Challenges in Mountain Resource Management in Nepal

Processes, Trends, and Dynamics in Middle Mountain Watersheds


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Schreier H.
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Proceedings of a Workshop held in
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Sponsored by the International Development Research Centre (IDRC)
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Cover Photographs: Adheri Khola, Jhikhu Khola Watershed at low flow (left) and high flow (right) - M. Carver

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Foreword

Over the past few decades the Middle Mountains of Nepal have experienced rapid population growth which has resulted in expanding cultivation on to marginal lands and introduction of multiple annual crop rotations. This land use intensification appears to be the most widespread in the Middle Mountains, making it one of the most intensively utilised mountain regions in the world. Given the remoteness, lack of infrastructure, and difficult topography, questions have been raised as to whether such intensive cropping systems are sustainable given the naturally high rates of erosion and the relatively low availability of inputs.

The world's press has devoted much attention to the claims that rapid deforestation in the Nepal Himalayas are in part responsible for devastating floods in the Ganges Lowlands and Bangladesh. Little scientific information is available to substantiate the claims that human activities are influencing the frequency and magnitude of lowland flooding. Very little long-term data on land use, soil fertility maintenance, erosion, and hydrological and sediment processes are available, and this long-term project was initiated to understand the linkages between biophysical resources and socioeconomic variables for sustainable resource use and management.

An interdisciplinary approach was undertaken to address these issues and the micro-level resource information developed was a critical precondition for better understanding and analysis of the resource dynamics in areas where previous research work on biophysical processes has been limited and primarily *ad hoc*.

The research undertaken provides a common framework for national research organisations in ICIMOD's Regional Member Countries for demonstrating the usefulness of approaches and methods used for addressing resource problems. It is hoped that this study will provide a useful insight into the scientific and technical understanding of natural systems and their interrelationships in mountain environments as a background to sustainable development.

On behalf of ICIMOD I would like to express my gratitude to the International Development Research Centre for the generous financial support provided and our sincere appreciation for the professional contributions and commitment of the University of British Columbia team to the success of the project. We are looking forward to continuing collaboration for the benefit of mountain farmers and their environment.

Egbert Pelinck
Director General
ICIMOD

Foreword

This workshop reports on research that ICIMOD together with the University of British Columbia in Canada has been conducting in the Jhikhu Khola watershed since 1989.

Nepal faces resources constraints and problems that are somewhat unique to her mountain ecosystem. Extremely high rates of natural erosion, marginal conditions for biomass production dominated by a mountain agriculture, a distinct dry season and very high population pressure all exert extreme demands upon this resource base. Farmers in Nepal have adapted their farming systems to these difficult conditions for generations but questions about the long-term sustainability of different production practices often arise. The Jhikhu Khola watershed was chosen as a site to study long-term changes in land use, soil fertility status, erosion processes and other aspects of land management and use. Different aspects of this work are reported in these proceedings.

The general objective of this Phase II project was to develop an understanding of land use and production systems in the dryland areas of the middle mountains of Nepal and to interpret and integrate this knowledge leading to changes which result in improved ecological and economic sustainability of these systems. specific objectives of the study are listed as:

a) To document and begin to understand indigenous knowledge and resource management systems;
b) To continue and expand the monitoring of hydrology, erosion and climatic processes begun in Phase I of the project;
c) To evaluate and quantify linkages and interactions between management and use cultivated lands, forests, grazing and other land uses;
d) To develop new methods and models for the integration and interpretation of socioeconomic and biophysical systems as these relate to sustainable development options;
e) To identify major constrains to sustained productivity and management of dryland farming systems and to initiate selected participatory research programmes to address identified constraints and problems;
f) To strengthen the institutional capacity of cooperating agencies.

The International Development Research Centre is extremely pleased and proud of this work. Mr. P.B. Shah who leads the work on the ICIMOD side and Dr. Hans Schreier of UBC have given more than can be expected of them. Likewise for other team members. This tremendous effort is reflected in the papers and results report. Both ICIMOD and the University of British Columbia are thanked for all the support and freedom they have given to Mr. Shah and Dr. Schreier as leaders of the project. Aside from reading these proceedings I would encourage those who can to visit Jhikhu Khola if this is possible.

IDRC thanks all those who have worked with and supported this project. This thanks also extends to farmers and their families in the watershed who have helped us in so many different ways. We hope that the knowledge gained through this research will lead to agricultural development options that are truly sustainable and that the benefits thereof will accrue directly to Nepal's farmers.

John Graham
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Environment and Natural Resources Division
IDRC, Singapore

Table of Contents

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We would also like to thank the administration of ICIMOD, particularly, Mr. E. Pelinck, (the Director General), Dr. M. Banskota, (the Deputy Director General), and Mr. M. Tuladhar, (Head, Administration and Finance) for their support in administering the project in Nepal. The assistance from the staff of the Mountain Natural Resource Division and Administrative, Finance, and Logistics Service, as well as the help from Greta Rana and Archana S. Karki, (Documentation, Information and Training Service) are gratefully acknowledged.

Many farmers have participated in the project. They assisted in the collection of the biophysical information, took part in the monitoring programme and provided an impressive amount of indigenous knowledge from which we benefitted greatly. Prabin Kunwar (high flow hydrometric measurements), Chandra Maya, and Mina Sedai (socioeconomic surveys) provided excellent services in the field.

Collaborating Institutions include The District Forestry Office in Dhulikhel, The Department of Soil Conservation (HMG/N), Nepal Agricultural Research Council (NARC), and the Department of Hydrology and Meteorology (HMG/N).

A special thankyou goes to the former and current graduate students at UBC (Dr. M. Schmidt, Martin Carver, Sandra Brown) and the Swiss connection (Dr. Martin Grosjean, Susan Wynann, University of Bern) who participated in many parts of the research. The cover photos were provided by Martin Carver and Lynn Belanger helped us with the production, editing, and graphics of the proceedings. Editing and formatting were carried out at the University of British Coumbia, Vancouver, Canada.

Overview and Objectives of the Workshop

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1. INTRODUCTION

Over the past 10 years we have become increasingly aware that the human use of natural resources exceeds the natural carrying or regeneration capacity and the question of its impact globally is increasingly being raised. This is nowhere more apparent than in the Middle Mountains of Nepal, where population pressure is placing great stress on the production capacity of the ecosystem to provide sufficient food, animal feed and fuelwood for the rapidly growing population living in this marginal environment.

In 1991 we organized a workshop in Dhulikhel (Shah, 1991) which brought together scientists working on all aspects of resource management in the Middle Mountains of Nepal. The aims were to share information, exchange ideas about resource problems and to look for common solutions to achieve a better balance between resource use and minimizing environmental degradation. This was at a time when air pollution was not yet an issue in Kathmandu and when questions about soil fertility were only starting to be raised. The questions of whether forest cover was increasing or decreasing was also a hotly debated issue at that time (Gilmour, 1991). Since 1991 Nepal has experienced a change in governance to democracy, and we thought it was appropriate to conduct another workshop in 1995 to revisit the status of the resources, to discuss the changes that have taken place since our last meeting, and to illustrate some of the issues that need urgent attention if we hope to restore the balance between adequate production and retention of a fully functional ecosystem.

2. ISSUES AND APPROACH

The use of resources in the Middle Mountains of Nepal is approaching the limits of the natural carrying capacity. The traditional sectoral approach to resource evaluation is no longer appropriate because forestry, agriculture, socio-economics, hydrology and climate are becoming more interdependent and environmental issues are beginning to influence the global economics. Many people talk about integrated resource management and watershed evaluations but truly integrated assessments are rare and this can in a large part be attributed to the structured disciplinary approach in which government ministries are organized. It is for this reason that we selected "CHALLENGES IN MOUNTAIN RESOURCE MANAGEMENT AND RESOURCE DYNAMICS IN MIDDLE MOUNTAIN WATERSHEDS" as the themes for our workshop. We intend to show that a watershed approach combined with Geographic Information Systems (GIS) has much to offer as an integration tool for resource evaluation, monitoring and management. This workshop is our modest attempt to foster better communication and collaboration between experts from a wide range of disciplines and point the way towards more interdisciplinary research. The farmers (male and female) in Nepal can be used as a classic example of truly interdisciplinary managers. They use their knowledge to manage all available natural resources (forests, agriculture, water) and adapt their techniques to the environmental conditions, the available infrastructure and changing market conditions. Emphasis is placed on providing examples on how researchers can improve their understanding of the natural processes by tapping indigenous knowledge and by incorporating farmers into the research program.

We hope that the proceedings will contribute to improved communications between experts from many disciplines, all working on the common problem of balancing resource use with carrying capacity, and reducing environmental degradation, when the former exceeds the latter.

The issues of population growth, resource degradation and urbanization discussed during the Rio Conference on the Environment and the Cairo Conference on Population can readily be addressed in the context of the Middle Mountains because degradation processes and indicators of resource deteriorations are clearly visible in the marginal environments of the Middle Mountains. Much has been written about deforestation, soil erosion, crop yield declines, and lack of infrastructure support, but good documented information is rare and exaggerated reports are widespread.

A better knowledge base is needed if we hope to make more educated decisions on resource management and this workshop will address the major resource issues pertaining to the Middle Mountains of Nepal. The aims of the workshop are not only to provide a status report on the resource conditions but to gain a better understanding of the processes that govern: land use dynamics, hydrology, sedimentation, erosion, soil fertility changes, socio-economic conditions, institutions and infrastructure. One of the themes is research for development; what have we learned from research and how can we translate such information into development.

There are no standard methods of assessing resources and evaluating the results for development. We are all searching for new ways to address the problems of population increases and resource degradation. What we hope to achieve with this publication is to communicate our experience, illustrate the approaches which have been used, discuss the advantages and weaknesses of these approaches and identify the large gaps in understanding the processes that govern production, resource exploitation and environmental degradation in this part of the world.

3. WORKSHOP ORGANIZATION

The workshop papers are organized in three parts. Part 1 consists of twelve papers by local and international experts covering the resource issues that are most pertinent to the Middle Mountains of Nepal. Part 2 focuses on the Jhikhu Khola Watershed study which has been carried out over the past six years by an interdisciplinary ICIMOD/UBC team. The focus of this project is to develop a comprehensive quantitative resource database of the watershed, to set up a long term monitoring program of resource degradation processes, to use computer techniques to collect, analyze and communicate information, to improve our understanding of indigenous knowledge, and to translate some of these research results into action to assist development. The third part of the Proceedings contains the outcome of the workshop discussion which includes recommendations.

The main themes covered in different parts of the proceedings are:

Hydrological processes:
Storm events; flooding processes; highland - lowland interactions; the scale of hydrological processes; large dams versus small hydro; sedimentation and nutrient cycling within the watershed; stream flow dynamics; and irrigation schemes.

Soil erosion:
Rates of losses during unusual storm events; losses from dryland agriculture; the role of surface cover; climate; and management implications.

Forestry:
Capacity building for managing community forestry; rates and processes of forest degradation; forests soil fertility; the role of women in managing forests; fodder trees; and agro-forestry.

Agriculture:
Land use dynamics; cropping systems; crop biodiversity; soil fertility and productivity; gender issues; agro-forestry; intensification versus use of marginal lands; and soil acidification.

Socio-economic factors:
The invisible woman farmer; indigenous knowledge in soil classification and irrigation; the castes system; income and productivity; markets; perceptions of resource problems; and rural interviews.

Research approaches and technology transfer:
Geographic information systems as a tool to model watersheds; solar technology for research, electricity and trickle irrigation; building bridges for science and community development; rehabilitating degraded lands; incorporating farmers into the research monitoring program; and using hypertext to communicate scientific results.

The workshop was held on April 10-11, 1995, at the Himalayan Hotel, in Kathmandu Nepal and a field trip to the Jhikhu Khola watershed was conducted on April 12, 1995. The International Development Research Centre (IDRC) in Ottawa, Canada, encouraged us to conduct the workshop and financed both the workshop and the publication of the proceedings. We hope that this document will serve a useful purpose in informing other individuals concerned with resource management in mountain environments.

4. REFERENCES

Gilmour, D. A. 1991. Trends in Forest Resource Management in the Middle Mountains of Nepal. In: Shah, P. B., H. Schreier, S. Brown, and K. W. Riley (eds). Soil Fertility and Erosion Issues in the Middle Mountains of Nepal. Workshop Proceedings, Jhikhu Khola Watershed, April 22-25, 1991, International Development Research Centre (IDRC), Ottawa, pp 33-46.

Shah, P. B., H. Schreier, S. Brown, and K. W. Riley (eds.). 1991. Soil Fertility and Erosion Issues in the Middle Mountains of Nepal. Workshop Proceedings, Jhikhu Khola Watershed, April 22-25, 1991, International Development Research Centre (IDRC), Ottawa, 285 pp.

Part 1

Resource Issues and Challenges in Middle Mountain Watersheds

Sedimentation of Lakes and Reservoirs with Special Reference to the Kulekhani Reservoir

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1. INTRODUCTION

Nepal is endowed with numerous glacial, tectonic and ox-bow lakes and some of the best examples are the well known Phewa, Begnas and Rupa lakes located at the Kaski District of Nepal. Future development in Nepal is dependent on capturing the hydropower potential, and the construction of reservoirs is a major dilemma. The Kulekhani reservoir (also known as Indra Sarobar reservoir) was developed in the early 1980's and is one of the major sources of electricity for Kathmandu. The construction of a 114 metre high rock filled dam created a reservoir of about 2 square kilometres in size, has a capacity to generate 92 megawatts of hydro-power (Phases I and II) and cost about a billion rupees.

The watershed area is in a fragile physiographic region which experience intense monsoon rainfall events. The land use is very intensive and with the high population pressure it is difficult to meet production demands. As a result conservation measures are inadequate and the erosion problem in the watersheds causes severe problems with sedimentation of lakes and reservoirs. To develop a soil conservation strategy and to arrive at a watershed management plan for the reservoir and hydropower generation it was essential to initiate a sediment monitoring program for the reservoir.

The Department of Soil Conservation initiated a sedimentation survey program in 1990 and considerable monitoring has taken place since that time. Sedimentation surveys have been carried out in Phewa, Begnas and Rupa Lakes and the Kulekhani reservoir. However, Begnas and Rupa lakes require additional monitoring for analyzing the sedimentation rates. This paper summarizes the efforts carried out by the Department of Soil Conservation (1993a, 1994a) in the monitoring of the sedimentation of Phewa Lake and the Kulekhani reservoir.

2. WATERSHED DESCRIPTION OF KULEKHANI RESERVOIR AND PHEWA LAKE

2.1. Phewa Watershed

The Phewa watershed is situated in the western part of the Pokhara Valley in the Kaski District (Western Development Region of Nepal), covers an area of approximately 123 square kilometres and has a mean annual rainfall rate of more than 3,500 mm/year.

The lowest part of the watershed is the outlet of Phewa Lake with the elevation of 793 metres, and the highest area in the watershed is the Panchase ridge in the west, at 2,589 metres elevation. Harpan and Andheri Khola are the major tributaries draining into the lake.

In the Phewa Tal watershed, agriculture constitutes about 39 % of the land use whereas forestry covers about 44 %, shrubland about 3 % and grazing lands another 3 %. The reservoir covers about 435 hectares and the remaining uses include barren lands, orchards, gullies and landslides. Of the 39 % of agricultural land (4,728 hectares) only 38 hectares consist of sloping terraces and about 84 % are level terraces with 8 % classified as valley cultivation and 7 % as cultivated fans (Table 1).

Nine percent of the watershed area has slopes steeper than 60 % and about 55 % of the watershed area is in the 30-60 % slope category. Of the remaining land, 18 % has slopes between 16-30 % and 11 percent has slopes less than 15 % (Table 2).

Table 1. Present land use status of Kulekhani and Phewa Watersheds.

Land Use Category	Phewa Tal Watershed		Kulekhani Watershed	
	Area (hectares)	Percent	Area (hectares)	Percent
Sloping Agriculture	38	0.3	4254	34.0
Level Terrace	3988	32.5	237	1.9
Valley Terrace/ Fans/ Tars	701	5.7	713	5.7
Forest	5431	44.3	5455	43.6
Shrubs	345	2.8	1147	9.2
Grazing and Grass lands	371	3.0	200	1.6
Barren / Rock Field	42	0.3	50	0.4
Lake	435	3.5	216	1.7
Gullies / Landslides	83	0.7	18	0.2
Others	829	6.8	210	1.3
Total	12263	100	12500	100

Table 2. Slope status of Kulekhani and Phewa Watersheds.

Slope Category	Slope in Percent	Phewa Tal (Percent)	Kulekhani (Percent)
I	< 15	11	9
II	16 - 30	18	28
III	31 - 60	55	52
IV	> 61	9	9
Lake/Wetlands		7	2

2.2. Kulekhani Watershed

Kulekhani watershed area, which covers 125 square kilometres and lies south west of the Kathmandu valley, is situated in the Central Development Region of Nepal. The watershed is subject to a monsoon climate, which brings rainfalls of about 1500 mm annually.

The outlet of the Kulekhani Reservoir is at about 1500 metres elevation and the south western ridge of Palung Khola marks the summit at 2,621 metres. Tasar, Chitlang and Bisingkhel Kholas are the major tributaries feeding the Kulekhani reservoir.

Agriculture constitutes about 42 % of the watershed area, forestry makes up 44 % of the land use, shrubland covers 9 % and grazing, about 2 % of the watershed. The reservoir, rock fields, landslides and residential areas cover about 3 %. Out of the 42 percent of agriculture land, about 81% are sloping (bari land) terraces and about 18 % are level and valley terraces (khet land) (Table 1).

Nine percent of the watershed area is steeper than 60 % and about 52 % of the watershed area falls into the slope category between 30-60 %. Of the remaining area, 28 % have slopes of 16-30 % and only 9 % have slopes less than 15 % (Table 2).

3. METHODOLOGY

The sedimentation survey is a part of a long-term monitoring effort of the lakes and reservoirs. Water depth of the reservoir is measured with respect to a reference water level and the differences in depth are used to estimate the sediment deposited at the bottom.

The instrument used for the depth measurement is a microprocessor controlled ROYAL RF-350A depth recorder (echo-sounding device). The deposited sediments are measured at several cross-sections along the lakes or reservoirs and the results are related to the original reservoir capacity. The positioning of the survey line is fixed by stretching a rope between the bench marks so that measurement can be made along the same fixed line year after year. The rope is marked at 25 metre intervals and these positions are recorded during the echo-sounding survey. This ensures that an accurate record of the locations of the boat with reference to the bench marks is maintained. The sounding is carried out during calm (windless) weather to assure easy boat handling and accurate measurements along the straight line of the rope.

The echo-sounder is a very precise instrument for water depth measurements. However, some errors may occur due to differences in site conditions. Calibration of the instrument is carried out by comparing manual readings with the depth measured by the echo-sounder and this gives results with accuracies in the plus/minus 10 cm range.

4. SEDIMENTATION SURVEY

4.1. Phewa Tal

Sedimentation surveys of Phewa lake were carried out in March 1990, May 1991, April 1992, December 1992 and January 1994 using 12, 11, 12, 15 and 18 fixed lines of measurements respectively. The base map of the reservoir was prepared using enlarged aerial photographs, and the distance of echo-sounding lines were measured using tachometric surveys in 1990 and 1992 by the staff of Nokia Cables Ltd.

4.2. Kulekhani

Sedimentation surveys of Kulekhani reservoir were carried out in March 1993, December 1993 and September 1994 using 18, 30 and 32 fixed lines of measurements respectively (Department of Soil Conservation and Watershed Management 1993, 1994). The base map of the reservoir was prepared from enlarged aerial photographs taken in 1986 and the distance of echo-sounding lines was measured by theodolite surveys.

