction of the District Forest Office (DFO) of the Department of Forest, His Majesty's Government, Nepal. The forested area is designated as national forest land and is subject to rules

established by the DFO organization. In recent years, the Nepalese government has been encouraging a decentralization of governance of forest resources. In part due to this policy, but also due to an awareness of forest depletion after the 1990 revolution, mobilization has occurred at the lowest level of government — the Village Development Committee (VDC) — and a Forest Protection Committee (FPC) between the Latauli, Deurall and neighboring lowland communities was formed. This committee has yet to be formally recognized by the DFO. Using the institutional variables defined in the theoretical section and presented in Figure 1, the results of the IFRI study will be provided.

Boundary rules

The forested area is designated property of the national government. It has the rights to all forest products within the forested area and could, if they wished, sell the area to a private buyer. However any villagers, from Derauli, Latauli or beyond can utilize forest products within the neighboring forest CPRs. Villagers state that no one can be excluded from using forest products if they so desire.

Use rules

Villagers of Latauli and Derauli (and neighboring villages) do have dejure rights to utilize the forests to support their daily subsistence requirements. Two primary forest products - grasses for livestock feed and branches or deadwood used for fuelwood - are completely open to full consumption by anyone who requires them. Only two use rules are established for the area: (1) a no encroachment rule established by the DFO, and (2) a requirement by the VDC that permission must be granted prior to the cutting of any timber and that the cutting must be monitored by a Forest Protection Committee official.

Monitoring practices

The monitoring of the above two rules is reportedly done jointly by forest guards who are based out of the Forest Ranger's Office roughly fourteen kilometers away, and Forest Protection Committee members who reside in nearby villages. Some monitoring by DFO guards was observed by the research team in the field but it appeared to be primarily conducted in the lowland areas of the watershed •- closer to market areas and closer to DFO range post. From villager reports. Interaction with these forest guards are extremely infrequent. When asked how frequently most residents interact with government officials, the response was rarely, only once or twice a year. Villagers also state that while the Forest Protection Committee is chartered to monitor the timber rules established by the VDC, no hiring of forest guards Is conducted. The guards are the users themselves. They are not paid, they do not volunteer, and they are not selected.

Sanctioning practices

People caught encroaching on the forested area by the DFO guards are subject to either verbal chastisement, a fine or incarceration. In the lowland areas, the IFRI team witnessed one home being torn down by officials after repeated warnings not to encroach the land. However no evidence of this practice was identified in the more distant upland communities. Understanding the exact sanctioning practices is a very difficult one to get clear information on, for the decision appears to be often made by forest guards in the field and these guards impose sanctions based on the specifics of each situation they encounter. Record keeping of these instances does not appear to be kept very well.

VDC officials report that the punishment for violations of their timber harvesting rule is verbal chastisement and required public apologies and a fine for first and second time offenders. Third time offenders are reportedly taken to the District Forest Office for possible trial. However no records exist, few funds have been reported and no third time infractions have occurred. Like the DFO guards, it appears the decision to sanction is dependant on each individual situation.

Conflict resolution mechanisms

The DFO appears to be the only recognized body where forest users can take forest disputes to be resolved. The villagers reported that conflicts are a rare occurrence in the area. This is due at least In part, to the existence of very few use rules established. More importantly, it reflects a lack of sufficient monitoring of these rules by both the DFO and the villagers.

Collective-choice rules

The DFO has primary authority in developing the operational rules that oversees the neighboring forest area. The DFO officials are appointed by the Nepalese government, and users of

the forest have no voice in people assigned to these posts. Other than the passage of the timber harvesting rule, the Forest Users Committee has had little other action in the development of operational rules.

PART VI: A DISCUSSION ON THE INTERACTION OF PHYSICAL AND SOCIAL ATTRIBUTES

The framework presented In Figure 1 describes CPR users who are faced with physical and social attributes of the existing world that they live in. These attributes combine to create incentives or disincentives for resource utilization. Our research question stated in Part I, was to understand how these physical and social components have influenced CPR user incentives over the past fifteen years to create the sedimentation problem in the Shakti sub-basin that we witness today. Our underlying hypothesis was that some differences must exist between the two sub-basins -- either physical differences, social differences or some combination of the two - for such a dramatic build-up of sediment to occur in the Shakti side of the watershed.

The Influence of Physical Attributes

Land use and sedimentation:

The GIS analysis shows quite clearly that the Shakti and Kair sub-basins differ significantly in their topographic, hydrologic and land use characteristics. Two striking results have been reported earlier: first, both sub-basins show a dramatic decrease in their dense forest areas and second, and even more striking, the comparison between the two sub-basins reveal that the land-use conversion is quite different. Within the Shakti side, almost fifty percent of the existing 1978 dense forest is categorized as degraded forest in 1992. Within the Kair side, almost thirty percent of its 1978 dense forest has been converted but almost entirely to agriculture land.

This dramatic difference provides evidence that the sedimentation in the Shakti side may be due at least in part to these land use practices. A recent erosion and sediment monitoring program along the same range of hills of Nepal (Nakarmi et al, 1991) reported that highly variable amounts of sediment (4-100 t/ha) were transported by adjoining sub-basins and these variations were a result of the existing land-use patterns.