5. RESULTS AND DISCUSSION

5.1. Phewa Tal

5.1.1. BATHYMETRIC MAP AND RESERVOIR CAPACITY

A bathymetric map of the lake was prepared at a scale of 1:10,000 based on the January 1994 sediment survey. During the highest water level, the area of the lake was 435 hectares in size and the gross capacity of the lake was 37.76 million m^3 (January 1994). With the reference water level at 794.15 the maximum depth of the lake is 23.4 m and the average depth is 8.70 m.

5.1.2. SEDIMENT DEPOSITED

The results indicate that the estimated annual sediment deposits in the whole Phewa lake area vary from 175,000 to 225,000 m^3. In the silt trap, the sedimentation rate varied between 90,000 and 120,000 m^3. The total estimated average sediment delivery rate from the watershed was calculated to be 17.37 m^3 per hectare for the period from 1990 to 1994.

Based on the five years of data and under the assumption that the lake loses its hydropower capacity when 80 % of the water volume is lost, then the lake has a 135 - 175 year lifespan. Annual deposition of about 90,000 to 120,000 m^3, as measured in the 68 ha silt trap area, would mean that the area would be filled up within the next 20 - 25 years. A more detailed record is needed to better understand the sedimentation process in the main lake area and the data needs to be analyzed statistically.

5.2. Kulekhani

5.2.1. BATHYMETRIC MAP AND RESERVOIR CAPACITY

Based on the sedimentation survey of September - October 1994, a bathymetric map of the reservoir was produced at the 1:7,400 scale, using 10 metre contour intervals (Figure 1). With reference to the highest water level (+1530.2 m), the area of the reservoir is about 216 hectares in size and the gross capacity of the reservoir is 72.41 million m^3 (October 1994).

5.2.2. SEDIMENTATION

A tremendous sedimentation rate was observed in the Kulekhani reservoir during and after the monsoon seasons of 1993 (between March to December) and 1994 (December 1993 to October 1994). With respect to the reference water level (+1530.2 m), the maximum decrease in the maximum water depth during the 1993 monsoon is 18.17 m, whereas the maximum decrease in the average cross-sectional water depth is 6.56 m. Similarly, during the 1994 monsoon season the maximum water depth in the main reservoir sections decreased to 3.29 m, and the maximum decrease in the average cross-sectional water depth was 1.83 m.

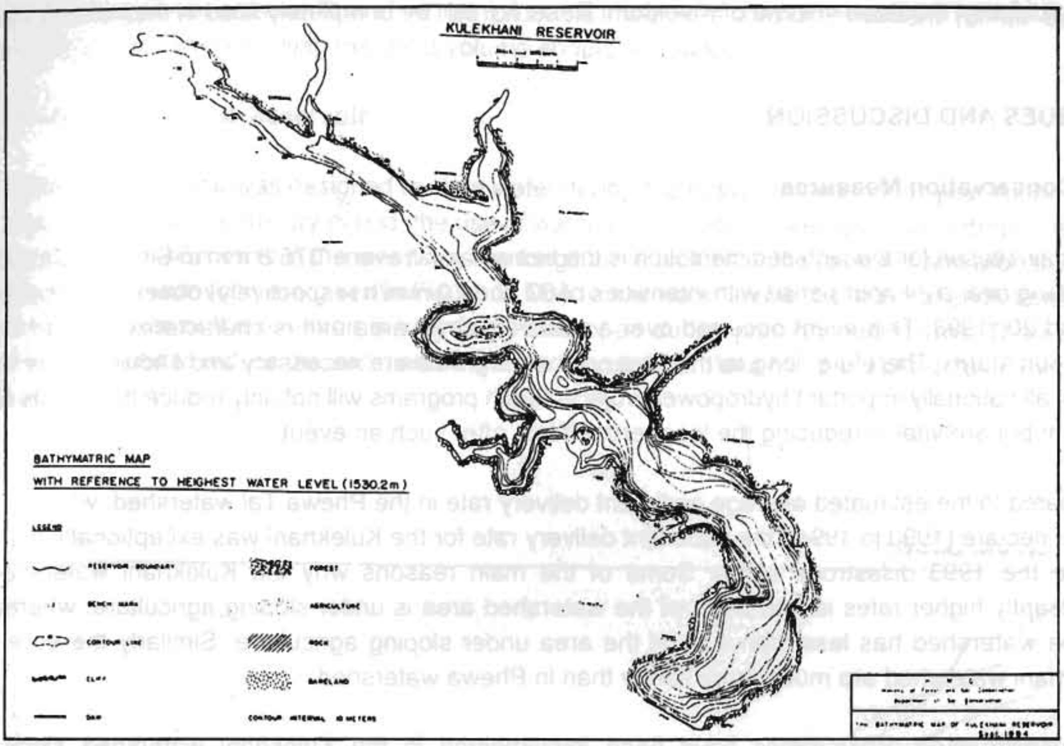

Figure 1. Bathymetric map of Kulekhani Reservoir.

The reservoir capacity is computed by multiplying the mean of the average depths of two cross sections by the area of the reservoir surface between those two sections. The gross capacity of the reservoir was reduced by 12.89 million m^3 of which 5.12 million m^3 were added during the 1993 disastrous monsoon storm and about 1.07 million m^3 were added during the 1994 monsoon season. If the sediment is distributed evenly throughout the watershed areas of 125 square kilometres, the annual sediment contribution rate accounts for about 45 m^3 per hectare before March 1993. During the 1993 monsoon season this rate increased to 410 m^3/ha and for the 1994 monsoon season we calculated the rate to be about 85 m^3/ha. The sediment contribution rate for the 1993 monsoon season was 10 times higher than during normal years, and for the 1994 monsoon, the sediment contribution rate was about twice the normal rate.

The gross capacity of the reservoir is computed by multiplying the average depth of two contour lines and the area between the contour lines using the bathymetric map. The capacity of the reservoir in December 1993 amounted to 75.11 million m^3, which is 10.19 million m^3 less than the gross capacity of the reservoir before the storm (85.30 million m^3). The capacity of the reservoir in October 1994 was further reduced to 72.41 million ^{3}, which is 12.89 million m^3 less than the original gross capacity of the reservoir (85.30 million m^3).

Considering the lower part of the intake (i.e. +1471 m) as the dead level, then the dead volume was reduced by 8.45 million m^3 by October 1994 out of total 11.2 million m^3. This translates into 75.4 % of the dead volume. If the trend remains the same and if no major conservation effort is made, the dead volume of Kulekhani Reservoir will be completely filled in less than 5 years.

Similarly, if the upper part of the intake (i.e. +1476 m) is considered as the dead level, the dead volume was reduced by 6.33 million m^3 by October 1994 out of total 11.2 million m^3 which translates into 56.5 %

of the dead volume. If the trend remains same and if no major conservation effort is made, then based on this calculation the dead volume of Kulekhani Reservoir will be completely filled in the next 10 years.

6. ISSUES AND DISCUSSION

6.1. Conservation Measures

The main reason for the high sedimentation is the heavy rainfall event (376.8 mm in Simlang and 535 mm in Tistung over a 24 hour period with intensities of 67 and 70 mm/h respectively) observed between July 19 and 20, 1993. This event occurred over a relatively small area and is characterized as an unusual monsoon storm. Therefore, long term conservation programs are necessary and should be the integral part of all nationally important hydropower projects. Such programs will not only reduce the effects of such a storm but are vital in reducing the long term effects after such an event.

Compared to the estimated average sediment delivery rate in the Phewa Tal watershed, which is 17.37 m^3 per hectare (1990 to 1994), the sediment delivery rate for the Kulekhani was exceptionally high even before the 1993 disastrous storm. Some of the main reasons why the Kulekhani watershed has significantly higher rates is that 34 % of the watershed area is under sloping agriculture, whereas the Phewa watershed has less than 1 % of the area under sloping agriculture. Similarly the soils in the Kulekhani watershed are much more sandy than in Phewa watershed.

Soil conservation programmes have been implemented in the Kulekhani watershed since 1978 (Department of Soil Conservation and Watershed Management, 1992). The main conservation measures were: planting of trees and grasses on degraded lands, introducing fruit trees, on-farm conservation, construction of conservation ponds, road slope stabilization, protection of irrigation canals, trail improvement, gully and landslide stabilization, torrent control, and stream bank protection. The scale of the soil conservation programme in the watershed is insignificant compared to the needs. Slope failures and stream bank cutting contribute tremendously to the sediments in the reservoir. It is very important to stabilize these activities particularly when it involves infrastructure like the dam, bridges and settlement areas. Since implementation through people's participation is the main strategy, and productivity conservation is the main theme of the soil conservation programme, local people are not keen to participate in stabilizing landslide and stream bank protection as these activities are less oriented towards productivity conservation considering the effort it requres.

Special emphasis should be given to the prevention and reclamation of landslides and gullies. Stream bank protection and the construction of sediment traps are needed to protect the hydro-power capacity of the reservoir. Implementation of such activities needs to be borne by the projects (such as hydro-power) which are directly affected by the sedimentation.

6.2. Sediment Management within the Reservoir

About 1.5 million m^3 of sediment were deposited in the reservoir above the dead volume area. Due to hydro-power generation, the water level before the monsoon is well below and most parts of the reservoir surface above the dead level are exposed. Therefore, flushes cf sediments to the front and mid parts of the reservoir are likely to occur at the beginning of each monsoon season. The October 1994 survey showed that during the 1994 monsoon, up to 1.13 million m^3 of sediments entered the dead volume area, whereas in the area upstream of the dead volume area, erosion rates of 68 thousand m^3 were measured. Therefore, management of the sediment within the reservoir is also equally important for the reservoir protection. More than 66 % of dead volume and about 15 % of live volume has been reduced since its construction in 1982. Reduction in live volume produces less electricity whereas filling of dead volume will stop hydro-power generation. Therefore, all probable measures to stop sediment (either from the watershed or reservoir) reaching the dead volume should be made.

6.3. Water Levels in the Reservoir

The Kulekhani Reservoir was designed to store water during the monsoon season for year-round hydro-power generation. During the dry period, the use of water for the hydro-power generation drops the water level by more than 40 metres in the reservoir. The longitudinal profiles of the reservoir and probable water levels before the monsoon are given in Figure 2. Due to low water levels, the flush of sediments to the front and mid parts of the reservoir is very likely to happen during premonsoon storms. Therefore, all probable measures to reduce the sediments from reaching the front and mid parts of the reservoir should be taken.

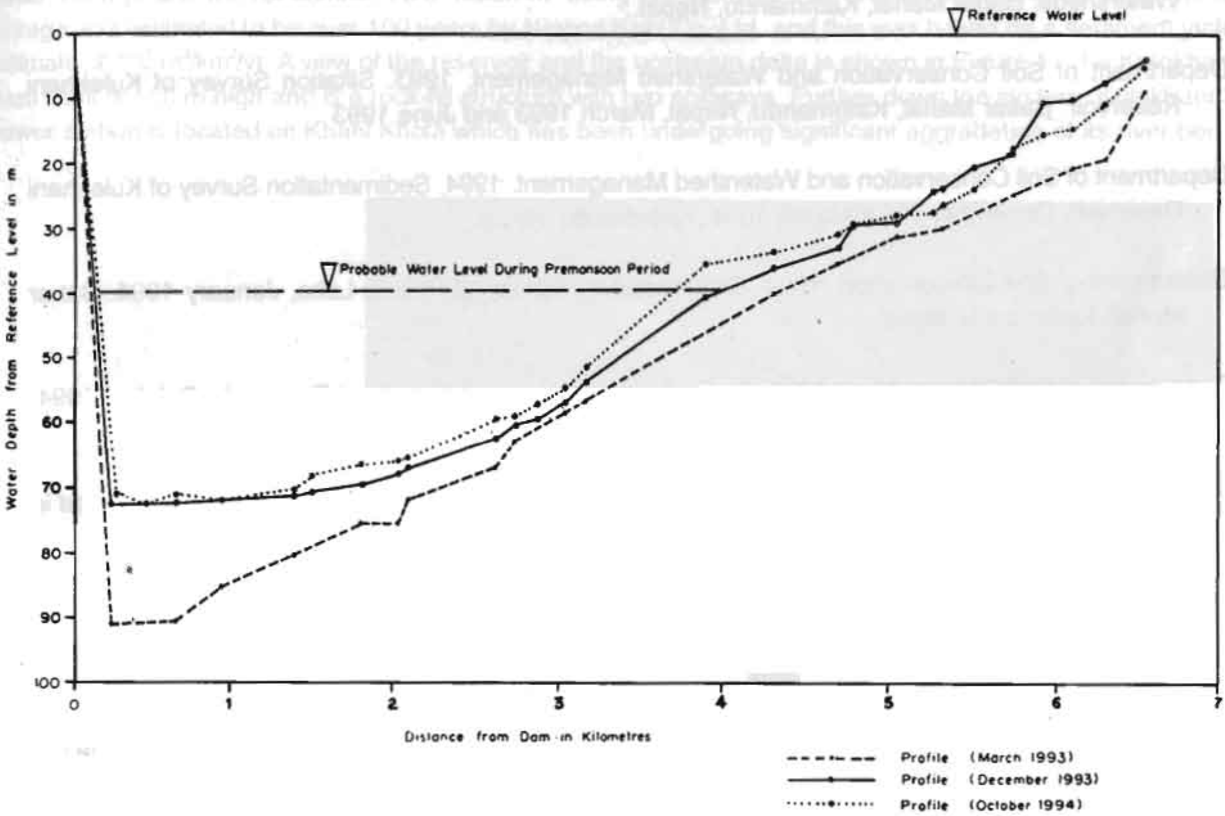

Figure 2. Longitudinal profile of Kulekhani Reservoir.

6.4. Discussion

It is nature's law that reservoirs will fill up with sediments one day. The issue is how the life span of the reservoir could be lengthened. Huge amounts of sediments are still in transit from the source to the reservoir. Monitoring of the sediment transport to the reservoir is essential for the necessary countermeasures to be taken in time to protect the reservoir from sedimentation. Every effort should be made to lengthen the life of the reservoir, and this includes watershed management, construction of sediment traps, structures, and management of the sediment above the dead volume area.

The observed annual sediment delivery rate from the Kulekhani watershed is much more than the designed rate of about 18 m^3 per hectare. The current rates drop the economic benefit of the Kulekhani Hydro-power Project dramatically. Also, if the dead volume is silted up as quickly as projected from the survey, this will affect the whole country's energy scenario and hydro-power economy (Sthapit 1994). Therefore, realizing the risk and the dramatic effects of monsoon storms, future hydro-power generation projects need to be designed to account for unusual events and very high sedimentation rates. Only then can we hope to materialize the great hydro-power potential available in Nepal. Otherwise the blessing will turn into a curse!

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Erosion from the Kulekhani Watershed, Nepal during the July 1993 Rainstorm

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1. INTRODUCTION

The Kulekhani Hydropower system is located in the Makuwanpur District, Central Region of Nepal, about 30 km southwest of Kathmandu. The Kulekhani No. 1 power station has an installed capacity of 60 MW and was commissioned in May 1982. Kulekhani No. 2 power station, installed capacity 32 MW, utilizes water from the tailrace of the No. 1 power station and was commissioned in December 1986. The total installed capacity of 92 MW for the two power stations comprises about 45 percent of the system capacity of Nepal (210 MW) and is primarily utilized in the dry season because most of the other stations in Nepal are run-of-river type. The total storage capacity of Kulekhani 1 reservoir was 85.3 million m^3 of which 12.0 million m^3 has been allocated to dead storage and the remainder, 73.3 million m^3 being live storage. The original operating life of the dead storage was estimated to be over 100 years by Nippon Koei Co. Ltd. and this was based on a sediment yield estimate of 700 $m^3/km^2/yr$. A view of the reservoir and the upstream delta is shown in Figure 1. The Kulekhani Dam itself is 150 m high and is a rock-fill structure with two spillways. Further down the system, Kulekhani 2 power station is located on Khani Khola which has been undergoing significant aggradation of its river bed.

Figure 1. Kulekhani Reservoir - Coarse bed-material (cobbles, gravel and sand) are shown as a deltaic deposit at the upstream end of the reservoir. The delta is about 2 km long and floating debris is seen adjacent to the delta. The Bisingkhal Khola delta is shown at the bottom right side of photo (September 1993).

2. SEDIMENT PRODUCTION FROM THE KULEKHANI WATERSHED

2.1 General Aspects of Sediment Production in Nepal

Sediment production in Nepalese watersheds has generally been acknowledged to be the highest in the world (Carson, 1985; Laban, 1978, Tautscher, 1979) and little reliable data of actual sediment production is available. Estimates for various land uses are presented in Table 1 and indicate the wide range of values which makes prediction of sediment yields difficult. However, in planning for dams in the mountains, it is essential that sediment yield estimates be realistic.

Now that a reliable estimate of sediment yield is available from reservoir deposition, one can work backwards and attempt to estimate the source of sediments and route these volumes down the tributaries and the mainstem to the reservoir. This paper presents two approaches for estimating sediment yield and comments on needed research for improvement of estimates.

Table 1. Erosion rates, Nepal.

Description of location and site; land condition	Rate Tons/km2/yr	Reference
Siwaliks, East Nepal, Chatra; S-aspect sandstone foothills; different landuse ranging from forest to grazing	780-3680	Chatra, 1976
Siwaliks, Far West Nepal, Surkhet; S-aspect sandstone foothills;		
- degraded forest	2,000	Laban, 1978
- degraded forest, gullied land	4,000	Laban, 1978
- severely degraded heavily grazed forest, gullied land	20,000	Sakya
Mahabharat Lekh, Central Nepal, Lothar; very steep slopes on metamorphic and sedimentary rocks;	3,150-14,000	Laban, 1978
- degraded forest (+ agriculture fields)	6,300-42,000	Laban, 1978
- gullied lands		
Middle Mountains, Kathmandu Valley; northern foothills of granites and migmatites with weak consolidation;		
- mainly degraded forest and scrubland	2,700-4,500	Laban, 1978
- dominantly overgrazed scrubland	4,300	Laban, 1978
- severely gullied land	12,500-57,000	Laban, 1978
Middle Mountains, Kathmandu Valley; steep slopes, south of valley, near Godawari; 75% dense forest		Kandel, 1978
1978	800	Laban, 1978
lands with good groundcover on shales, hard limestone and quartzite		
Middle Mountains, West Nepal, Phewa Tal Watershed; S-aspect moderately steep slopes on parallel dipping phyllitic schists;		
- protected pasture	920	Mulder, 1978
- overgrazed grassland	34,100	Mulder, 1978
- overgrazed grassland	2,200	Laban, 1978
- gullied, overgrazed grassland	2,900	
Middle Mountains, West Nepal, Phewa Tal Watershed N-aspect steep slopes on phyllitic schists		
- scrubland	*	Mulder, 1978
- dense forest land	*	Mulder, 1978
Darjeeling, Indian Himalayas	5,000-7,500	Starkel,1972

*Study in progress

2.2. Rainfall Intensity and Runoff

On the 19th and 20th of July, 1993, a major rainstorm hit the south-central part of Nepal. Based on rainfall data from several stations in the Kulekhani watershed and nearby watersheds, an isohyetal map was developed by Nippon Koei Co. Ltd. (1994) and is shown in Figure 2. Peak rainfall was observed at 10:00 pm, July 19 with an intensity of 70 mm/hr. The maximum amount of rain falling in one day was 540 mm on July 19, 1993 for the Tistung Station. More details related to the rainfall distribution and frequency can be found in Nippon Koei Ltd. (1994), JICA (1993) and SMEC (1994).

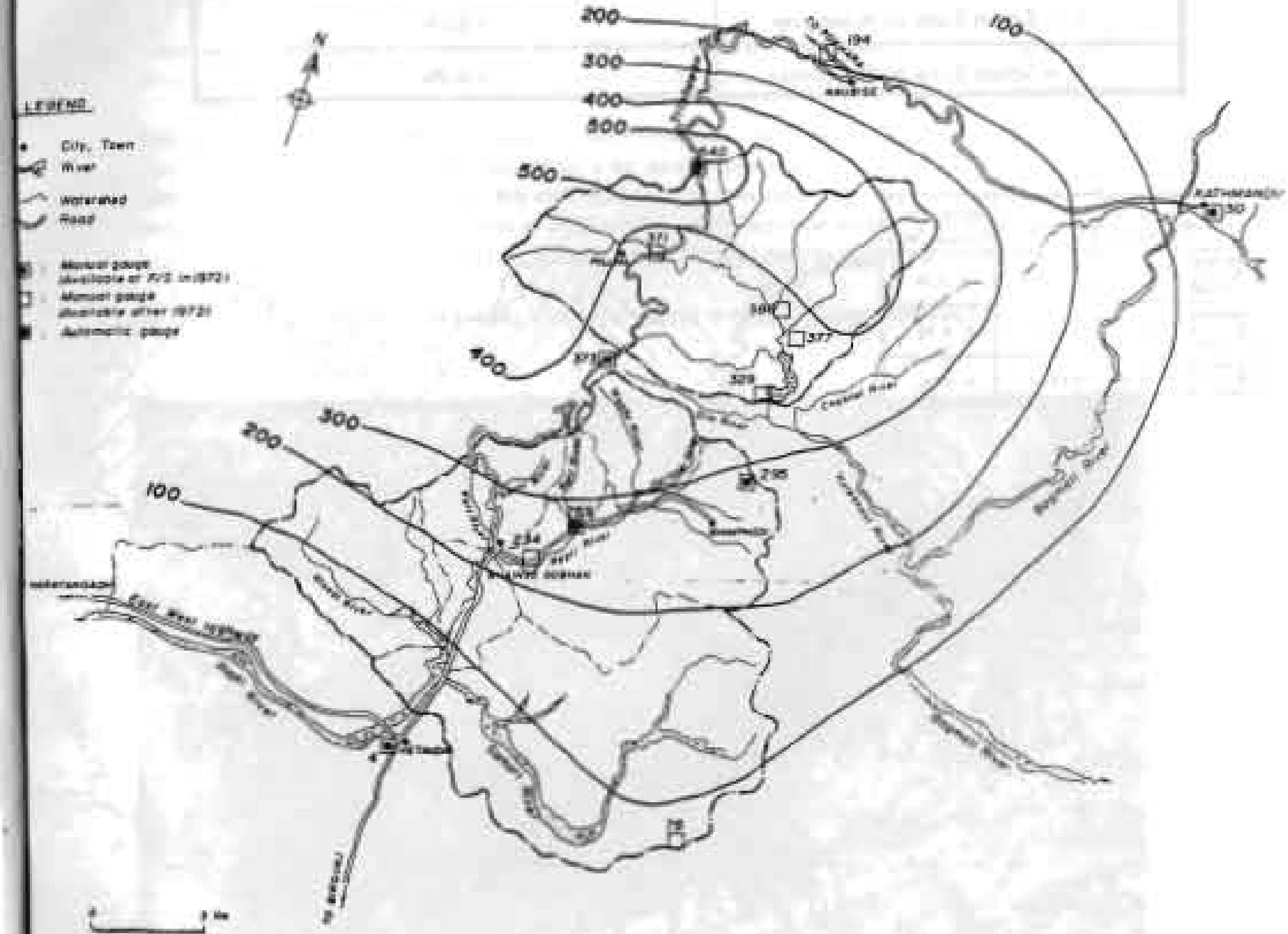


Figure 2. Nepal isohyetal map of 1-day rainfall July 19, 1993.

2.3. Sediment Sources Within Kulekhani Watershed

A geological map of the watershed, shown in Figure 3, indicates that the southern portion of the watershed is composed of Palung Granite while the northern part is predominantly schist. From reconnaissance and study of air photos taken after the flood it was evident that a large number of landslides occurred. In fact, the following table gives an estimate of the landslide surface area ratio to the catchment area for three basic geologic formations:

Zone	*Area Ratio* = $\frac{\textit{landslide area}}{\textit{catchment area}}$
G = Granite Zone	= 9.2 %
S_1 = Schist Zone on West side	= 5.9%
S_2 = Schist Zone on East side	= 4.0%

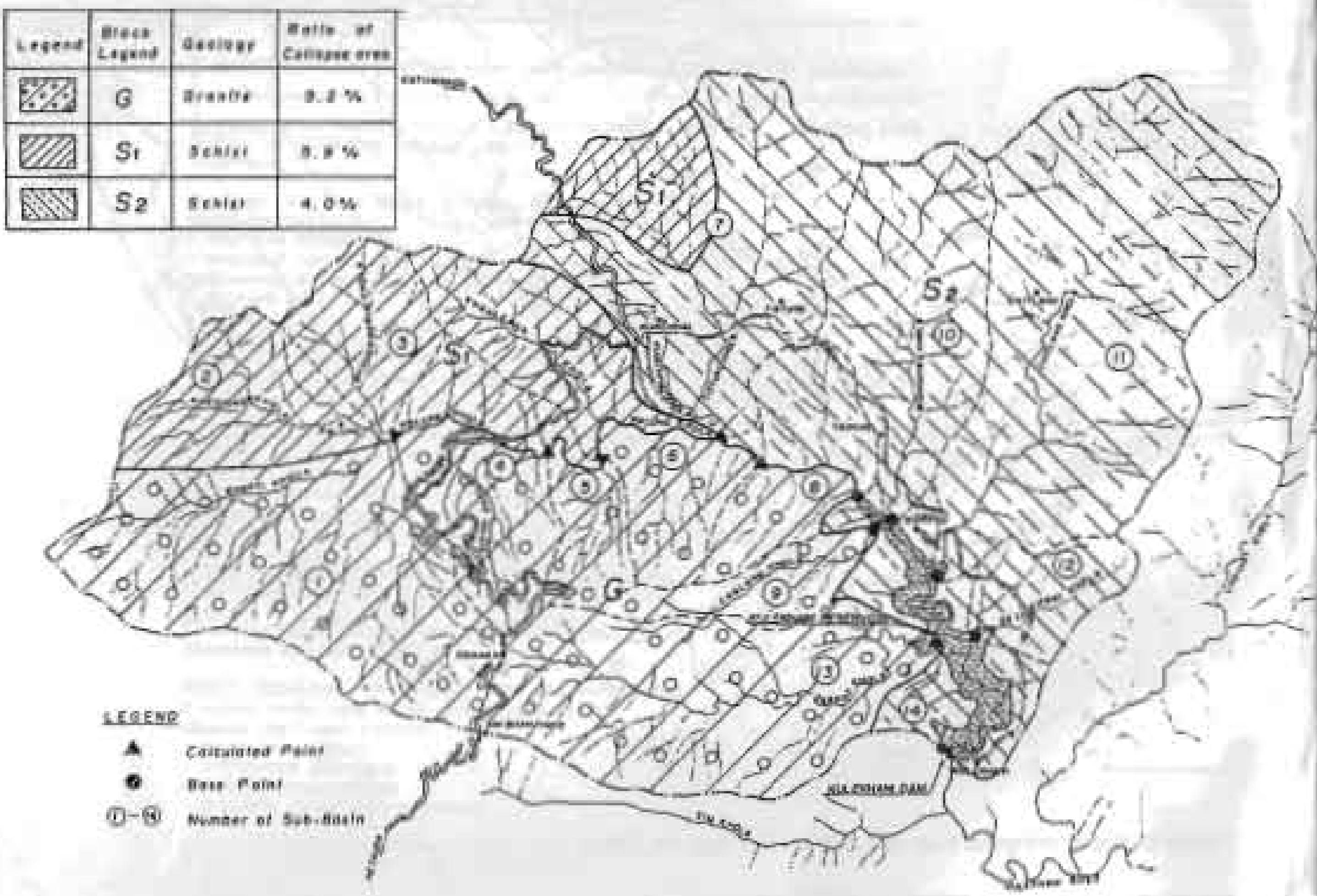


Figure 3. Location map showing density of landslides (collapses) and geology of Kulekhani Watershed.

In assessing landslides in more detail, the following characteristics were noted:

1) landslides generally occurred within the 300 mm/day rainfall isohyet indicating a "threshold" for the occurrence of extensive landsliding (Figure 4);

2) some slides deposited a large portion of their material on downstream alluvial fans and only the finer material moved further down the system as shown in Figure 5 for the Phedigaon Khola;

3) other landslides slumped directly into the main stem and the material was rapidly moved down the system;

4) some major landslides had much of their slumped material held in place by roads and gully check structures resulting in low sediment delivery to the mainstem; and

5) downstream from the first three tributaries: the Phedigaon, the Gharti and the Bhangkhora Kholas, the mainstem formed a large, wide deposition area and it appears that a large portion of the generated sediment dropped out in this reach - the sediment delivery was relatively low. From an assessment of the longitudinal slope profile, the reaches of relatively flat mainstem river slopes constitute deposition zones and sediment delivery ratios would vary along the profile and also probably with time.

Based on these characteristics, two approaches were used to compute sediment yield.

Figure 4. Watershed just south of Kulekhani Watershed. Many landslides have developed inside of the 300 mm/day rainfall isohyet (Aerial Photo - December, 1993).

Figure 5. Phedigaon Khola and Gharti Khola. The Phedigaon Khola is at the right of the photo and shows extensive alluvial fan deposits of schist while the Gharti Khola on the left shows remnants of large granite boulders (September, 1993).

2.4. Computation of Sediment Yield

Sediment yield research indicates that a significant portion of eroded sediment drops out prior to reaching the conveying main river of a watershed and "sediment delivery ratios" have been developed based on catchment area. However, most of the data used to derive this ratio was from middle and Western USA which would not be representative of the Middle Mountains of Nepal. Therefore, another relationship from Japan was used, namely the Kaki formula:

Sediment Yield, $Y = a \times E$

Where: Y = sediment yield in m^3

E = landslide eroded volume in m^3

a = sediment discharge ratio

$$a = \frac{(\text{river slope, } S)^{0.4}}{(\text{catchment area } A, \text{ km}^2)^{0.2}} \quad \text{where } A >= 1.0 \text{ km}^2\text{, and}$$

$$a = \frac{S^{0.4}}{A^{0.3}} \quad \text{where } A <= 1.0 \text{ km}^2$$

The above relationship was used in combination with estimates of landslide erosion volumes to arrive at a landslide sediment yield = 4.84 million m^3. The total sediment yield, which also includes river bank and bed erosion was estimated to be 5.85 million m^3 by the above method. Detailed tables for each watershed are shown in Nippon Koei Co. Ltd. (1994).

A second method based on detailed field assessment of sediment movement was also used as a check on the first technique. This second method estimated the percent sediment passing in the following manner:

Step 1	Step 2	Step 3		
% passing out of slump	X % passing out of tributary	X % passing out of mainstem	=	Sediment Delivery Factor

The above method starts with the volume of material involved in a landslide slump and estimates the percent that passes out of that slump. Using the landslide volumes measured in the field, the landslide component of sediment yield came to 5.54 million m^3. This is slightly higher than the 4.84 million m^3 computed by the first method but this second method is thought to be more applicable to Nepalese mountain conditions. More extensive research is essential to develop this "routing" of landslide volumes, but much of this research involves direct field measurements which will also result in a more thorough understanding of processes. To complete the second method an estimate of 0.10 million m^3 was made for bank erosion,) 0.55 million m^3 for bed erosion in first and second order tributaries only, and 0.25 million m^3 for sheet and rill erosion for a total sediment yield of 6.44 million m^3 entering the reservoir. The two techniques are compared to the sediment yield as determined from the reservoir surveys:

Technique	Sediment Yield	
	million m^3	million tonnes
1. Kaki formula	5.85	-
2. Sediment routing	6.44	-
3. Reservoir survey	4.00	6.40

The two techniques used to measure sediment yield are relatively close, but the yield of 4.00 million m^3 should be used since this value was obtained by direct measurement of the material deposited within the reservoir. The unit sediment yield then works out to be:

$$\frac{4{,}000{,}000}{126} = \underline{31{,}746}\ m^3/km^2/flood$$

From reservoir surveys, the sediment yield was computed as follows:

Sediment Yield From Kulekhani Watershed
(from reservoir surveys)

	Total over 12 years (in reservoir)	Total Yield (Upstream)	Annual Yield-Upstream	Unit Annual Yield
	(million m^3)	(million m^3)	(m^3/yr)	(m^3/yr/km^2)
1993 (pre-flood March)	2.2	1.8	150,000	1,200
	Flood Yield (in reservoir)	Flood Yield (Upstream)	Assume	(Unit Flood Yield)
1993 (post-flood Dec.)	4.8	4.0	4.0 million m^3	31,700

From the above table, it is apparent that unit sediment yields vary greatly and that major rainstorms have a devastating effect on the watershed.

Another approach to assess sediment yield is to utilize data from other rivers in the Himalaya such as shown in Figure 6. The Kulekhani data, converted to tonnes per year, ranges from 240,000 to 6.4 million tonnes per year and is plotted on Figure 6. The low value, prior to the flood, plots with the lowest values for other rivers, but the high yield for the single event plots higher than any other rivers. The main reason for this excessively high yield could be the fact that the event can be described as a debris flood which is somewhat rare. The return period of the event has been estimated to be 100 years or more (SMEC, 1994). Also, the data for other rivers probably has been averaged over a number of years resulting in a significant lowering of yield estimates due to rather dry years. If one averages the 13 years of record, the yield value becomes 658,000 tonnes/year or 5.350 tonnes/km^2/yr (3,340 m^3/km^2/yr.). This average value now plots near the highest values for other rivers. However, this technique of averaging one high value with 12 rather low values does not give a representative future yield.

3. SEDIMENT PROCESS IN THE KULEKHANI RESERVOIR

Fortunately, the Department of Soil Conservation - HMG Nepal conducted a survey of the Kulekhani reservoir just prior to the July 1993 flood and with a re-survey in December 1993, it is possible to assess the sedimentation process and the amount of deposit within the dead storage and live storage zones (Dept. of Soil Conservation, 1994). The location of the reservoir cross-sections is shown in Figure 7 and the longitudinal deposition profile is shown in Figure 8.

The March 1993 survey indicates that the entire length of the reservoir had undergone deposition with a distinct delta located 6 to 7 km above the dam. The largest volume of sediment, however, was probably in the first 1.5 km, near the dam, since the reservoir is widest through this lower reach (see Dept. Soil Conserv., March 1994 for cross-sections).

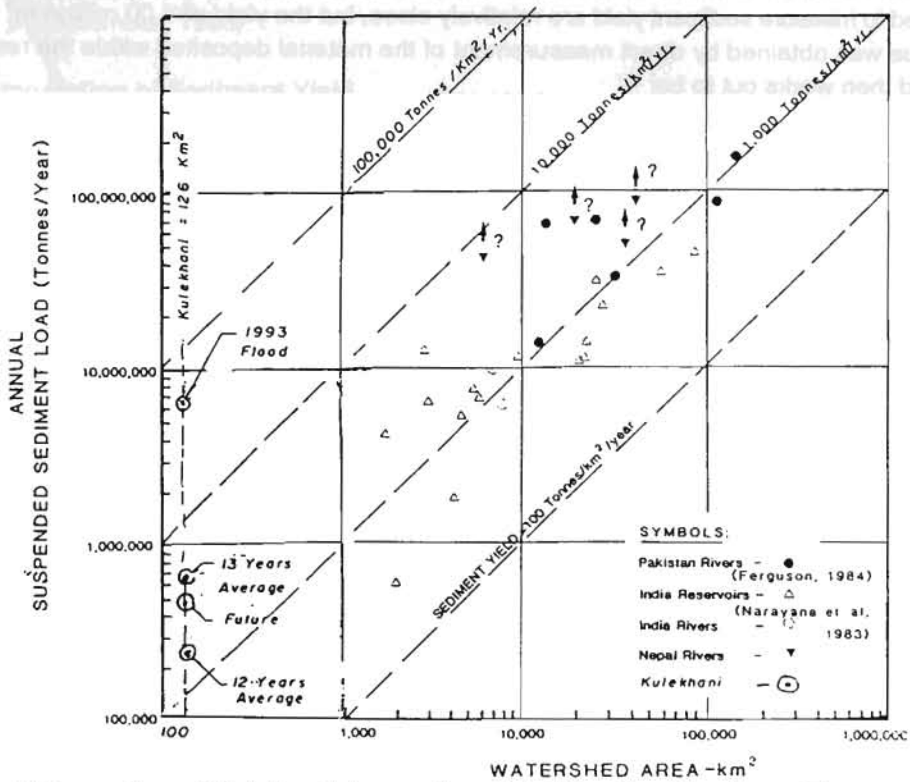


Figure 6. Comparison of Kulekhani river sediment yield to other Himalayan Rivers.

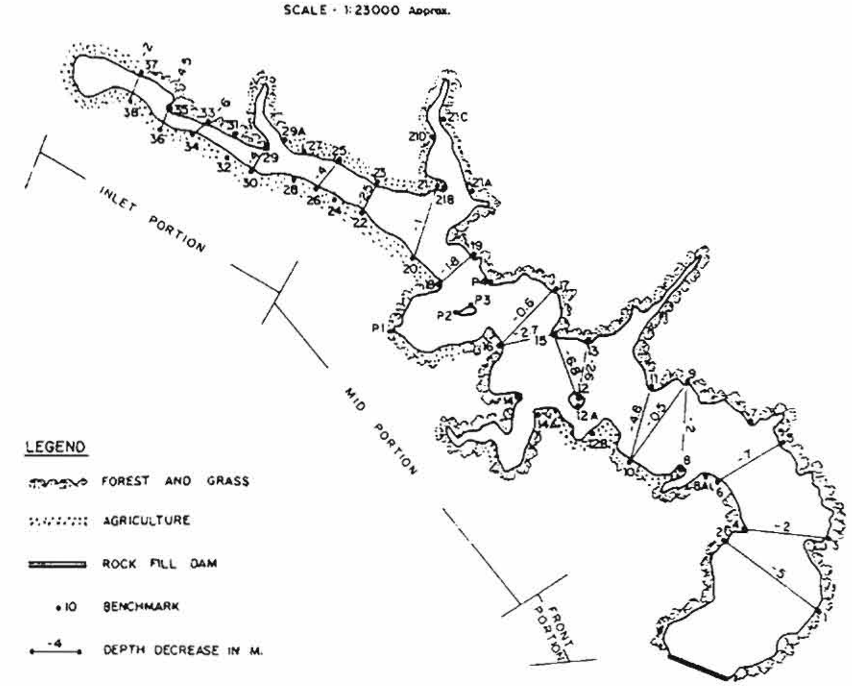
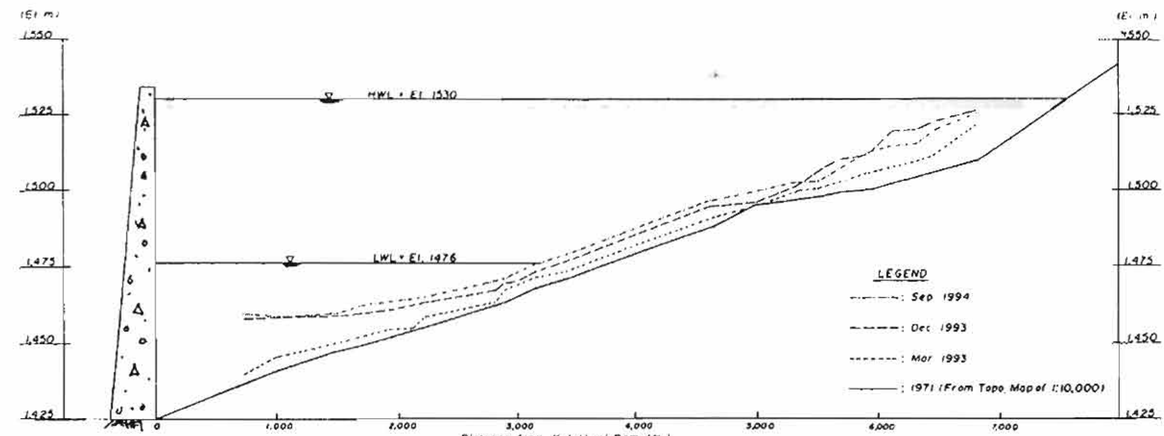


Figure 7. Kulekhani reservoir.