In this study, degraded forest was identified where thin canopy cover existed and significant soil surface was exposed. It is well understood that reduction of forest canopy (dense to degrade forest) results in more sediment erosion (Pereira, 1989). The large degraded forests in Shakti sub-basin appear to occur over steep terrain and leave the soil subject to direct exposure to heavy rainfall. On the other hand, agricultural practices, can often do much in controlling the problem of sediment erosion. Terracing slows down run-off by reducing slope length and provides more opportunity for water infiltration into the soil that is important for crop production lives and Messerli, 1989). The significant agriculture development and identification of terraces in the Kair side suggest that speed of water runoff is probably reduced. In addition, the villagers found in these hills often apply animal manures in their crop lands to improve soil fertility and improves soil aggregation. Aggregated soils offer more resistance to erosion.

Topography and sedimentation:

The topography (slope >30°) for a major part in the Shakti offer severe limitations for the people to convert forest into cropland because of difficulties in agricultural operations in steep sloping terrains. To a certain extent, the opposite might be true in the case of Kair sub-basin. The influence of slope is, of course, greatly modified by the size and general topography of the drainage area (Brady, 1990). The length of the slope as indicated by the peak elevation (6185ft) is considerably high in Shakti than in Kair (5400ft) because of the greater extension of the inclined area. Wischmeler and Smith (1978) note that the influence of topographic factors on sedimentation increases dramatically as percent slope and slope length increase. This implies that for a given percent slope, loss of soil will increase with an increasing length of the slope. This could give rise to greater concentration of flood water due to increased velocity of run-off water. In addition, the smaller the basin area the more the influence of slope will be magnified (Brady, 1990). Finally, while we have no rainfall evidence to support this statement, the smaller size of the Shakti basin with its higher peaks may result in proportionately higher rainfall than Kair. In general, the precipitation increases with altitude as dry air mass reaches saturation during long ascent (Birot, 1965).

Stream and sedimentation:

Stream order and length can help further describe variation in sub-basins according to their channel patterns as viewed from air photographs and maps. However, the stream characteristics are primarily based upon particular topographic and geologic obstacles encountered. This implies

that for a given amount of rainfall the Shakti sub-basin will produce greater flooding because of a steeper terrain and longer slope length in uplands and higher bed slope of the stream in the valley floor. On the other hand, the more gentle slope and large sized basin exhibited in the Kair side should allow more opportunity for infiltration and detention storage of rain water. Similarly, flatter areas which are in more abundance in Kair side, typically exhibit more dense vegetation which diminishes run-off and sedimentation. This situation is favorable for more consistent flow of water in the stream and may result in less occurrence of floods in the Kair side.

The Influence of Social Attributes

According to the 1991 census data, there does not appear to be major differences between the two sub-basins in terms of community attributes. Both sides appear to have been dramatically influenced by the migration pressures which began in the late 1950s, and both appear to be subject to fairly high population growth rates. Both sides have similar ethnic group composition and are subject to similar economic endeavors and difficulties.

These dramatic similarities between all upland villages from either sub-basin provide more power in the inferences we can make from our micro study of the Derauli and Latauli villages. It is apparent that most of these villagers are quite poor and are in dire need of agriculture land in order to support their families. The availability of government owned forest land nearby provides a great temptation to them, and the institutional structure that surrounds the Derauli and Latauli communities create an incentive structure that lead these individuals to succumb to this temptation. The benefits far outweigh the risks. The problem is the typical one faced by all CPRs - - the difficulty of exclusion. The no more than ten forest guards employed by the Department of Forest are simply unable to effectively monitor all areas of their jurisdiction. When they do encounter someone who has broken a rule, they are inconsistent in how they sanction. While a DFO presence was noticed in lowland areas during the field visit, this does not appear to be the case in the difficult terrain of the upland areas. Not one conflict with Department of Forest Officials was reported in the IFRI study - and Deurali and Latauli are relatively close to the DFO range post when compared to other villages deeper in the two sub-basins. Simply put, the forest monitoring system at the DFO level is not surprisingly overwhelmed and ineffective in the upland areas.

Local institutional efforts have been no more effective - at least in the Derauli and Latauli villages. This is in part due to the inability of the DFO to provide clearly defined property rights to the villagers who utilize these forest CPRs. The local Forest Protection Committee - who lack true property rights to the CPR -- pass rules which are not in the community's eyes viewed as legitimate. The one forest product rule that this FPC has developed - the timber harvesting rule - is completely ignored by local villagers. And their neighbors, the designated FPC guards, provide no monitoring support. If an infraction is reported, the fee is either not collected or the collection of that fee Is not documented. To date, no forest product conflicts have been reported and yet forest plot samples reveal a high number of timber products being extracted. Finally, and most importantly, the slash and burn practices for agriculture expansion and shifting cultivation continues unabated.

PART VII. CONCLUSION

To answer the research questions presented in Part I, we conclude that physical differences -- an increase in degraded forest areas, coupled with topographic and hydrologic influences -- in the Shakti sub-basin are causing the sedimentation problem. The community attributes provide the incentives for encroachment, and the lack of institutional attributes provide nothing to produce counter-balancing disincentives. We believe the conversion of dense forest to degraded forest in the Shakti side is due to purely topographic attributes - there exists little forest land available that is even capable of being cultivated. Consequently, the villagers settle for the next best thing -- forest product consumption.