Survey Line	Riverbed Elevation Sep 1994 (El m)	Riverbed Elevation Dec. 1993 (El. m)	Riverbed Elevation Mar. 1993 (El. m)	Riverbed Elevation 1971 (El. m)
1 - 2	1459.3	1457.9	1439.8	1436.5
3 - 4	1458.5	1458.2	1445.1	1440.5
5 - 6	1459.8	1458.8	1450.0	1447.5
7 - 6	1462.0	1459.5	—	1449.0
9 - 8	1463.8	1460.7	1454.5	1451.5
9 - 10	1464.3	1462.3	1454.8	1454.0
11 - 10	1465.0	1463.2	1458.3	1455.0
12 - 13	1470.8	1467.5	1463.4	1462.5
12 - 15	1471.2	1469.7	1467.2	1463.5
13 - 14	1473.1	1470.5	—	1465.5
16 - 15	1475.7	1473.3	1471.6	1460.0
17 - 16	1478.9	1476.5	1473.6	1471.0
18 - 19	1496.3	1494.3	1490.40	1487.5
20 - 21	1499.7	1495.4	1494.5	1495.0
22 - 23	1502.5	1501.0	1499.2	1497.0
24 - 25	1503.0	1506.0	1500.5	1497.8
28 - 27	1506.4	1509.7	—	1499.0
30 - 29	1512.6	1511.6	1505.6	1500.0
31 - 32	1514.7	1519.5	—	1502.5
34 - 33	1515.8	1520.0	1509.7	1504.5
36 - 35	1519.5	1522.5	1511.2	1505.5
38 - 37	1525.2	1526.0	1521.4	1509.5

Figure 8. Trend of sediment deposition in the Kulekhani reservoir.

During the monsoon flood of 1993, the surveys indicate that most of the deposition took place in the dead zone with a bed rise of about 18 m at cross-section 1-2. Also, a distinct coarse-material delta was formed at the upstream end with its pivot point located at cross-section 31-32 (6.2 km from the dam) and the rise in average riverbed level was about 12 m as shown in the longitudinal profile (Figure 8). From computations using the end-area of the deposition and distance between representative cross-sections it was determined that about 4.8 million m^3 of sedimentation had occurred in the reservoir during the 1993 Monsoon. Further, from examination of the deposition profile it appears that the coarse material extends to about cross-section 9-10 (1.9 km upstream from dam) and that fine material has accumulated along the lower portion of the reservoir. The volume of fine material was estimated to be 2.9 million m^3 with the remaining 1.9 million m^3 made up of coarse material. The reduction of water storage within the dead zone and live zone of the reservoir were estimated to be as follows:

Storage in Kulekhani Reservoir

Year	Dead Zone Volume (million m^3)	Live Zone (million m^3)	Total Storage (million m^3)
1981	12.0	73.3	85.3
1993 (Mar.)	10.8	72.3	83.1
1993 (Dec.)	7.6	70.7	78.3

The lost storage was estimated from the reservoir storage curve and from the approximate bed profile in 1981 as obtained from the topographic map. The procedure gives approximate values of sediment volume in the reservoir until December, 1993.

Also, during the monsoon of 1993, there were two major floods with the largest being on July 20 (Q peak = 1,340 m^3/s) and the other one on August 10 (Qp=756 m^3/s) and both of these contributed to the sedimentation of reservoir. However, because the August rainfall lasted only 4 hours and because the deposition would be partly upstream from the December 1993 survey it was assumed that the 4.8 million m^3 of sedimentation could be attributed to the July 20, 1993 flood.

From surveys of the delta in June, 1994 and from field reconnaissance in September, 1994, it became apparent that head cutting had occurred and possibly 0.7 Mm^3 of delta coarse material and fine material has been added to the dead storage. The delta is composed primarily of sand overtopped by coarser gravel and cobbles as shown in Figure 9. The finer delta deposits move far into the reservoir while the gravel and cobbles stay at the upstream end as shown in Figure 10. There is concern as to when sediment will start to be drawn into the power intake which has an invert level of 1471 m.

4. RESEARCH TOPICS

After assessing the watershed and the flood event, a number of questions remain in regard to prediction of sediment yield for other watersheds.

a) Is the 300 mm/day "threshold" for extensive landslides transferable to other geologic zones?

b) What is a reasonable aerial extent for a rainstorm having a rainfall intensity of 300 mm/day?

c) Because the base of most landslides are along tributaries or mainstems of rivers, should not the sediment yield of landslides be related to stream order or stream length as opposed to catchment area?

Figure 9. Kulekhani Reservoir Delta. Headcutting of sand and gravel deposit during low stages of the reservoir. The deposits are primarily sand with gravel lenses near the top (June, 1994).

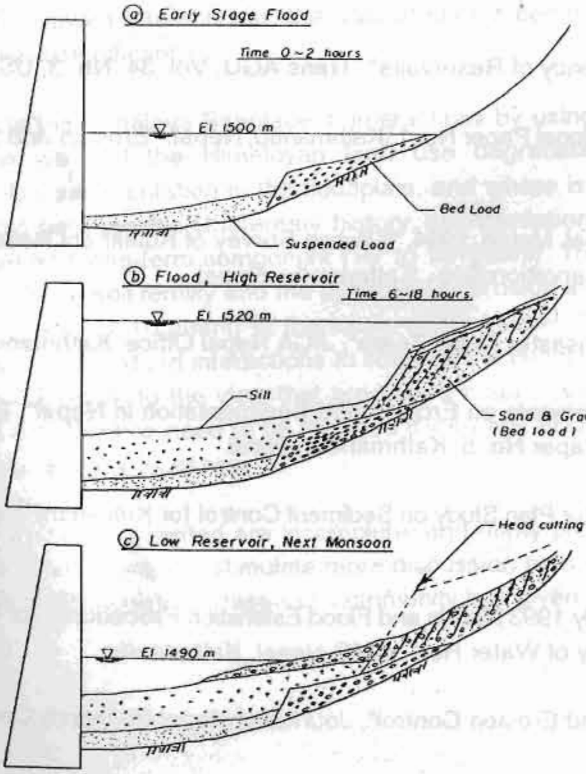


Figure 10. General concept of reservoir sedimentation.

d) How can large sediment particles be treated in terms of sediment routing when some of the particles are breaking up and wearing down in a downstream direction?

e) How does sediment yield decline with time after a massive amount of erosion is generated during a major storm?

There are certainly more questions that need to be answered in regard to managing sediment, but basically the state of knowledge is somewhat limited - how can we manage sediment processes if we don't know the magnitude nor the frequencies of sediment producing events? Meaningful data is gathered only after massive destruction or as part of a major project but this is inadequate.

5. CONCLUSIONS

The major rainstorm of July 19, 20, 1993 generated many landslides in the Kulekhani watershed which resulted in 4.8 million m^3 of sedimentation within the Kulekhani I reservoir. The majority of sediment, 83 percent, was generated from landslides which were much more frequent within the 300 mm/day rainfall isohyet. An analysis of watershed hazards and sediment routing generated a sediment yield that was somewhat higher than the actual yield as measured from reservoir deposition and this amounted to 4.0 million m^3.

The project sediment yield estimate was much lower than occurred during the 1993 flood but there are few techniques by which designers can predict sediment yields for extreme events. From this large documented event it can be conclusively stated that estimating future sediment yield on a catchment area basis, such as 700 m^3/km^2/year is inappropriate - the model is wrong - landslides occur along linear tributaries and new research is required to estimate yields from debris torrents.

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Sediments and Soils in the Floodplain of Bangladesh: Looking up to the Himalayas?

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1. INTRODUCTION

The 120 million people living in Bangladesh occupy one of the world's largest delta complex which is affected every year by floods, riverbank erosion and sediment accumulation. Are these floods and sedimentation processes influenced by land use changes, deforestation and human misbehaviour in the middle mountains of the Himalayas, as it is widely suggested by Upreti (1993)?

Water, erosion and accumulation of sediments from the Ganges, Brahmaputra and Meghna rivers largely dominate life in Bangladesh. Twenty percent of the country or 2/3 of the arable land are under water every year during a normal monsoon season (ISPAN, 1993). The flood of the century submerged 58% of Bangladesh in 1988, and 2000 people died. One million people are affected by riverbank erosion every year (Rana, 1993). The annual average discharge of all rivers into the Bay of Bengal is 35,000 $m^3 s^{-1}$ of water (ISPAN, 1993), and 2 billion t yr^{-1} of sediments are deposited in the delta each year (Rana 1993, ISPAN, 1993).

The disastrous effect of floods and river sedimentation in Bangladesh is often attributed to a direct highland-lowland interaction. The human intervention in the Himalayas was often blamed as playing the major role. However, this view contrasts with the scale-concept of Ives and Messerli (1989, Figure 1). They argued that, at the micro-scale, human impact can be dominant, but at the macro-scale of highland-lowland interactions (Himalaya-Floodplain interactions), the natural impact becomes the dominant force and the human fingerprint becomes insignificant.

In this article, we illustrate the Himalaya-Bangladesh interactions by using the example of sediments and sediment transport. Can we find the Himalayan land use degradation signal in the floodplain of Bangladesh? What controls sedimentation in the floodplain, and where is the material coming from? First we look at the relationship between the Quaternary history, sedimentation and soils in Bangladesh, which represents the large-scale and long-term component (10^2 to 10^4 years). Then we will give two examples on the effects of sedimentation on soil fertility and the dynamics of erosion and accumulation processes. This represents the short-term view (1-10 years) at the local-regional scale. Finally, we try to put the findings into the context of the highland-lowland interactions to contrast the impact of natural versus anthropogenic processes. We hope to contribute to the view that processes need to be examined at different scales in time and space, and all complexities need to be included if we hope to gain a better understanding of the 'real' highland-lowland interaction processes.

We fully confess that the views presented are incomplete, and many processes are not well understood. We see this contribution as an attempt to stimulate more discussion on a very complex problem which has wide ranging implications and to which the research community has given insufficient attention.

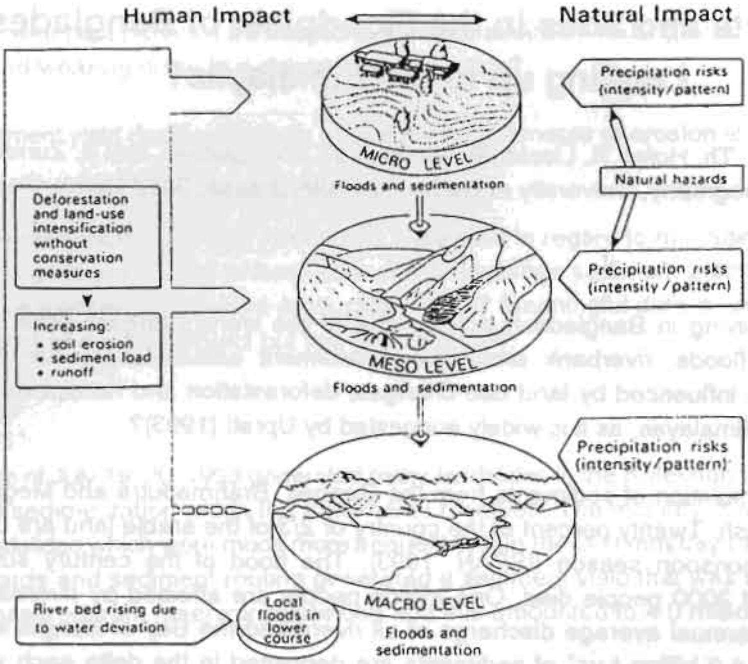

Figure 1. Schematic representation of the relationship between human and natural processes at three different scales (Ives, 1989).

2. Late Quaternary History, Sedimentation and Soils in Bangladesh: the Long-Term Effects.

The delicate equilibrium between erosion and accumulation in the delta is mainly controlled by the level of the erosion baseline, which is the sea level in the Bay of Bengal. The global sea level changes and evolution of the delta complex during late Quaternary times is shown in Figure 2.

The sea level was 120 m lower 18,000 years BP ago than today. Regional differences of ±5 m are due to tectonic movement. The steeper topographic gradients in the river beds gave rise to large-scale erosion and dissection of the delta. When the sea level rose during the early Holocene (9000 - 8000 yr BP), most of Bangladesh was under water, and the coastline was at the Rajmahal hills in the Assam Province of India (Rana, 1993). A new delta complex accumulated, particularly during the mid-Holocene, when the ocean reached the current water level, at about 5000 yr BP. Some compartments of the delta (e.g. the Madhupur terrace) were lifted up and taken out of the active accumulation zone due to Holocene tectonic activity (Rana 1993; MPO, 1995). The deposition of young sediments continued in the area of the current river courses all through the late Holocene period and up until today.

We conclude that the interaction between global climate and sea level changes, regional tectonic movement and local topography dominate the pattern of sediment accumulation in the floodplain over time. It further implies that the landscape and the soils in the entire delta started with exactly the same substrate in terms of geology and mineralogy as today. According to the different ages of the various delta compartments, we find different stages of weathering, soil development and fertility levels in the soils. This in turn has wide implications on the cropping pattern and the productivity of land. Table 1 shows a comparison between an early Holocene-late Pleistocene (MPO, 1985) red soil in the Madhupur tract and a late Holocene floodplain soil in the Ganges/Brahmaputra area.

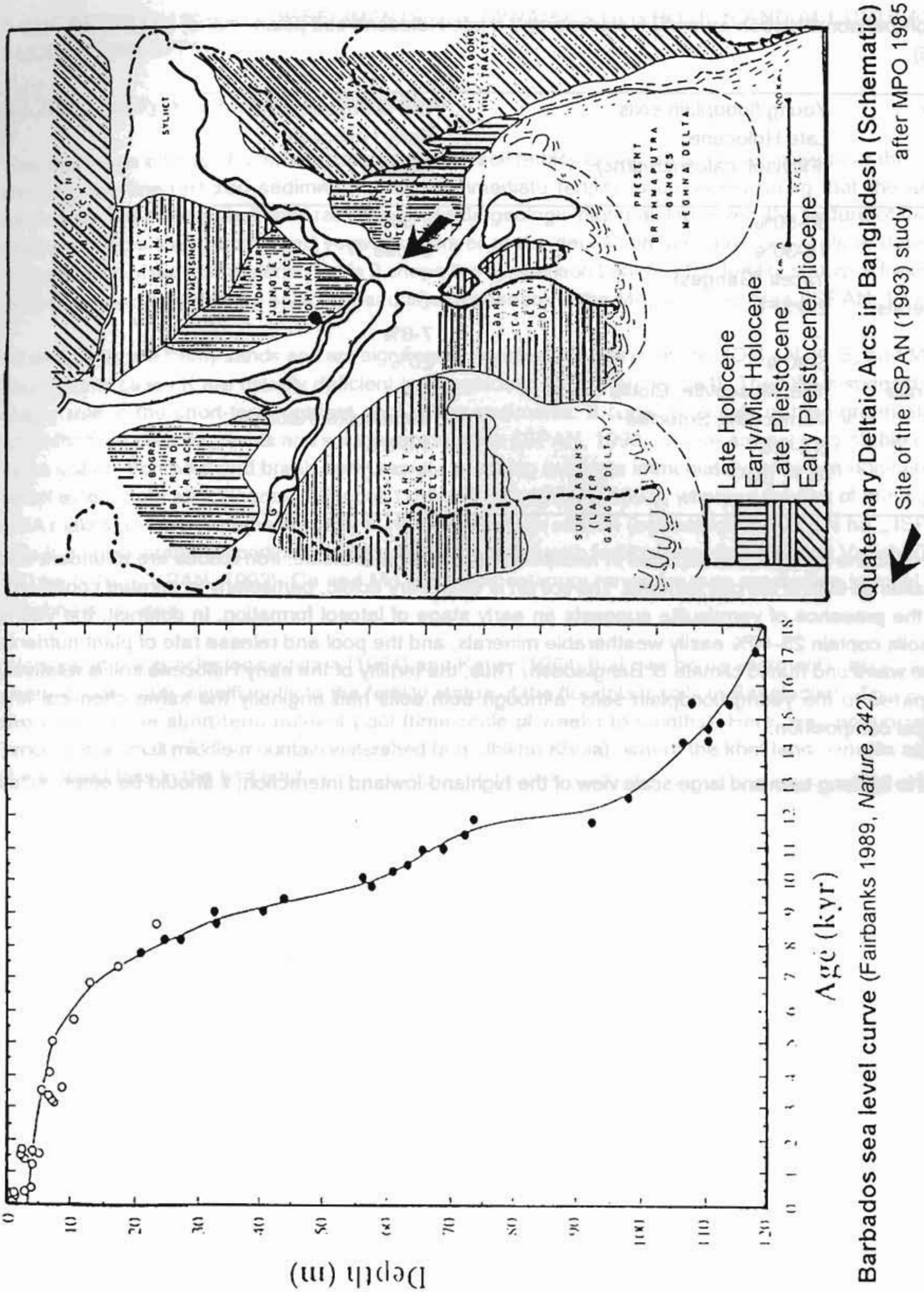

Figure 2. Barbados sea level curve and quaternary delta arcs in Bangladesh.

Table 1. Comparison between an early Holocene and a late Holocene soil (Islam, 1964; UNDP/FAO, 1971; MOP, 1985).

Mineralogy	Young floodplain soils Late Holocene (Fluvisol, calcaric/eutric)	Old floodplain soils Early Holocene Latosol
Quartz	30-50%	< 30%
Feldspars	15-30%	traces
Carbonate	traces (Ganges)	-
Heavy minerals	2-9%Fe	-
Fe-oxides	-	7-8%
Micas	5-30%	20%
Clay -Minerals	Illite, Muscovite, Biotite Vermiculite, Smectite	Illite Vermiculite, Kaolinite
pH	5.5-8.5	4.6-6.5
deficiency	N, P, (K)	N, P, K

The early Holocene latosols are depleted in feldspars, muscovite and biotite; iron oxides are abundant and Kaolinite makes up 60% of the clay minerals. The soil pH is often very acidic, particularly in aerated conditions. However, the presence of vermiculite suggests an early stage of latosol formation. In contrast, the young floodplain soils contain 25-40% easily weatherable minerals, and the pool and release rate of plant nutrients is high in the warm and humid climate of Bangladesh. Thus, the fertility of the early Holocene soil is relatively poor compared to the young floodplain soils, although both soils had originally the same chemical and mineralogical composition.

With regard to the long-term and large-scale view of the highland-lowland interaction, it should be emphasized that a constant supply of sediments is transported into the floodplain (estimated time-scale in the order of 10^2 to 10^3 yr). We find young, fertile fluvisols that are not in equilibrium with the warm/humid tropical climate in Bangladesh instead of the expected low-fertility latosols. This is one important and beneficial aspect in the discussion of floods and sedimentation. Yet the immediate fertilizing effect of the young sediments has to be documented. Furthermore, the riverborne sediments consist of materials that originate both from geological processes like landslides (e.g. feldspars, micas and olivine) and pedogenesis (e.g. smectites and organic matter). However, it is difficult to identify the source of these materials (highland versus lowland). Are the deposits eroded sediments from the floodplain itself?

In summary, the sedimentation in the floodplain plays an important role in fertility, and crop production seems to be dominated by a combination of natural processes on the global (sea level changes) and regional scales (tectonic movement). Human impact seems to be insignificant at this level of scale. These conclusions support the hypothesis by Ives and Messerli (1989) which suggests that the long-term and large-scale processes dominate the sediment processes in the delta. However, we have to oppose the above mentioned long-term view to the short-term dynamics of sedimentation and accumulation in order to get a more comprehensive view of the processes during the last decades.

3. THE FERTILITY STATUS OF SEDIMENTS, THE DYNAMICS OF EROSION AND ACCUMULATION: THE SHORT TERM EFFECTS

3.1. The Quality of the Sediment Deposition

The short-term effects of riverborne sediments on soil fertility is best seen immediately after their deposition. Usually, the fine-textured sediments provide immediate fertility to crops indicating that the accumulated sediments are transported soils rather than sterile geologic material. However, the texture of the deposited material, micro-topography, and vegetation cover at the deposition site play a key role in determining the nutrient value of the new material. Table 2 shows the comparison between the fertility status of fresh riverborne sediments and surrounding soils (pre and after monsoon) in the Meghna river area (ISPAN, 1993).

All sediments are loamy sands and are significantly enriched in organic matter (OM), N, K, S, and Mn. Nitrogen and in some cases K are usually deficient in Bangladesh soils (Karim, 1964). The OM is suggested to play a major role in the short-term nutrient pool of the sediments. It consists mainly of blue-green algae (BGA), allochthonous plant fragments and soluble amino acids (ISPAN, 1993). These are not very stable components in the soil environment and break down rapidly releasing nutrients immediately. Nitrogen originates only to a small extent from allochthonous sources (150 g N ha^{-1}, ISPAN, 1993), whereas fixation of atmospheric N by BGA makes up the bulk of the N supply during the monsoon season (estimated 16-20 kg N ha^{-1}, ISPAN, 1993) This is a considerable proportion of what is usually applied with fertilizer for High Yielding Variety (HYV) crops (60 kg N ha^{-1}, ISPAN, 1993). Ca and Mg are in the optimum range for crop production in most soils in the Meghna river area.

We support the conclusion by Islam (1964) and Karim (1964) that riverborne sediments, especially their OM content, contribute significantly to the fertility status of the floodplain soils in Bangladesh. This is particularly the case for the short-term nutrient pool (time-scale of weeks to months). Here, we see similarities to the process in a small middle-mountain watershed (e.g. Jhikhu Khola), where the khet land benefits annually from the nutrient loss in the bari land.

Table 2. Fertility status of fresh riverborne sediments compared to the residual soil premonsoon and surrounding soil after one cropping season (ISPAN, 1993).

	Premonsoon	Sediments	Postmonsoon
OM [%]	3	5.1	2.6
pH	5.6	6.3	5.3
N [μg/g]	23	193.8	18.4
Ca [meq/100g]	10.3	12	11
Mg [meq/100g]	4.4	4.5	2.3
K [meq/100g]	0.18	0.44	0.21
P [μg/g]	17.1	19.8	23.6
S [μg/g]	31.1	156.8	51.7
B [μg/g]	0.4	1.0	0.8
Fe/ [μg/g]	616	706	838
Cu [μg/g]	10.9	6.1	4.5
Mn [μg/g]	78.4	427.3	50.2
Zn [μg/g]	3.5	3.8	4.3

This is, in fact, conventional wisdom which unfortunately is not sufficiently recognized and more documentation of this process is needed when discussing flood protection and construction of embankments. The effect of such action on the sustainability of soil fertility for crop production needs to be given more attention. However, the current demand for plant nutrients is dramatically increasing due to land use changes, induced by triple cropping patterns and cultivation of HYV crops. The high nutrient demand by these crops and rotation systems overrides the natural fertilizing effect of the sediments, and high amounts of fertilizers are required to sustain productivity of the soils.

3.2. Erosion and Accumulation in the Floodplain: Where do the Sediments Come From?

The origin of the sediments is a major question in the debate of highland-lowland interactions in the Himalayas. Does soil erosion in the Himalayan Middle Mountains contribute to soil fertility in Bangladesh?

Changes in the floodplain river courses can give an idea about the dynamics of erosion and accumulation of sediments in the floodplain itself. Figure 3 shows a section in the Brahmaputra (Jamuna) area with the riverbed 1973 and 1993 as it was mapped based on LANDSAT images.

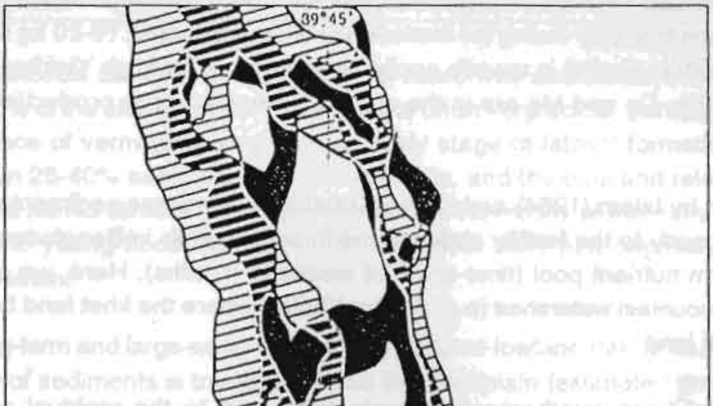

Figure 3. Riverbed of the Brahmaputra/Jamuna 1973 and 1993.

The comparison indicates that the Jamuna river has been displaced by some 60 m / yr^{-1} during the last 30 years. In some places, a displacement of 800 m yr^{-1} is common (Wahed, 1993; Rana, 1993). Such massive year-by-year river erosion and mobilization of sediments in the floodplain itself suggests that the suspended material in the river likely originates from locally or regionally transported soil, rather than material directly transported from the mountains. Here, it is important to note that this view refers to the short-tern dynamics of the system. In the long-term, however, all the material ultimately originates from the Himalayas, but the transportation rate, the distances of and time requirements for transport, and the origin of the material is widely unknown.

4. CONCLUSIONS

The deposition of young sediments in the floodplain of Bangladesh is extremely important with regard to the short-term and the long-term nutrient pool of the soils. A similar observation was made in the small watershed of the Jhikhu Khola, pointing out that some of the highland-lowland processes are comparable regardless of the scale of the landscape under consideration.

Ultimately, the sediments originate from the Himalayas. However, looking at the short- to medium-term process of erosion-accumulation in the floodplain itself, the regional transport of sediments is likely dominating. Sediment transport in the floodplain is mainly controlled by natural factors at different temporal and spatial scales, while the Quaternary history and sea level changes act at the global scale, and tectonic movement at the regional scale. Human impact on the macro level seems to be considerably less important than the natural processes. There is a fundamental difference in these processes at the micro-level of the Jhikhu Khola where the human influence is likely dominating. We support the view by Ives and Messerli (1989) that the relationship between human and natural impacts on processes changes with the different scales under consideration.

We learned from the Jhikhu Khola watershed that the micro-scale response to human impact is sensitive. From the Bangladesh floodplain, we learned how nature controls the large-scale processes in the highland-lowland interaction. However, we are at present unable to understand the link between these opposing positions. There is an urgent need to connect both scales and in our opinions, an understanding of the meso-level processes is the only way to address this complex question. As long as we do not understand the transfer functions from the micro- to the meso- and to the macro level, we are not able to comment on the highland-lowland interactions. Until such research results are available, many questions relating to the 'Himalayan Dilemma' remain unanswered.

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Are Small Hydels an Answer to Eliminate Deforestation? Some Ideas from an Impact Monitoring of a Small Hydel in Salleri, Solu Khumbu

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1. INTRODUCTION

Rural electrification by small hydropower plants is seen as one important step towards development in rural areas and therefore evokes many expectations. Local people as well as Governments wish and expect that electricity will reduce unemployment, outmigration, modernize their standard of living and reduce the pressure on resources, particularly by reducing forest degradation (Aitken, 1991). Expectations are high, but little research has been carried out to study the real impacts of electrification and the acceptance of electricity by the people. In this context, SDC (Swiss Development Cooperation) set up an impact monitoring program in the Salleri Utilization Project in the Solu Khumbu area of Nepal, to evaluate the impacts of a small hydel on the society, economy, and environment. In this paper findings from an 1992 impact investigation (Ott, 1993) are presented. Special emphasis is placed on the environmental aspect of small hydels and especially on the question whether small hydels could eliminate deforestation.

2. SALLERI ELECTRICITY UTILIZATION PROJECT

The Salleri Utilization Project (SELUP) was initiated by the SDC (Swiss Development Cooperation) in cooperation with HMG (His Majesty's Government). It is situated near the Salleri Village Development Community, in Solu Khumbu, eastern Nepal. Besides the electrification of the district capital, a key factor for the location of the small hydel was the wool dying factory in Chialsa, a Tibetan refugee camp, which was to be electrified. The power plant is a classic run-of-the-river scheme, using water from the Solu Khola river. Its capacity amounts to a total of 400 kW (ITECO, 1992).

The whole supply area covers about 60 km^2 in the Solu Khola Valley and is comprised of 20 settlements, including the rapidly growing district capital, with a total of about 6,000 - 7,000 inhabitants (Figure 1). Up to 1992, when the study was conducted, some 400 houses had been electrified. Today, 8 years after initiation of the small hydropower plant, about 700 houses are supplied with the new form of energy. With an elevation range of 2,000 - 2,800 m, the project area lies in the temperate zone with severe winters and humid summers. The name of Salleri (salla means 'pine' in Nepali) refers to the composition of the natural vegetation and the previously abundant forest. It appears that the major decrease in forest land was associated with the development of Salleri and the resulting demands for firewood and timber around 30 - 40 years ago. The forests above the traditional Sherpa settlements were less affected by this demand, and the current revegetation status is reasonably good. Extensively forested slopes can still be found in the northern part of the valley, but overall the firewood supply situation is not as critical as in many other areas of Nepal, such as that found in the Jhikhu Khola watershed. Since the founding of the district capital in 1961, rapid changes have also been taking place in the community. A constantly growing government staff, who are totally dependent on market supplies and on the local infrastructure, has led to booming settlements and created a flourishing local market. These new income possibilities have attracted new immigrants, mainly from the south. Thus, the

economy of the region today is very dynamic and is not only based on agriculture but also on trade, handicrafts and temporary migration.

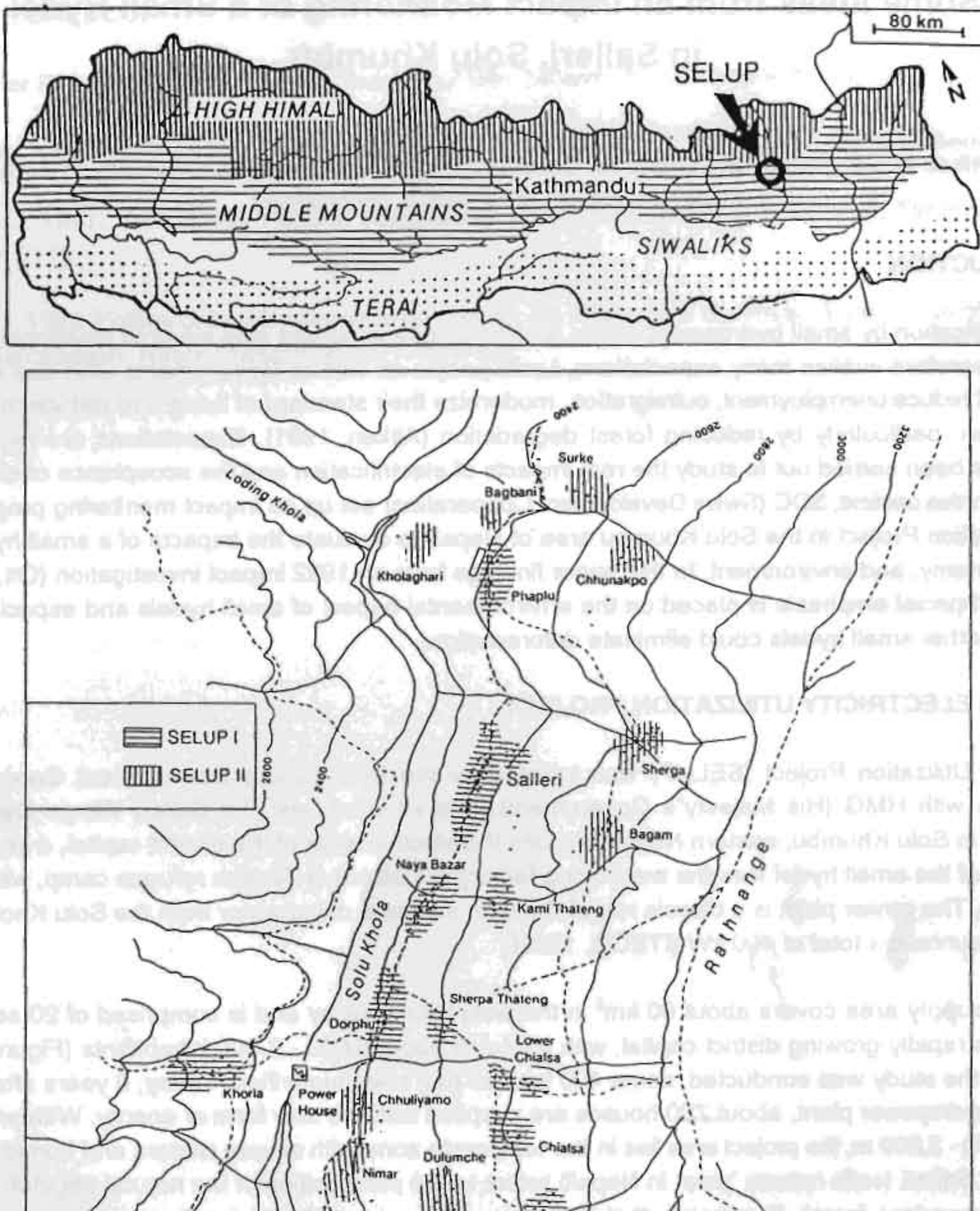

Figure 1. Location of the Salleri Electricity Utilization Project, in Solu Khumbu District, Nepal.

The business survey showed that the total number of businesses including teashops, shops, small cottage industry, etc. amounts to about 220 and the age breakdown of businesses in the most dynamic settlements of Salleri and Naya Bazar reveals that nearly 50% of them were only started in the last five years.

3. METHODOLOGY USED IN THE IMPACT MONITORING STUDY

The methodology combined quantitative as well as qualitative analysis and mapping. It allowed for constant cross-checking and provided a reliable data base for a time series analysis of an impact monitoring study to be carried out in the future. During the 2.5 months fieldwork a household survey was conducted and 250 house owners were interviewed to establish their socio-economic status in the community. Out of these families 83 were selected, based on a rough wealth ranking, for a detailed survey to determine their energy consumption patterns. Methodological difficulties arose when trying to evaluate the impacts of electrification on the environment, especially on forest resources. For quantitative ecological studies long-term investigations with detailed baseline studies are mandatory, but were not possible in the given time frame. Thus only indirectly surveyed and qualitative data was used to provide information on this topic.

3.1. Energy Consumption Pattern

Table 1 shows how electricity is used by the households. The percentage can be regarded as representative for the area electrified in 1992. Electricity for lighting was accepted by one hundred percent of the inhabitants, independent of wealth, ethnicity, occupation or age. About a third of the sampled households use the new energy for cooking purposes, but except for 4 families, electricity only partially takes the place of firewood. For example, the subsidized bijuli dekchi (a low 450-watt cooker) has been sold 70 times, but it can never totally replace cooking with fire, because frying is not possible with it. Heating as understood in a western context is not known traditionally in Solu. Fire is used for cooking and heating at the same time. Thus only 14% of the households interviewed light fires only for heating purposes. With the new energy source electrical heaters have been installed. In this case electricity promotes new needs that were not present earlier. The utilization of electricity by businesses is summarized in Table 2. Concentrating on the potential of firewood saving, we considered only some of the businesses such as the carpet factory, bakery, saunas, teashops and lodges. The great potential of using electricity for cooking in teashops is still not fully realized, because only 26% of all teashop owners use electricity for purposes other than lighting.

Table 1. Electricity consumption patterns by the households.

	Lighting		Cooking		Heating		Electrical Appliances	
	#	%	#	%	#	%	#	%
Firewood	2	2.2	86	95.6	12	13.3	-	-
Kerosene	0	0	0	0	0	0	-	-
Electricity	90	100	32	35.5	10	11.1	74	82.2

Setup I, 90 households

In this context it would be interesting to analyze the factors which could promote or impede the substitution of firewood with electricity. We found mainly two factors which have influenced the decision to use electricity for cooking (Figure 2): wealth and cash income, and the firewood situation. The combination of these two factors shows that there are people who would like to substitute firewood but could not afford the relatively high investment in appliances and the running costs. On the other hand there are relatively well off people who do not 'yet' consider changing their energy source.

Table 2. Utilization of electricity by businesses.

ELECTRIFIED BUSINESSES

Business	No
Mill	6
Paper Industry	2
Furniture	1
Carpet Factory / Chialsa	1
Video Projection	6
Photo-copy	2
Bakery	1
Sauna / Hotel	1
Photo colour lab	1
Printing press	1

PARTIALLY ELECTRIFIED BUSINESSES

Radio-Watch repair	3
Hair dresser	1
Teashop + Lodges	19
Taylor	3

ELECTRIFIED ONLY FOR LIGHTING

Goldsmith	2
Dental service	1
Taylor	1
Teashop	72
Shop	59

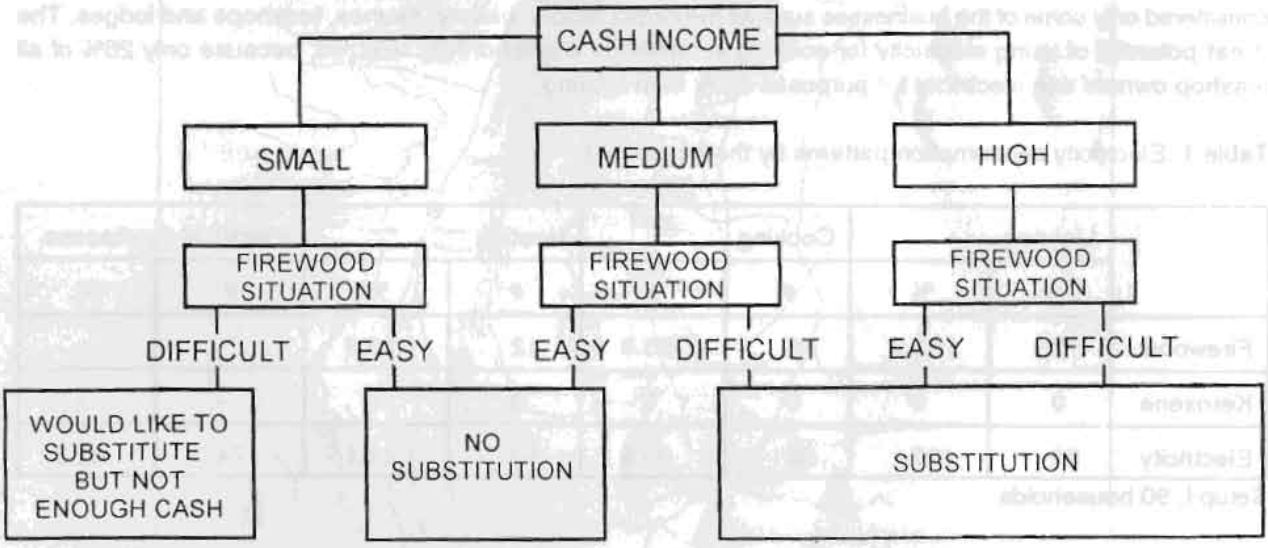

Figure 2. The decision-making-process for substituting firewood with electricity.