While we cannot say in absolute terms, we strongly believe that this institutional description of Latauli and Derauli is an example of the institutional structure found in most or all of the upland communities of both sub-basins. We make this statement for two reasons: First, the Deurali and Latauli villages are close (relatively) to the DFO range post in comparison to other upland areas. It is not controversial to state that DFO monitoring probably is not any more effective in CPR forests which are deeper into the watershed and further away from the range post. Second, the GIS analysis informs us that forest encroachment is dramatic in both sub-basins, which supports the statement that the incentive structure for forest encroachment appears to be the same throughout the watershed. If institutional arrangements were different we should see differences in land-use change over the fifteen year period in pockets of the sub-basin. If these arrangements exist they must be recently emerging.

The encroachment is in a large part a result of ineffective monitoring and sanctioning

practices. The DFO, without a large army of guards are helpless to control this encroachment. Some better monitoring and sanctioning scheme needs to be devised. When asked why haven't they turned over forest governance to the village development committees completely, a DFO official replied "we don't turn it over to their control because we are afraid they will overharvest to improve their economic condition." Frankly, from the results of this analysis, it couldn't get much worse.

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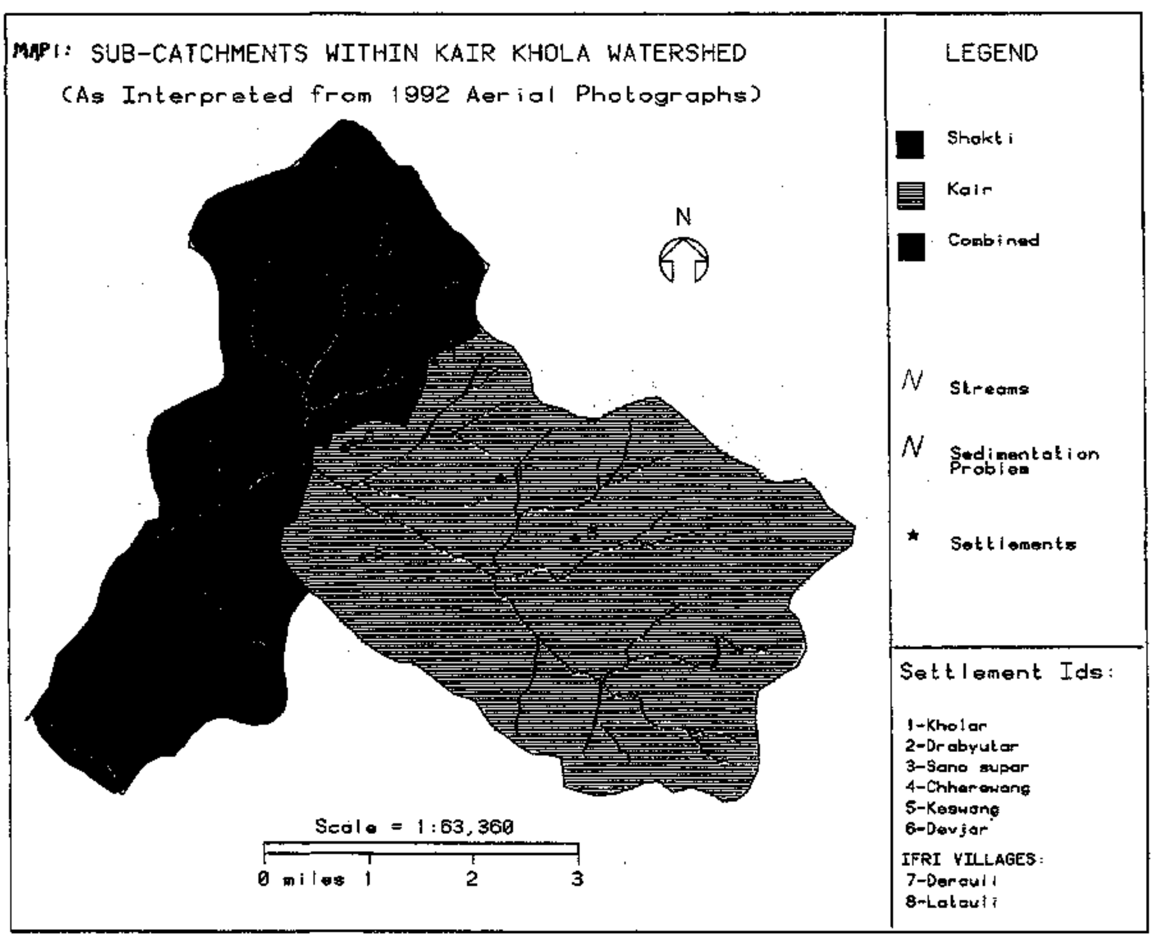
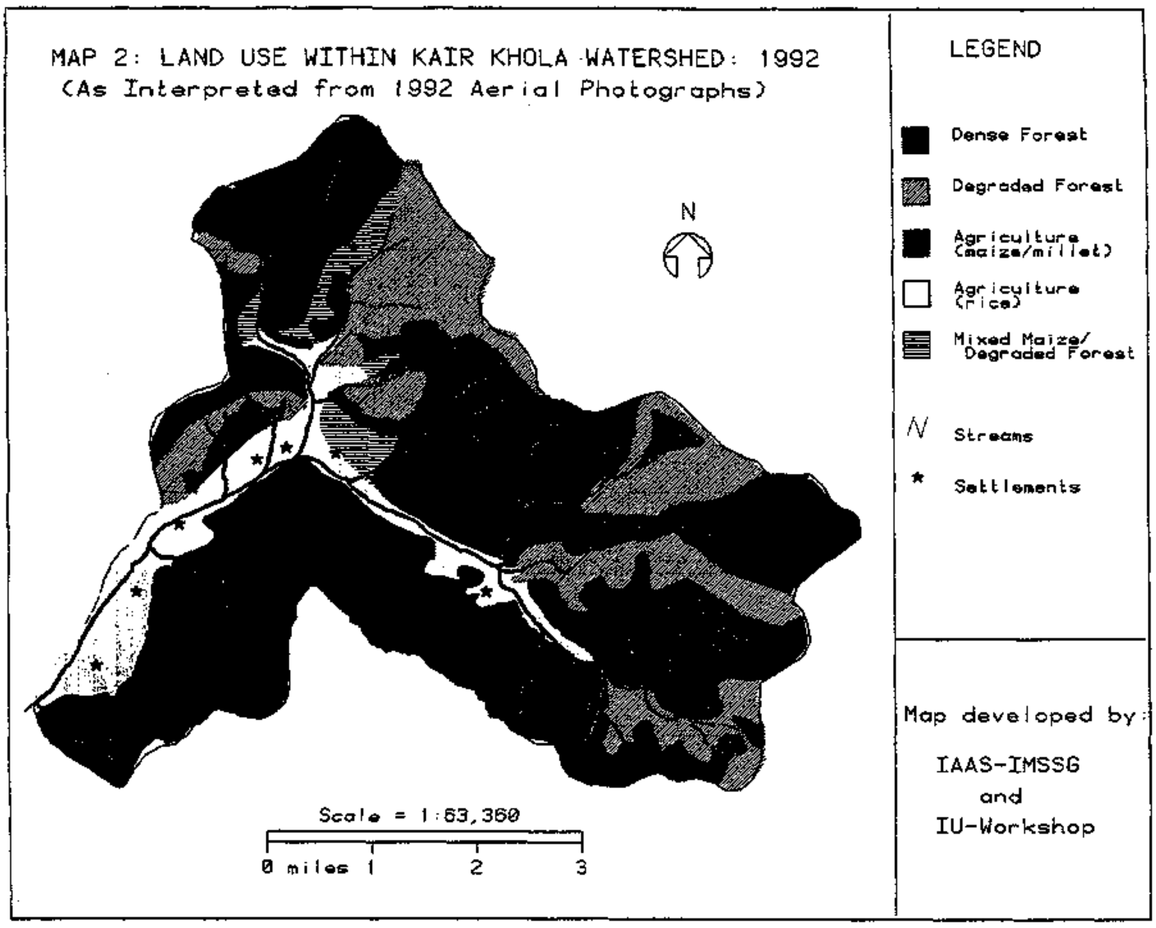
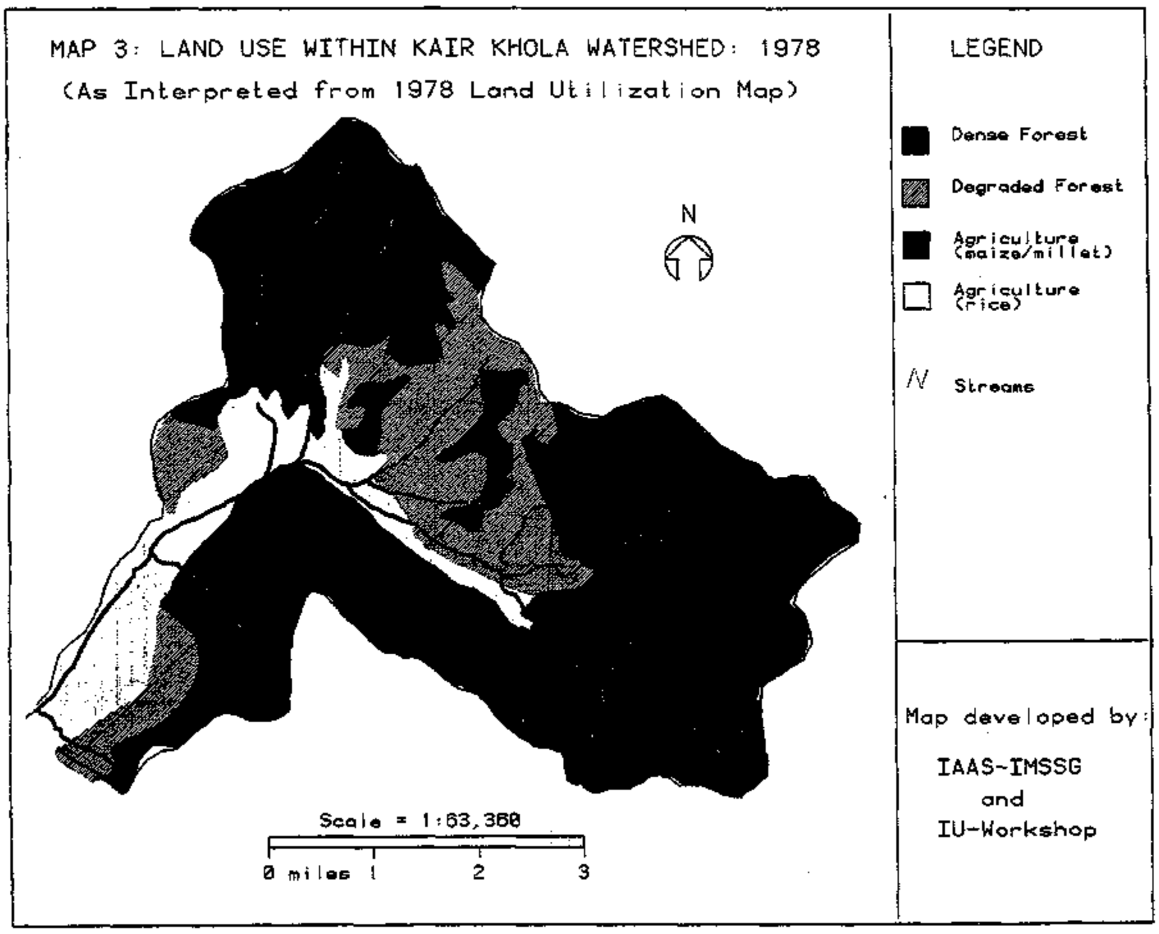
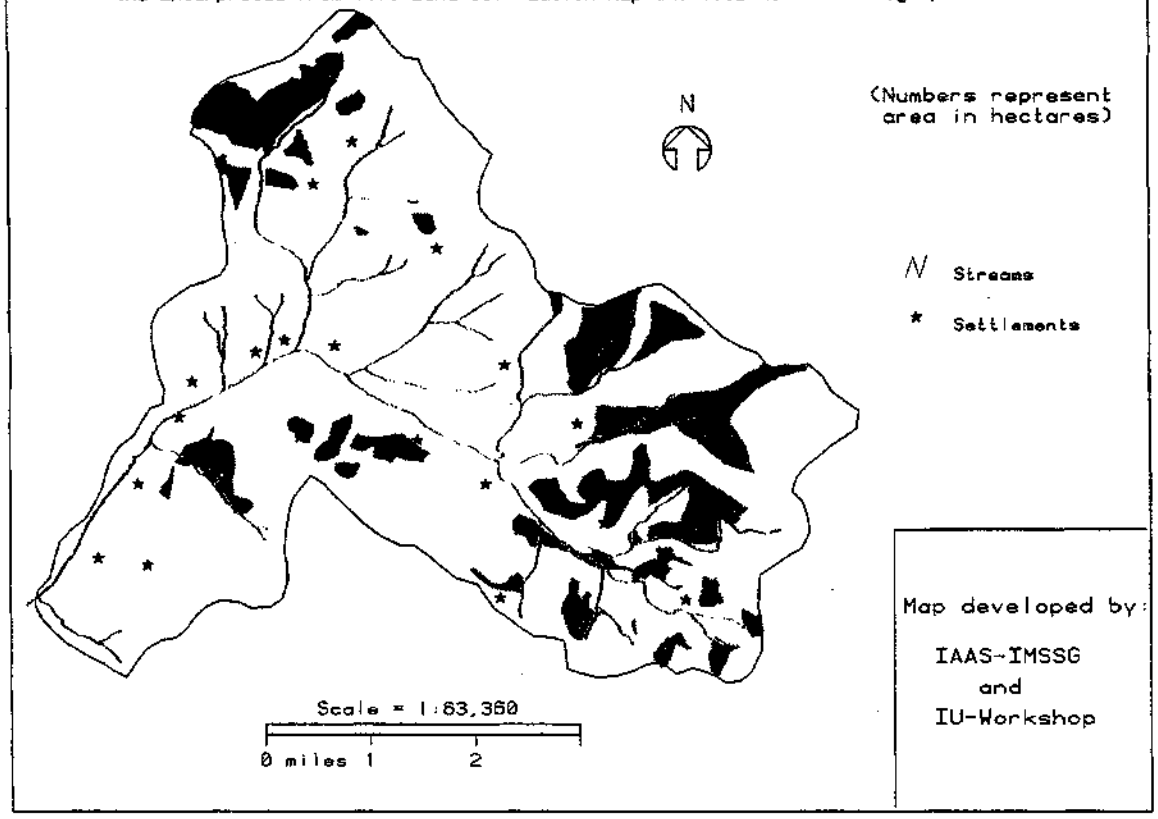