Looking closer at the firewood situation (Figure 3) we can roughly divide the region into three areas. People living in the old traditional Sherpa villages (Surke, Sherga, Bagam, etc.) have good access to firewood, because they own the nearby forests, their economy is mainly based on agriculture, and they have relatively little exposure to innovations. In two areas the supply of firewood is perceived to be difficult for different reasons. People in the dynamic settlements along the main trail mainly have to purchase firewood, while people in the south and in Kholaghari suffer from the low quality and quantity of forest in the lower part of the watershed. To evaluate this we should also take into consideration that people in Salleri and its surroundings are relatively wealthy compared to many other parts of Nepal, but the majority of the population (55%) has a small disposable cash income less than 15,000 Rs. For them electricity for cooking is not affordable, since they already spend considerable amounts of their income for lighting and running appliances (about 10% of their income). More than 1800 Rs. is spent per year on electricity for partial cooking with the low wattage cooker. In other areas of Nepal many more people have to be included into this group of people who suffer from a difficult firewood supply and cannot afford electricity.

3.2. Electrification and Environment

Some firewood can be saved due to electrification in the Solu area. A household using a low wattage cooker can save 30-50 % of the traditionally required firewood. Thus actual saving of firewood can slow down the deforestation rate by 2 to 3 years. That means that in 2 to 3 years the firewood need would be the same again as today's firewood requirements without electrification. If we make the assumption that each of the roughly 600 connected households in the area will in future regularly cook with the low wattage cooker, the maximum firewood saving would amount to one third of the current actual consumption. More substitution cannot take place because the output capacity of the two turbine group is not sufficient to support a greater substitution rate.

The firewood saving by businesses especially for the paper and wool dying factories are remarkable. Estimations show that the wool dying facilities in Chialsa consumed about 83 t of firewood per year, which equals the firewood consumption of about 20 households over a full year.

In contrast electricity does not only help to save firewood, it might also be a factor in increasing the demand of wood. Even if electrification was mentioned only as one of many forces promoting the expansion of settlement, we cannot neglect the increasing demand for new households and therefore for timber and firewood. The annual house building rate is 3 %. The demand for timber for the construction of 30 new houses (2-storey Sherpa houses) annually is equivalent to the firewood needs of about 600 households for one month. In addition, daily consumption by newly established households aggravates the firewood situation.

Unfortunately, no baseline survey has been carried out on the availability of the forest resources and it is therefore difficult to define the balance between clearing and revegetation for a sustainable use of the forest. It is difficult to determine the impact and savings of electrification on the forest. Since the natural conditions for revegetation in this humid and temperate climate are good, we suggest that a combination and further promotion of alternative energy is needed. Also adequate management of the forests, with local community participation would be the best solution and may even lead to a stabilization of this natural resource.

The other positive environmental effect of electrification is the replacement of kerosene and batteries. Public health has thereby improved. In addition, the consumption of batteries for radios and torches has been reduced drastically. Before electrification a household consumed 3.7 batteries a month, and for all the 700 electrified households this represents a savings of 31,000 batteries.

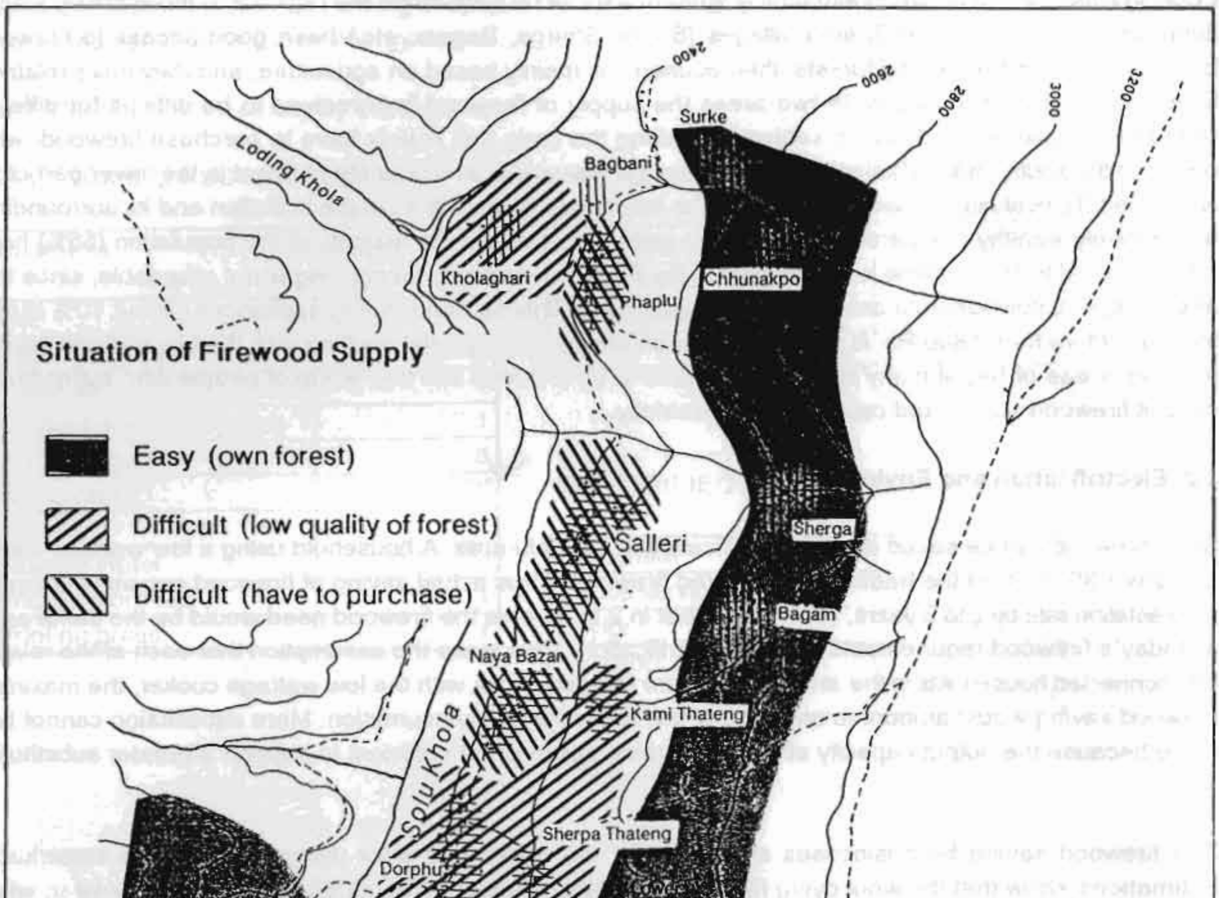

Figure 3. Firewood supply situation in the project area.

4. CONCLUSIONS

There is an obvious connection between electrification and high expectations for development. As shown in this paper local realities do determine the utilization of electricity and the impact of the new energy (Figure 4) on the forest resources.

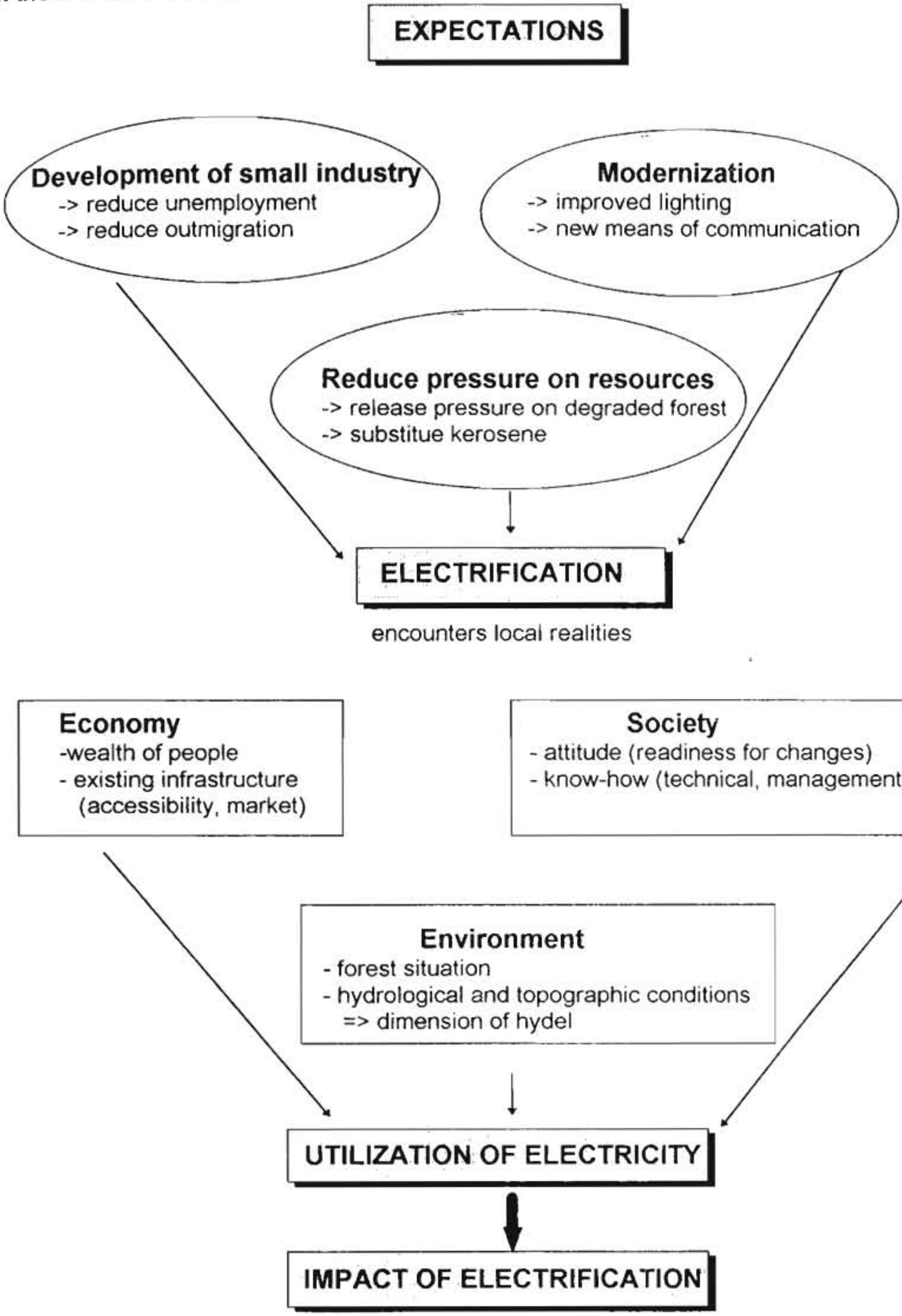

Figure 4. Rural electrification: expectations and realities.

Therefore, the following criteria need to be considered in order to assure a successful substitution of firewood by rural electrification from small hydropower plants:

1. For small hydropower plants (the run-of-the river scheme) the discharge has to be relatively constant during the year. In Nepal only rivers with a glacial run-off regime are therefore suitable. That means we have to exclude many parts of Nepal where rivers are not fed by glaciers (Siwaliks, lower Middle Hills).

2. The local society has to be relatively wealthy, equipped with some technical knowledge, and must have possibilities of off-farm employment. Without this people cannot afford the necessary investments for appliances and the running costs. As long as people cannot convert saved labour from reduced collection of firewood into cash income, they have no other choice than using firewood.

3. The output capacity of the small hydropower plants has to be big enough to allow a substantial substitution of firewood.

4. The firewood situation must be limiting. As long as firewood collecting is not too difficult and the investments and the running costs are relatively high people keep their traditional fuelwood energy supply and this means: innovations need time.

Coming back to the introductory question of whether small hydels can eliminate deforestation we conclude that they can only mitigate, but not stop the pressure on forest resources. Therefore we suggest that:

1. Rural electrification and improved community-based forest management have to be combined to attain sustainable forest use.

2. The propagation of alternatives to electrical cooking such as firewood-efficient stoves and solar cookers should be continued.

3. In the long term stand-alone units of small hydro-power plants should be connected to a network and whenever possible connected finally to the national grid to balance peak load.

Even if small hydels do not seem to contribute a major part to the reduction of deforestation, we cannot ignore the other very important impacts of rural electrification on society and economy. The potential to increase the standard of living of the local society is especially important but cannot readily be quantified. Electric light in houses and streets symbolizes'modernization' and development in which everyone wants to be included (Ott, 1993).

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Soil Fertility Management and Agricultural Production Issues with Reference to the Middle Mountain Regions of Nepal

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1. INTRODUCTION

To achieve an increase in food production, the Government in the past 35 years has established a nationwide network and infrastructures for agricultural research, extension/education, farm irrigation, farm credit and marketing institutions. Through these agencies, attempts were made to develop, introduce, extend and market seeds of high yielding crop varieties, fertilizers, agrochemicals and agricultural tools.

Despite these attempts, food grain production only increased from 3,152,000 metric tons in 1961/62 to 5,690,000 metric tons in 1989/90. The average annual production increases are 2.1 %, and this rate does not even keep pace with the population growth rate over the same period. This modest increase in food production was attributed mainly to the expansion in agricultural land rather than as a result of an increase in productivity or the use of agricultural inputs and technologies (Eighth Five Year Plan, 1992). The static or declining productivity for most of the major crops (Figure 1) is also an indication of the inadequacy of the development efforts which in many cases were unable to maintain previous levels of production. The problem is more acute in the Hill and Mountain regions (Figure 2) where the yields of main food crops have declined. From the point of view of crop productivity and environmental stability, the development efforts over the recent past are not at all impressive.

Realizing this fact, the eighth 5-year plan which is currently underway has shifted policy emphasis away from merely "increased food production", towards "increased integrated agricultural production which is in harmony with ecological and environmental conditions and which fosters efficient institutional services and sound management". The result from this shift is yet to be seen.

There are various reasons for the stagnation or decline of crop productivity. Low and declining soil fertility has been recognized as the most crucial problem (Pradhan et al., 1992; Hobbs and Giri, 1992; Pandey, 1991; World Bank, 1990; Joshy and Deo, 1976). The indiscriminate encroachment of agriculture into the forest as well as the expansion onto steeply sloping lands has resulted in irreparable losses of soils and natural vegetation causing severe land and environmental degradation. This, together with continuous soil mining through the use of high yielding varieties, intensive multiple cropping systems and inadequate and imbalanced fertilization further contributed to soil fertility and crop productivity declines. Increased population pressure is no doubt the root of the problem.

Since there is no or little scope for expanding cultivable land, additional food which is needed to feed the growing population has to come from increased yields from the existing land area. The yields could be increased by raising cropping intensity, extending irrigated areas and growing high yielding varieties but this would result in further depletion of soil fertility if the removed nutrients taken up by the plants are not replenished. Therefore, management of soil fertility and plant nutrition is the key factor to sustaining agricultural productivity and environmental stability. In this paper, some of the key issues in soil fertility management and agricultural production pertinent to the middle mountains region will be discussed.

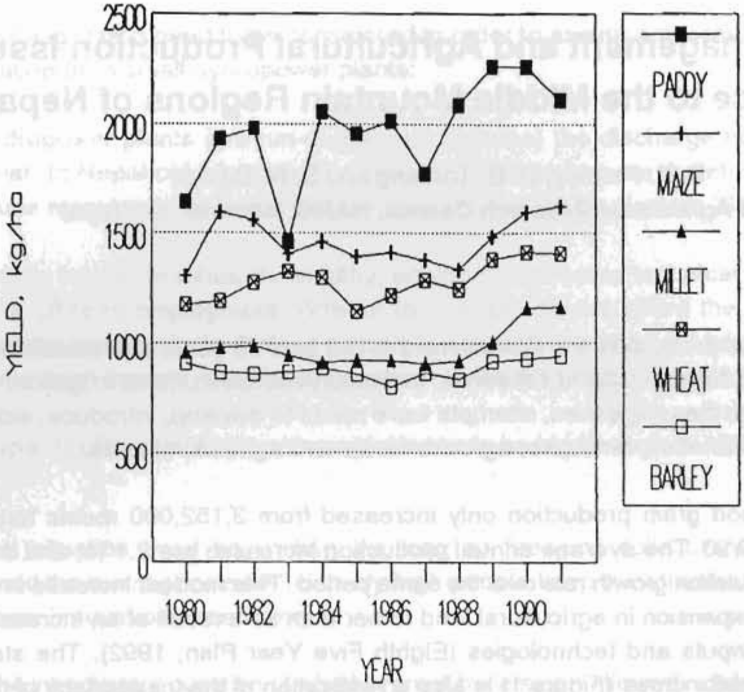

Figure 1. Food crops productivity trend, Nepal.

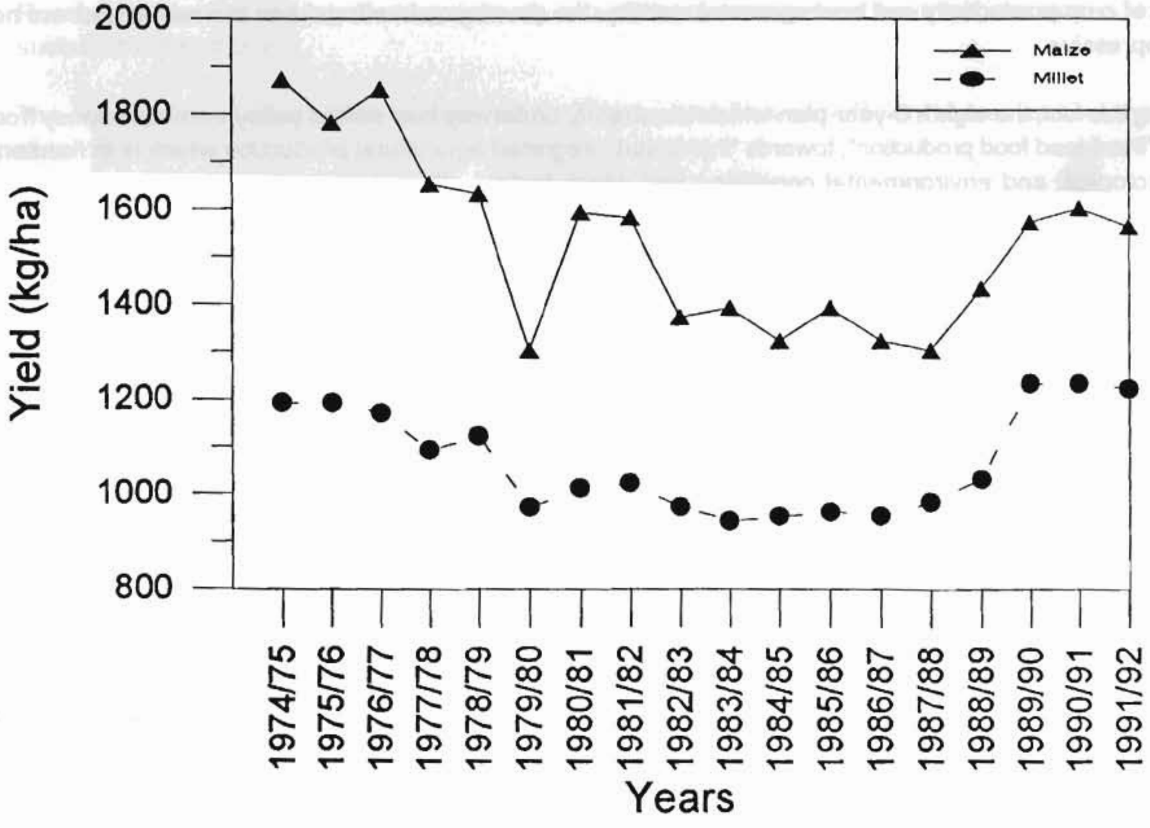

Figure 2. Maize and millet production trends in Nepal Mid Hills.