MAP1: SUB-CATCHMENTS WITHIN KAIR KHOLA WATERSHED
(As Interpreted from 1992 Aerial Photographs)
LEGEND
Shakti
Kair
Combined
N
Streams
Sedimentation Problem
Settlements
Settlement Ids:
1-Kholar
2-Drabyutar
3-Sano supar
4-Chherewang
5-Kaswang
6-Devjar
IFRI VILLAGES:
7-Derauli
8-Latauli
Scale = 1:63,360
0 miles 1 2 3


MAP 2: LAND USE WITHIN KAIR KHOLA WATERSHED: 1992
(As Interpreted from 1992 Aerial Photographs)
LEGEND
Dense Forest
Degraded Forest
Agriculture (maize/millet)
Agriculture (rice)
Mixed Maize/ Degraded Forest
Streams
Settlements
N
Scale = 1:63,360
0 miles 1 2 3
Map developed by:
IAAS-IMSSG
and
IU-Workshop


MAP 3: LAND USE WITHIN KAIR KHOLA WATERSHED: 1978
(As Interpreted from 1978 Land Utilization Map)
LEGEND
Dense Forest
Degraded Forest
Agriculture (maize/millet)
Agriculture (rice)
Streams
N
Scale = 1:63,360
0 miles 1 2 3
Map developed by:
IAAS-IMSSG
and
IU-Workshop

MAP 4: 1978 DENSE FOREST THAT IN 1992 IS MAIZE/MILLET AGRICULTURE
KAIR KHOLA WATERSHED, CHITWAN, NEPAL
(As Interpreted from 1978 Land Utilization Map and 1992 Aerial Photographs)



MAP 5: 1978 DENSE FOREST THAT IN 1992 IS DEGRADED FOREST
KAIR KHOLA WATERSHED, CHITWAN, NEPAL
(As Interpreted from 1978 Land Utilization Map and 1992 Aerial Photographs)

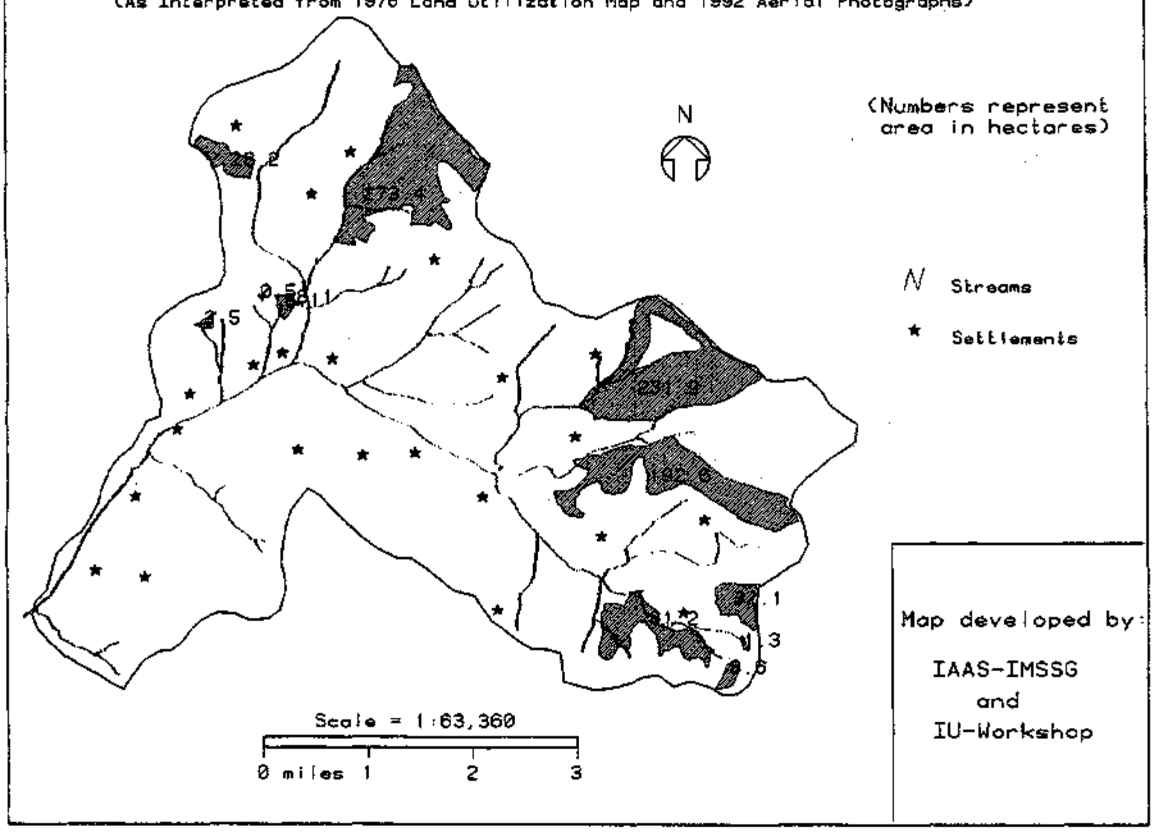


FIGURE 1: AN ANALYTIC FRAMEWORK FOR UNDERSTANDING WATERSHED SEDIMENTATION*

1. WATERSHED PHYSICAL ATTRIBUTES

- Natural:
  - Climate
  - Topography
  - Hydrology
- Human-driven:
  - Current agriculture and forest patterns -------------->

2. WATERSHED SOCIAL ATTRIBUTES

- Community
  - Population growth and Migration patterns
  - Economic conditions
  - Access to Markets
  - Harvesting technologies
  - Agriculture practices
  - Forest product requirements
- Institutional
  - Boundary rules
  - Use rules
  - Monitoring practices
  - Sanctioning practices
  - Conflict resolution mechanisms
  - Collective choice rules

3. INCENTIVES:

For natural ---> resource use

4. ACTIONS:

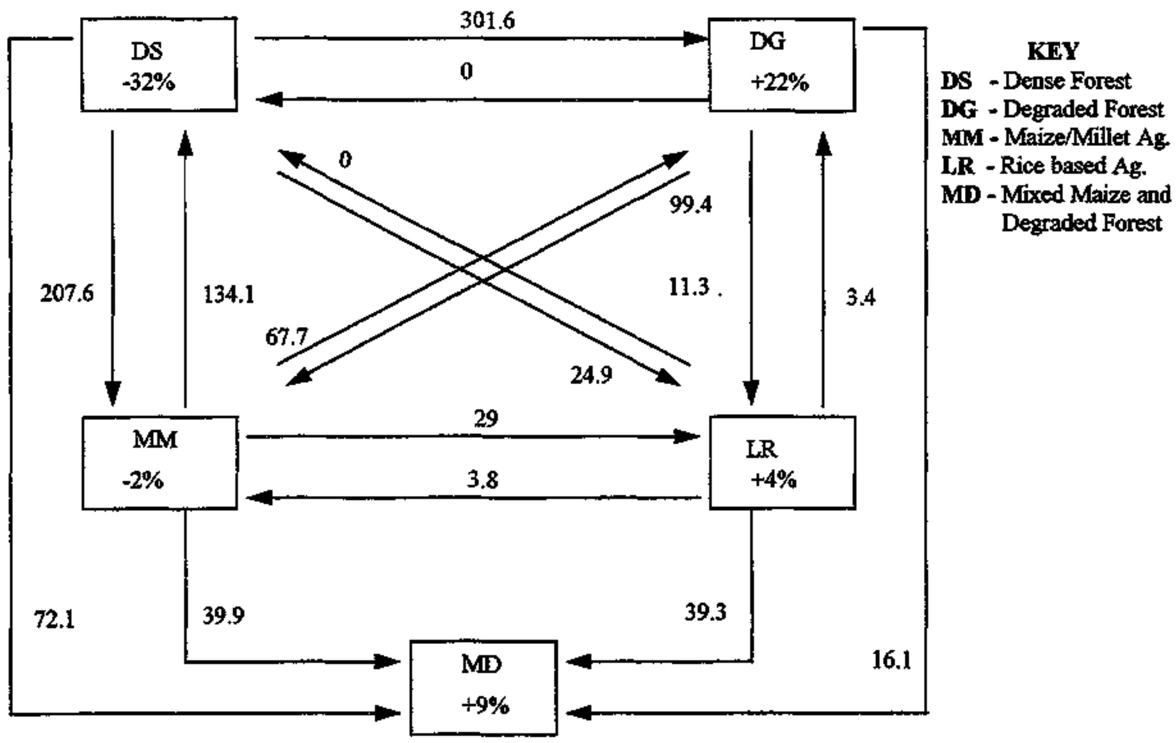
Land use --->

5. OUTCOMES

- Sedimentation in lowland
- Changes in land cover pattern ----> Feeds back to human driven physical

*Based on the Institutional Analysis and Development framework developed by colleagues at the Workshop in Political Theory and Policy Analysis, Indiana University.

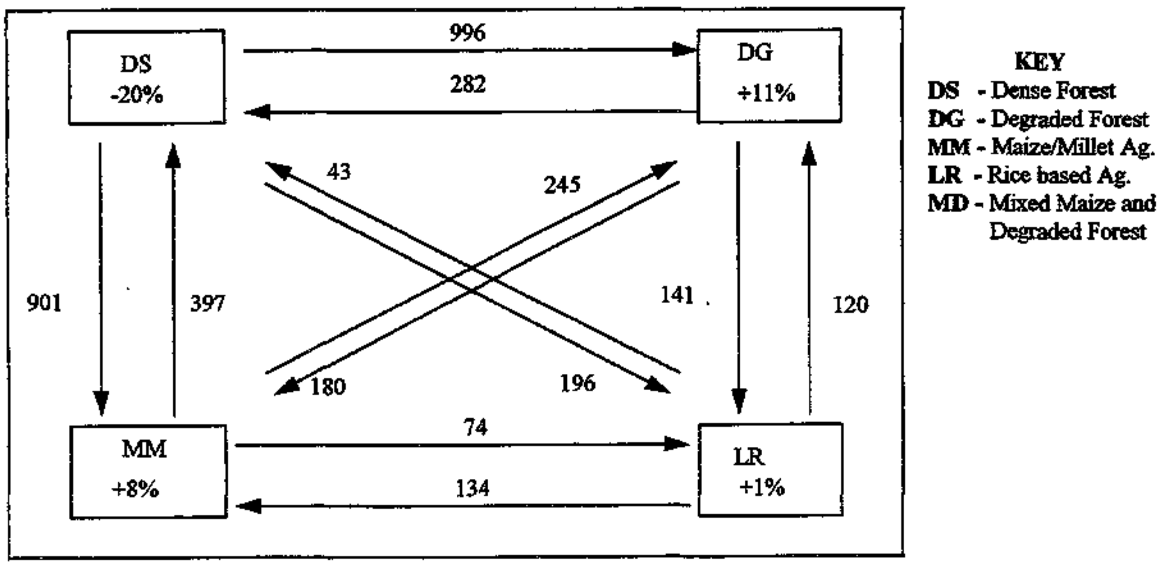
FIGURE 2: Land-use Change In The Shakti Sub-Basin of the Kair Khola Watershed, Chitwan, Nepal
1978-1992



(Numbers Represent total hectares into or out of stated land use)

FIGURE 3 :Land-use Change In Kair Sub-basin of the Kair Khola Watershed,Chitwan,Nepal