2. SOILS OF THE MIDDLE MOUNTAIN REGIONS

The middle mountain region, which occupies about 30 percent of the total land of the country, is the homeland of 45 % of the total population (approximately 19 million, based on the 1991 population census). The region has a very complex topography, elevation, geology and vegetation; hence the soils in this region are also diverse.

The LRMP has identified 4 different land systems in this region and these are further sub-divided into 7 Land Units (LRMP Land Systems report, 1986). The river valleys, which are the grain basket of this region, have alluvial soils of different texture and depth classes. These valleys are intensively cultivated with 2-3 crops a year where irrigation is available. The main cropping sequences in the low land cultivation system are rice - rice - wheat, rice - wheat - maize, or rice - wheat and rice - potato. The elevated terraces (*Tars*), which are formed by the erosional deposition, have mostly neutral to acidic red soils and are generally cultivated with upland crops such as maize, millet, upland paddy etc. However, if irrigation water is made available, rice-based cropping systems are followed. In general, the soils derived from granite are sandy, from shale, silty and from limestone, clayey.

The soils of this region are generally slightly acidic to acidic in reaction, and the organic matter content is in the medium range. In terms of nutrient content, the nitrogen and available phosphorus are low to medium, and the availability of potassium is medium to high.

3. TRADITIONAL SOIL FERTILITY MANAGEMENT PRACTICES

Almost all farmers in Nepal have traditionally followed integrated soil fertility management practices throughout time and these practices are built into the indigenous methods of farm management. For example, terracing, slicing the walls of terrace riser, bringing flood water into the field, leaf and in-situ green manuring, application of organic manures (FYM, compost, oil cakes, bone-meal etc.), shifting herds for in-situ terrace manuring and inclusion of various legumes in crop rotations are all in-built agronomical practices that supply plant nutrients to the field. Similarly, there are a number of other indigenous soil and nutrient management practices that are followed in different cropping systems and based on local conditions and resources.

Over the time, it was felt that these technologies alone were insufficient to meet the production demands for food required to sustain the increased population. Therefore, chemical fertilizer was brought into the farming system and this is a relatively recent introduction to most Nepalese farmers. Farmers have accepted fertilizers into their system but for various reasons, most of them use fertilizers only as a supplement to their indigenous resources. Nevertheless, its use is increasing and is becoming an essential input into the farming system. The biggest problem is the availability of both organic and inorganic nutrients and its transport to the fields.

An analysis of the present situation reveals that Nepal's future food security will not be passing without crisis if measures to cope with the declining soil fertility are not taken seriously. Combinations of all possible sources of nutrients are needed to arrive at an "Integrated Plant Nutrients System" that is appropriate for sustainable agricultural development.

4. FERTILIZER USE

The 1992/93 fertilizer consumption reached a level of 75,099 metric tons of nutrients with an average consumption of only 25 kg NPK fertilizer nutrients per hectare per annum. Of the total fertilizer distribution, 62% was in the Terai, 36% in the hills and 2% in the mountain regions (Figure 3). Fertilizer use in the hills and mountain regions is low due to inadequate institutional services, poor transport infrastructures and farmers' low buying capacity.

There is no doubt that fertilizer has raised the crop productivity in agriculture. However, there is a growing resistance to its use due to the high cost and increased concern about environmental hazards. Two years ago, the government lifted a major portion of the subsidy on most of the fertilizer materials except urea. This caused stagnation in fertilizer use last year and may further cut down its use in the coming years. This may accelerate the nutrient imbalance problem in the soil and will result in reduced productivity.

A blanket dose of 100:60:40 kg/ha of N, P_2O_5 and K_2O were recommended for high yielding varieties and 60:40:30 kg/ha for local varieties in the 1960's. In the 1970's, these fertilizer recommendations were revised, and extrapolated to individual districts on the basis of accumulated experimental results and soil survey data (Joshy and Deo, 1976). However, those recommendations were based mainly on work conducted in the Terai having thus a limited use for hill conditions.

The HMG/N in cooperation with FAO implemented a Project called "Increased Food Production and Farmers' Income in the Hills through Fertilizer and Related Inputs". During its campaign between 1983/84-89/90, the project conducted around 3332 fertilizer verification trials on the main food crops (rice, wheat, maize and potato) in 22 hill districts in the Eastern, Central and Western Developmental Regions. The results have been comprehensively analyzed and documented in Project's Field Documents No 1, 2, 3 (Jensen, 1987), 5, 6,7 and 8 (Pandey, 1991) for rice, wheat, maize and potato crops and are also available in a computer data bank at the Soil Science Division. Based on all the soil tests, crops responded well to nitrogen, moderately well to phosphate and there was only a slight to moderate response to potash (Pandey, 1991).

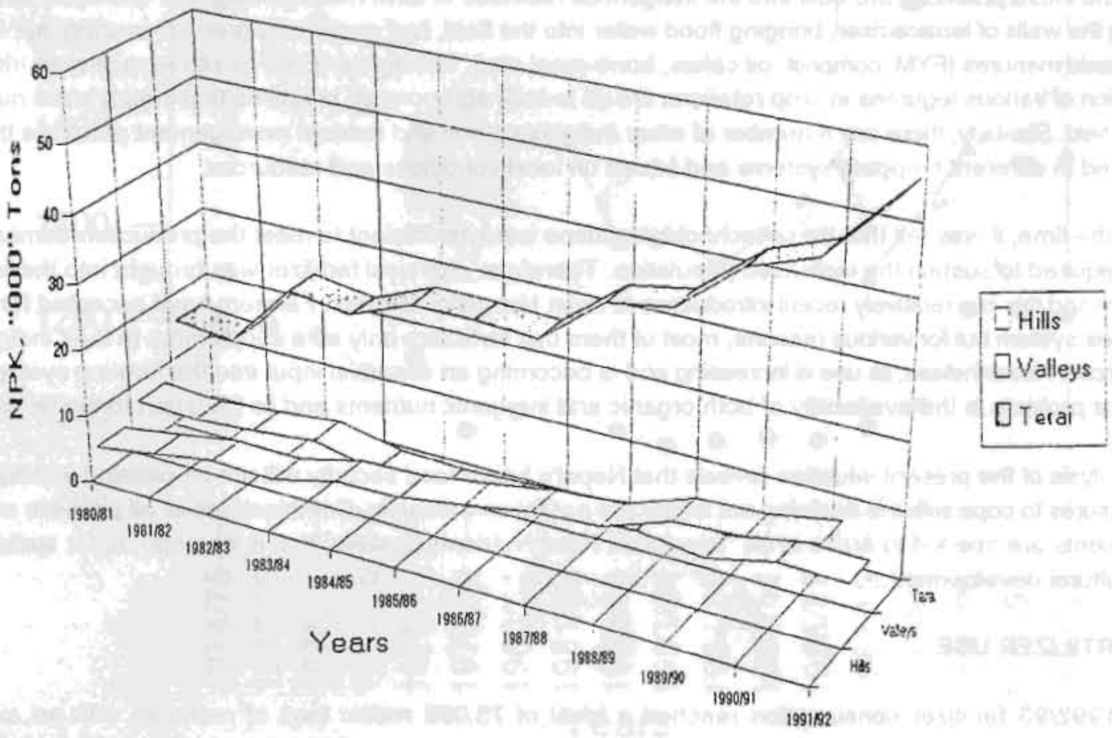

Figure 3. Fertilizer-NPK consumption trend in Nepal.

Based on these findings, the optimum plant nutrient recommendations for farmers with and without resource constraints were computed as shown in Table 1.

Table 1. Plant nutrient recommendations (kg/ha), Guidelines for resource constrained and non-constrained farmers, computed at national level.

	Farmers with Resource Constraints					Farmers without Resource Constraints				
Crop	N	P2O5	K2O	Net Return Rs/ha	VCR	N	P2O5	K2O	Net Return Rs/ha	VCR
Rice	70	40	30	4,596	5.64	140	40	30	5,737	4.59
Wheat	60	40	30	3,763	4.75	120	40	30	5,038	4.31
Maize	60	45	30	4,012	5.00	120	45	30	5,369	4.51
Potato	45	30	60	10,414	13.09	90	30	60	15,682	13.53

The nitrogen, phosphate and potassium recommendations were also calculated for each district for which the response function curves are available for each of four crops. The project also carried out more than 2600 fertilizer demonstrations on rice, wheat, maize and potato crops in 23 hill districts.

An economic analysis of these fertilizer trials and demonstrations confirmed that the use of mineral fertilizer is a viable means of increasing crop production and farmers' income even in the hill areas of Nepal. The results showed that one bag of NPK fertilizer can produce, on average, 5 to 6 bags of food grains. Thus, the volume of food grains transported from the Terai to the hills could be reduced by more than 80 percent. This would significantly relieve the financial burden on the government every year.

An analysis of the results indicates that crop yields could be increased by 55-60 % over the present level if farmers would make use of judicious amounts of fertilizers and related inputs. In fact, the yield increases were more than 100% above those in the control plots where no fertilizers were applied and this applies to all four crops (Table 2).

In recent years, the use of mineral fertilizers has increased because of the inadequacy of farmyard manure and farmers are realizing that decreased crop productivity is due to the decline in soil fertility. The above recommendations would be appropriate for crops under irrigation in river valleys, tars and hill slopes with humid-sub-tropical-to-warm temperate climate. However, arguments are being raised about the sustainability of the increased productivity even with the use of the same fertilizer rates over the years. Before making any conclusion, long term evaluations and assessments are needed to support this statement.

5. IS INTEGRATED SOIL FERTILITY MANAGEMENT AN APPROPRIATE ALTERNATIVE?

For centuries, farmers in Nepal have been practicing different indigenous soil fertility and plant nutrition management systems through crop-livestock-forest integration. However, alone they might not be adequate to sustain the agricultural productivity needed to feed the growing population. Therefore, a combination of all possible practices including mineral fertilizer use as part of the "Integrated Soil Fertility and Plant Nutrients management Systems" could be an appropriate alternative for sustainable agricultural development.

Table 2. Yield Comparison Between Fertilized V/S Non-fertilized and Farmers' practice in Rice, Maize, Wheat and Potato.

Nutrient Rates $N-P_2O_5-K_2O$ kg/ha	Yields kg/ha	Yield Increases Over Farmers' Plot kg/ha	%	Nutrient Rates kg/ha	Yields kg/ha	Yield Increases Over Farmers' Plot kg/ha	%
Rice				Maize			
Farmer	2,937.5	0	0	Farmer	3,242.0	0	0
60-0-0	3,854.9	917.4	31.2	60-30-20	4,084.9	849.2	26.0
90-30-30	4,577.9	1,640.4	55.8	20-60-40	4,723.8	1481.8	47.7
0-0-0	2,170.4	-761.1	-26.1	0-0-0	2,433.8	-808.2	-25.0
Wheat				Potato			
Farmer	2,342.2	0	0	Farmer	11,656.8	0	0
60-30-20	2,955.1	612.9	26.4	40-20-50	14,728.8	3,072.0	26.4
80-40-100	3,650.0	1,307.8	55.8	80-40-100	19,790.2	8,133.4	69.8
0-0-0	1,352.7	-989.5	-42.3	0-0-0	7,001.8	-4,655.0	-39.9

Emphasis on integrated soil fertility management should be given to reduce the soil erosion, conserve water, regenerate and recycle biomass and especially to increase the supply and efficiency of plant nutrients through organic and inorganic inputs.

The main findings of the recent research work by Maskey and Bhattarai (1994); Sherchan et al., (1993); Joshy et al., (1992); Subedi and Gurung (1991); Gurung and Neupane (1991); Pandey (1991); LAC (1988) provide the basis for designing Integrated Soil Fertility Management and are briefly discussed below.

5.1. Organic Manure

A document has been developed to describe the methods of FYM/composting, its preparation, storage and application. Identification of rapid composting methods through the use of fungi (Trichoderma) inoculation is under study and initial results are encouraging.

Response to the application of different sources of organic manures (compost, FYM, poultry waste, city compost, oil cakes, bone meals, as well as in combination with mineral fertilizer) were evaluated. Response of 5 tons/ha poultry manure, 20 tons/ha FYM/compost and 100:40:30 kg/ha fertilizer NPK were found to be comparable.

A comprehensive survey and study were made on conventional composting materials as well as farmers' methods of FYM/ compost preparation, storage and application.

5.2. Biofertilizers

Azotobacter is recommended for use with cereal and vegetable crops in the higher hills in combination with organic manures. A 3-29 % yield increase is expected from its use but it was found to be ineffective in combination with mineral fertilizers.

Rhizobium is recommended for pasture and grain legumes. A number of effective strains have been identified, multiplied and distributed. A 10-65 % yield increase is expected due to inoculation of suitable strains.

5.3. Green Manure

A number of local plant species have been identified as suitable for green manuring purposes. Their manure value in nutrient cycling and soil organic matter enrichment also were evaluated. Some 30-60 kg of N/ha could be produced through green manuring in rice fields.

5.4. Legumes In Farming Systems

Legumes are grown in approximately 262,000 ha in Nepal and legumes rank fourth in production after rice, maize and wheat. However, the acreage under legumes is negligible in the hill regions except for some areas where soyabean, groundnut and black gram are grown as mixed/relay cropping with maize. However, pasture legumes and several leguminous trees (used as fodder, composting materials and green leaf manuring) are extensively grown in the hill farming systems, and even a slight improvement in their N fixing efficiency could bring substantial amounts of atmospheric N into the soil system. Rhizobium inoculation should receive more attention in the cropping system research and the recent initiatives by the International Crop Research Institute for the Semi Arid and Tropical Agriculture (ICRISAT), the Australian Centre for International Agricultural Research (ACIAR) and NARC are a first step.

5.5. Fertilizers

Ampie information has been generated for fertilizer use and crop response. As a result, district specific recommendations are now available.

5.6. IPNS

Various IPNS combinations were tested in different agro-ecological regions in collaboration with FAO IPNS Network Program. The results are being extended to farmers through NARC's Outreach Research Sites. A number of coordinated long term soil fertility experiments based on IPNS principles are on-going in different ecological zones of the country.

5.7. Watershed Management

A better base for sustainable agriculture could be realized if watersheds would be managed efficiently using integrated soil fertility management systems in combination with alternate land use such as agroforestry, horticulture, pasture, fodder trees and soil, water and vegetation conservation practices.

6. CONSTRAINTS TO INTEGRATED SOIL FERTILITY MANAGEMENT SYSTEMS (ISFMS)

There are a number of constraints in ISFMS and their extension at the farm level. Some of them are:

1. An already depleted natural resource base: Regeneration of the degraded biomass in the system is a pre-requisite for the effective promotion of ISFMS. The ISFMS as a concept already exists in most farming communities. What is urgently required is the build-up and management of suitable biomass in the system.

2. Lack of institutions to regulate the production, supply and distribution of green manure seeds, biofertilizer inoculum, leguminous forage/fodder seeds and seedlings, to support the extension of ISFMS. There is a high demand for these items by the farmers and some farmers have been importing green manure seeds from neighbouring states in India. Many more are interested but are reluctant to put their land under green manure seed production because of its initial economic disadvantage in relation to alternative crops.

3. Lack of extension service to promote ISFMS at the farm level. The existing research and extension services were created to replace the traditional agricultural system with modern inputs such as fertilizers, agrochemicals, high yielding seed varieties and farm machineries. Now, there is an increased fear that the high inputs-based modern technology is overexploiting the resources and creating a natural imbalance at the cost of future generations. Therefore, an overall shift towards more sustainable and environmentally friendly technology is essential.

   Although, most extension workers know the positive effects of ISFMS, they have not been able to take it to the farmers. The approach has to be changed from uni-modal to multi-modal, non-renewable purchased inputs to renewable locally generated inputs, from individual contact to group mobilization, from plot demonstration to block demonstration and so on. Therefore, the extension service needs to be reorganized and refocused.

4. Lack of adequate research information: a blanket recommendation for ISFMS cannot be made. It needs to be adjusted to local conditions and the researchers and extension specialists should be able to show the farmers how crop nutrient requirements can be balanced using local resources in combination with fertilizers. At present, research information is scarce and it is difficult to formulate the best combinations of nutrient sources given the available resource base in the hills.

5. Labour intensive and time taking technology: ISFMS is a labour intensive and slow responding technology. Farmers may not accept it when it is introduced for the first time because it may be expensive and the risk for crop failure is high. Nevertheless, if it is developed as a method of utilizing the byproducts and wastage of the farming system, farmers will, no doubt, adopt it. For example, if compost making and application is calculated as a sole farm activity no economist may consider it as an economically viable practice. Even farmers may abandon it. However, if integrated with livestock raising, it is simply a byproduct. The farmland would be the best site for waste disposal and provide a valuable nutrient input for food production. By greater recycling the system becomes sustainable.

6. Lack of long term land use policy by the Government: the ISFMS is also a biomass-based approach. In some cases it may conflict with crop production in cultivated land and many farmers like to import biomass from external sources. The forest has been an outside source of fodder and litter for livestock and in the process is producing FYM. Because of economic and demographic pressure the forest surrounding the farm land is overexploited. The frequent change of the government policy in the use of forest resources as "public goods/ common property" has also been responsible for aggravating forest/ pasture land degradation. A sound land use policy which regulates forest use is absent. It has resulted in a negative agricultural and environmental balance. This component has been seriously considered in the forthcoming 25 years' Agriculture Perspective plan, which is now under review for approval.

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An Integrated Nutrient Management System for Sustaining Soil Fertility: Opportunities and Strategy for Soil Fertility Research in the Hills

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1. INTRODUCTION

The soil fertility management systems in the hills of Nepal are dependent upon access to the forest and farm fodder resources, livestock management, crop production systems and the socioeconomic conditions of farmers which includes land tenure, land holding size and external input purchasing capacity.

In the present context, the need to meet a rising demand for food grains due to an increasing population is reflected in increasing crop intensification. In many areas of the country organic sources are no longer adequate to replenish the nutrients removed by crops and trees or lost through other means such as erosion or leaching. Chemical fertilizers are the only easy and ready made materials which can be efficiently used to replenish the deficit, however, their use is restricted in the hills because of transportation difficulties and not being available when needed. Even when they are available the poor purchasing capacity of the farmers limits their effective utilization.

This paper attempts to highlight the soil fertility systems of the hills and present the results of several field experiments carried out by Pakhribas Agricultural Centre (PAC). It also discusses future research strategies.