1978-1992



(Numbers Represent total hectares in to or out of stated land use)

Table 1: Landuse area changes in Kair Khola Watershed
(By Sub-basin)

	Shakti			Kair		
LANDUSE	1978	1992	Percent Change	1978	1992	Percent Change
Maize based (MM)	343.4 (24%)	313.5 (22%)	-2%	606.1 (16%)	1294.2 (34%)	+16%
Lowland Rice Based (LR)	34.4 (2%)	81.8 (6%)	+4%	161.6 (4%)	179.8 (5%)	+1%
Dense Forest (DS)	865.1 (61%)	410.9 (29%)	-32%	2384.8 (63%)	1576 (41%)	-22%
Degraded Forest (DG)	180.3 (13%)	496.3 (35%)	+22%	642.3 (17%)	714.6 (19%)	+2%
Mixed Maize and Degraded Forest (MD)	N/A	121.1 (9%)	+9%	N/A	73.3 (2%)	+2%
TOTALS[7]	1443.2	1423.6		3792.8	3837.9	

* Numbers represent hectare values of land category within the sub-basin. Percentages are percent of total land area within sub-basin.

[7]Hectare area totals differ because of slight digitizing errors when producing the 1978 and 1992 Geographic Information System coverages.

Table 2. Demographic Characteristics of 9 Upland Villages Within the Kair Khola Watershed

COMMUNITY ATTRIBUTE	SHAKTI SUB-BASIN: Sano Supar, Kholar and Drabyutar Villages	KAIR SUB-BASIN Deurali, Latauli, Devjar, Chherewang, Khirki and Kaswang Villages
Ethnic Composition	89% Chapang 6% Magar 5% Other	92% Chapang 8% Tamang
Percentage Employed in Agriculture	83%	91%
Literacy Rate	39%	31%

Source: 1991 Nepal Census

Table 3. Land Area under Four Slope Classes in Kair and Shakti Sub-basins

Slope class		Land area			
		Shakti sub-basin		Kair sub-basin	
degree	percent	hectare	percent	hectare	percent
< 5'	< 8.7	0	0	152	3.97
< 20	< 36.4	19	1.31	912	23.76
< 30	< 57.7	498	34.98	773	20.13
> 30	> 57.7	907	63.71	2001	52.14
Total		1424	100	3838	100

Source for slope class: Land system maps (72 A/9 and 72 A/10, LRMP, Nepal)

* < 5 = Alluvial plains and fans, flat to moderately sloping
< 20 = Moderate to steeply sloping hill and mountain
< 30 = Moderate to steeply sloping mountain terrains
> 30 = Steeply to very steeply sloping mountain terrains

Table 4. Major Elevation (ft.) Ranges and Area in Shakti and Kair sub-basins

	Shakti sub-basin	Kair sub-basin
Total area, ha	1424 (27%)	3838 (73%)
Valley (basin floor)	500	500
Middle part of basin	1500-3000	1500-3000
High lands (peaks)	6155	5400

Source: Topographic maps sheet no. 72 A/9 and 72 A/10 (Department of Land Survey, Kathmandu, Nepal)

Table 5. Characteristics of Shakti and Kair Stream Orders

Stream order	Shakti stream		Kair stream	
	Number	Average length (m)	Number	Average length (m)
First	8	828	18	1112
Second	6	1131	8	1189
Third	1	975	5	1368
Fourth	0	0	1	1010

Source: The streams identified on aerial photographs (1:50 000), ordered according to Strahler (1964) and length measured using GIS.

Table 6. Characteristics of Lowland and Upland Villages Within the Kair Khola Watershed

Settlement Name	U/L[a]	Caste Heterogenity[b]	Largest Caste (%)
Sulltar	L	5	Kami 47%
Kuwapani	L	2	Chapang 99%
Sinjali gaun	L	5	Sanyasi 38%
Bhandari gaun	L	3	Chetri 45%
Sewnaji towe	L	3	Chapang 53%
Samfra rang	L	4	Magar 23%
Dogara	L	2	Gurung 96%
Khola gaun	L	2	Chapang 88%
Nibuwatar	L	3	Kami 57%
Sano Supar	U	4	Chapang 79%
Kholar	U	1	Chapang 98%
Drabyutar	U	2	Chapang 80%
Deurali	U	1	Chapang 100%
Latauli	U	2	Chapang 99%
Devjar	U	2	Chepang 89%
Chherewang	U	2	Chepang 88%
Khirki	U	1	Chepang 100%
Kaswang	U	1	Chepang 100%

Source: 1991 Nepal Census

[a]U=Upland Village, L=Lowland village

[b]Numbers represent a count of the different castes represented in the village.

Table 7: Household Population Growth for selected Upland Villages in the Shakti Sub-basin of the Kair Khola Watershed

Village	Population 1978	Population 1992	% Growth
Darbyutar	25	30	20%
Kholar	35	40	14%
Sano supar	20	25	25%

Source: Villager discussions, GIS ground truthing, November 1994

Table 8: Household Population Growth for selected Upland Villages in the Kair Sub-basin of the Kair Khola Watershed

Village	Population 1978	Population 1992	% Growth
Chherewang	20	40	100%
Devjar	25	30	20%
Kaswang	3	7	130%

Source: Villager discussions, GIS ground truthing, November 1994.