2. ORGANIC AND INORGANIC SOURCES OF FERTILIZERS

There are three major sources for nutrients in the hills of Nepal. These are: farm yard manure, compost/leaf litters and chemical fertilizers. The contribution from soil microbes, both symbiotic and non symbiotic, in harvesting atmospheric nitrogen is not well documented. However, a number of reports are available that show that symbiotic microbes do improve the productivity of legume crops (Bhattarai, 1987, Gurung, 1993).

In the hills, the use of chemical fertilizers is a relatively new practice among farmers, whereas compost and FYM are age old traditional practices in crop production. It is commonly believed that the production of compost is decreasing; the cause is often related with decreasing forest resources and animal population, but no scientifically documented data is available to verify this statement. The use of chemical fertilizers has increased steadily over the years since their introduction in the early 1960's (Pandey, 1993). The increased use of the major nutrient elements has been calculated at 11.1 percent N per annum, 13.5 percent phosphorus and 8.2 percent of potash (APP, 1994). In the hills and mountain regions, the overall consumption of fertilizers is thought to have grown at 10.5 to 11.8 percent between 1986/87 and 1991/92 (APP, 1994).

Both organic and inorganic sources of nutrients are important for promoting sustainable crop production. Organic sources have many advantages and are considered as complete fertilizers; they also act as soil conditioners. Inorganic sources are mainly seen as a means to meet the high demand for plant nutrients under highly intensified agriculture and to replenish nutrients and correct any imbalances. Reports are available which show that the use of chemical fertilizers in the hills is economically justifiable (Joshi, 1976, Pandey, 1991), but if used inappropriately, there can be adverse effects which result in soil degradation and damage to the environment. Farmers are already reporting adverse effects on soil productivity, stating that to maintain the same yield level increasing amounts of chemical fertilizers have to be used every year. The Agriculture Perspective Planning (1994) gives emphasis to soil fertility research by complementing chemical fertilizers with indigenous techniques and also relies heavily on the use of inorganic fertilizers. Looking at the prospects for Nepalese agricultural development, an integrated nutrient management approach becomes an important issue if sustainable agricultural development is to be achieved.

3. TRADITIONAL SOIL FERTILITY MANAGEMENT SYSTEMS

3.1. Nutrient Flow, Cycle and Balance

A number of the traditional soil fertility management systems and soil classification systems used by farmers in the hills of Nepal have been described by biologists and social scientists (Tamang, 1993, Subedi, 1989, Gurung, 1993). Information on these systems is still relatively sparse. Figure 1 depicts the nutrient flow system and cycle, but quantitative information is lacking. Many of the technical and socioeconomic factors which influence the system are only poorly understood. These external factors, which may have an adverse effect on nutrient cycling, need to be understood by researchers as well as others engaged in development activities.

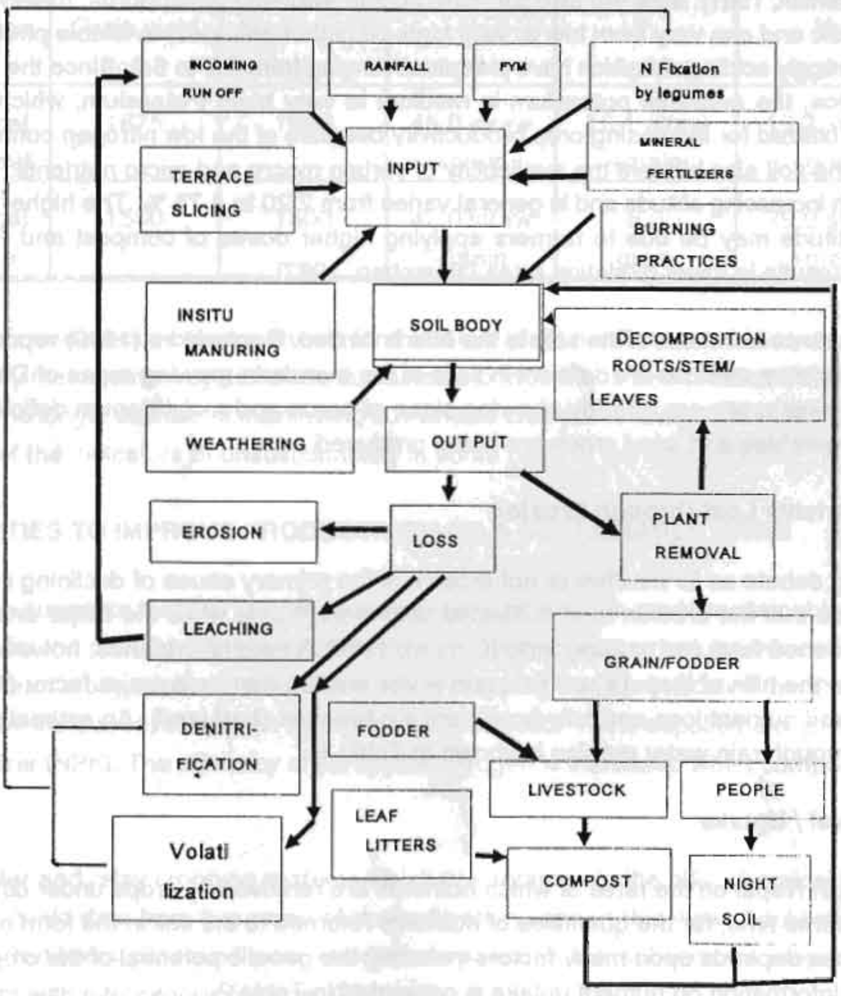


Figure 1. A typical nutrient cycle in a subsistence hill farming system in Nepal.

Soil fertility management as practised by farmers in the hills includes in-situ manuring, use of sediment-laden irrigation water, terrace slicing, burning plant residue, winter fallow and water ponding on khet land. No quantitative estimation of the contribution of these practices to crop production is available. On average, 10 t/ha fresh compost or FYM, with an estimated composition of 0.5% nitrogen, 0.2 % phosphorus and 1.25% potassium on a dry weight basis, is applied to each crop grown in the hills. No information is available as to how much chemical fertilizer is applied to crops and it is difficult to generalize.

Other important parameters to consider when trying to understand the nutrient cycle are the natural ability of the soil to supply and hold nutrients and its susceptibility to changing farming practices.

3.2. Soil Characteristics

Dry land sloping terraces (bari land) on steep to very steep hill slopes, are extremely variable in soil depth and texture which results in variations in their fertility status. Irrigated or partially irrigated terraced level land (khet land) has less variation within a single terrace.

The inherent nutrient holding capacity of the soils is poor, with low nitrogen and cation exchange capacity in the eastern hills (Goldsmith, 1981). Soils are also generally poor in available phosphorus; however, the amount is very often site specific and can vary from low to very high. At higher altitudes, available phosphorus is very low because of the strongly acidic soils which have pH values ranging from 4.7 to 5.9. Since the major minerals are feldspar and mica, the available potassium is medium to very high. Potassium, which is adequately available, is not fully utilized for increasing crop productivity because of the low nitrogen content of the soils. The acidic nature of the soil also hinders the availability of certain macro and micro nutrients. Organic matter content increases with increasing altitude and in general varies from 2.20 to 4.75 %. The higher organic matter content at higher altitude may be due to farmers applying higher doses of compost and FYM and lower temperatures which results in lower oxidation rates (Sherchan, 1987).

Information on the micronutrient status of the soils in the hills is limited. Gupta et al. (1989) reported that boron, magnesium, copper, calcium and zinc are deficient in soils of the mandarin growing areas of Dhankuta district. Cabbage and cauliflower crops are already showing signs of boron and molybdenum deficiencies in areas where off-season vegetables and seed crops are being produced.

3.3. Major Plant Nutrients Lost through Erosion

There is a continuing debate as to weather or not erosion is the primary cause of declining soil productivity. Some reports indicate that the erosion from cultivated land is negligible while the major erosion occurs on marginal land, abandoned land and grazing land (Carson, 1986). There is evidence, however, that erosion studies conducted in the hills of Nepal show that rain water erosion can be a major factor (Maskey, 1991), causing heavy soil and nutrient loss annually from slopping terraces (bari land). An estimation of the major plant nutrients lost through rain water erosion is shown in Table 1.

3.4. Nutrient Removal / Uptake

Information is lacking in Nepal on the rates at which nutrients are removed by crops under different cropping patterns and at the same time, for the quantities of nutrients returned to the soil in the form of residues. The nutrient uptake of crops depends upon many factors including the genetic potential of the crop, soil type and soil moisture. Some information on nutrient uptake is presented in Table 2.

Table 1. Nutrients loss through rainwater erosion.

Land type / Land use	Nitrogen kg/ha/yr	Phosphorus kg/ha/yr	Potassium kg/ha/yr	Sources
Maize/millet, bari	55.0	2.53	7.88	Gurung, 1993
Maize + soyabean khet	0.43-0.83	.002-.003	0.07-.17	Maskey, 1991
Rainfed bench terrace	3.8	5.0	10	Carson, 1992
Rainfed marginal land	15	20.0	40.0	Carson, 1992
Grazing land degraded	75	100	200	Carson, 1992

Table 2. Nutrients removed from soils by plants.

Land type	Crops	Grain yield kg/ha	Straw yield kg/ha	N kg/ha	P kg/ha	K kg/ha	Source
bari land	Local wheat	1675	1638	45.0 straw +grain	10.1 straw +grain	19.7 straw +grain	Sherchan, 1991
khet land	Local rice	1500	1500	42.0 straw +grain	8.0 grain	29.0 straw +grain	Carson, 1986

The availability of more precise balance sheets for the major plant nutrients would help to assess whether the present soil fertility management systems are sustainable or not. It has been realized that the present system is in danger and no longer capable of maintaining sustainable crop productivity in the long run. Shrestha (1992) reported some of the indicators of unsustainability in some parts of the eastern hills.

4. OPPORTUNITIES TO IMPROVE PRODUCTIVITY ON A SUSTAINABLE BASIS

Recent research suggests that the current cropping systems may be made sustainable. They also indicate encouragement for the development of sustainable soil fertility management guidelines for a future research strategy. A long-term study conducted on a rice-wheat cropping system indicated that the productivity of rice and wheat can be increased, or at least maintained, if compost/FYM is supplied along with a balanced dose of chemical fertilizer (NPK). The efficiency of the applied nitrogen is increased when compost is applied (Figure 2).

Under mixed, inter and relay cropping systems which are common in the hills, chemical fertilizers have poor residual effects. Yield data from five years of rice cultivation support this view. Application of 60:30:30 NPK kg/ha chemical fertilizers produced poor residual response in the subsequent crops when compared to compost alone or with nitrogenous fertilizer (Figure 3).

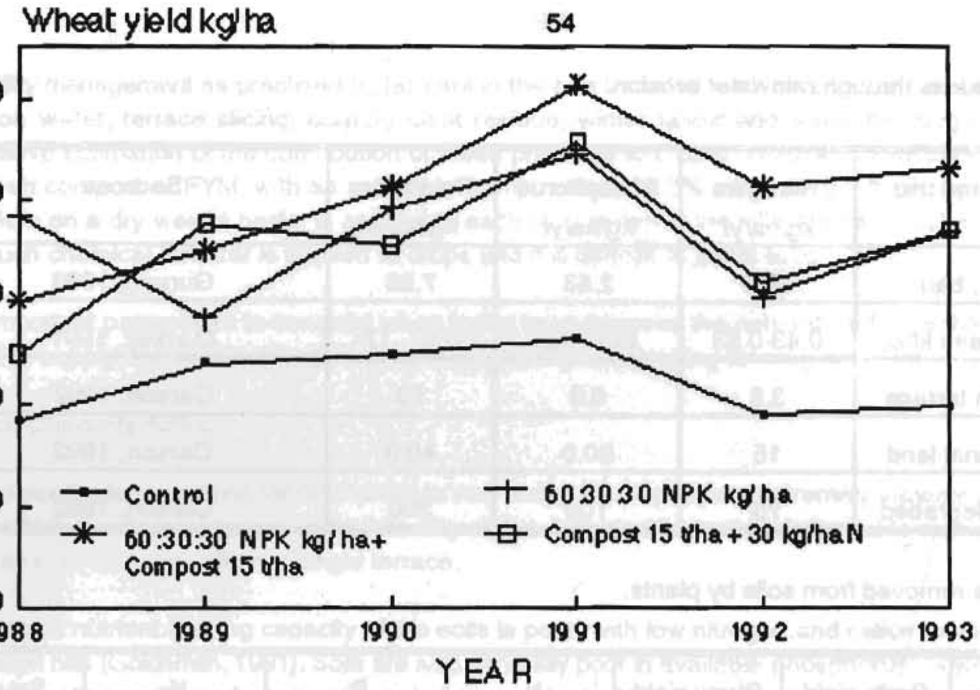


Figure 2. Wheat yield response to organic and inorganic fertilizers over the years.

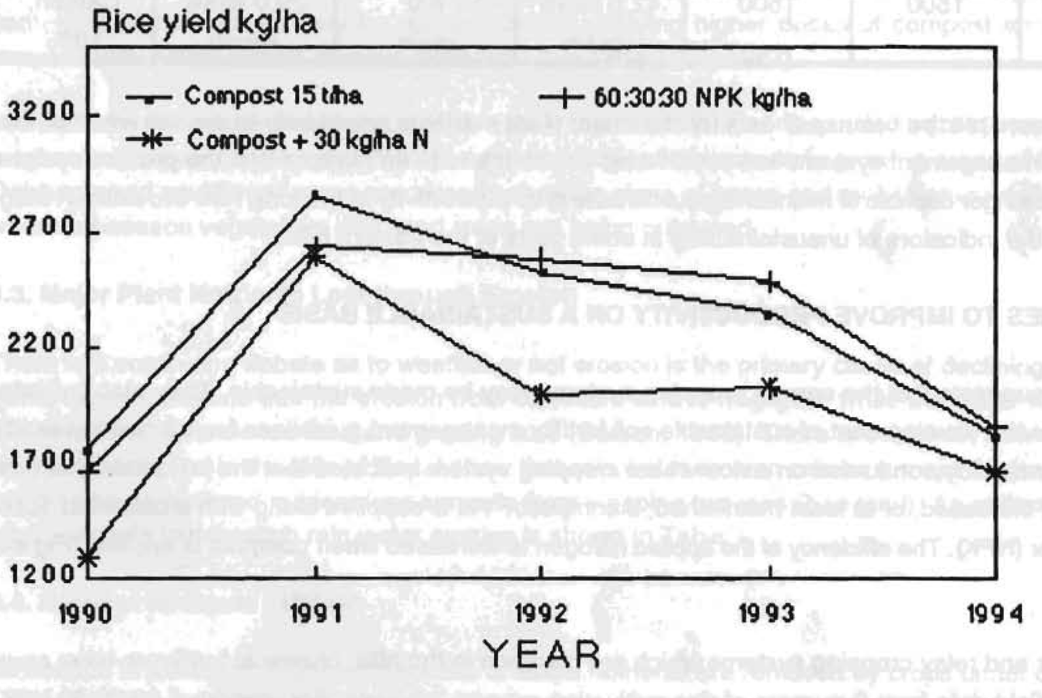


Figure 3. Residual effect on rice of compost and chemical fertilizers applied to the preceding wheat crop.

Millet relayed with maize is the most common cropping pattern in the mid hills of eastern Nepal, where the pattern covers approximately 114,704 ha (67%) of the available cropping area (LRMP, 1986). Experimental results show that chemical fertilizers at 120:60:30 NPK kg/ha alone can not maintain the crop productivity of both maize and millet. The use of compost in combination with chemical fertilizers is necessary if productivity is to be maintained in the long run (Figures 4 and 5).

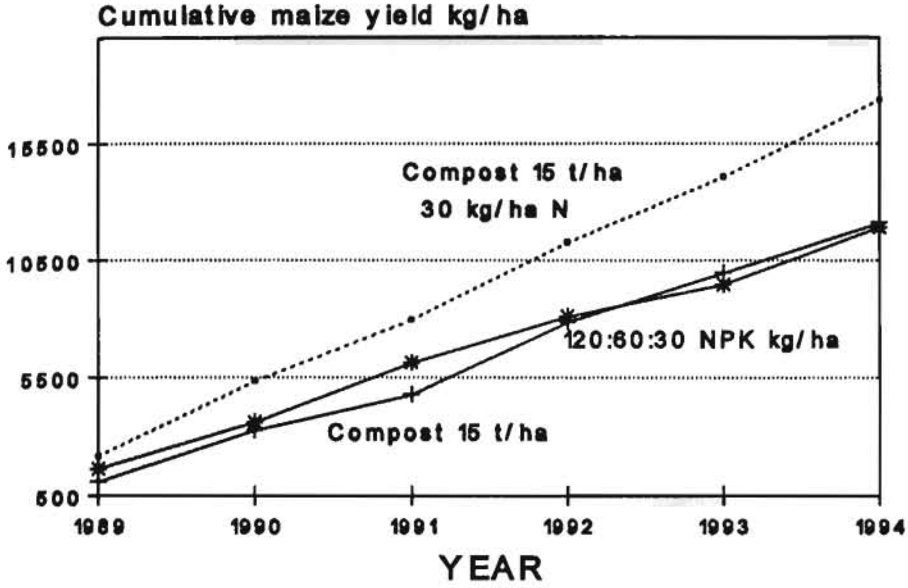


Figure 4. Maize yield response to chemical fertilizers and compost.

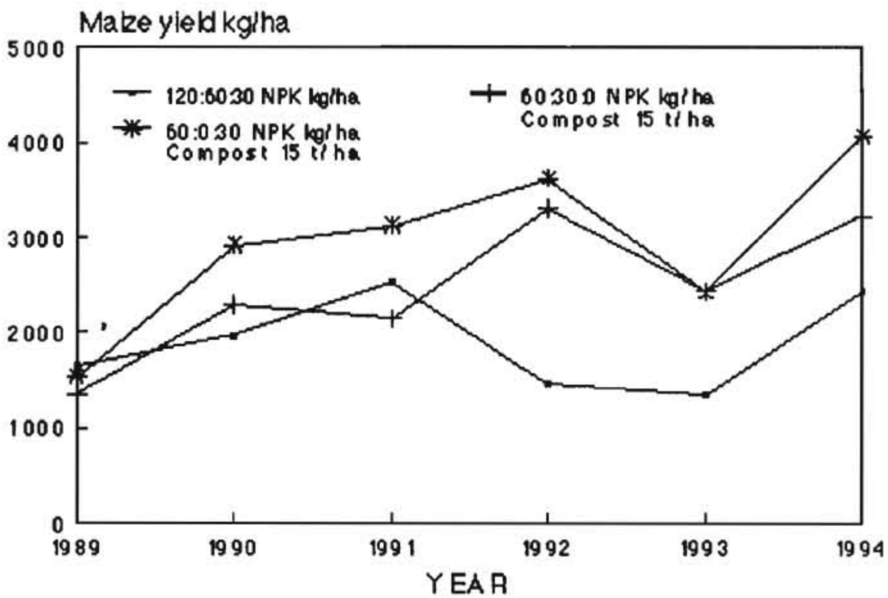


Figure 5. Maize yield response to chemical fertilizers in combination with compost and chemical fertilizer.

Similar to the rice-wheat system, there is also a poor residual effect from chemical fertilizers alone on millet yields in a maize/millet relayed system (Figure 6). From these findings it may be concluded that the release of nutrients from organic sources is more readily available to the succeeding crops, whereas inorganic fertilizers are lost through deep leaching or fixed by clay minerals and therefore become unavailable to plants.

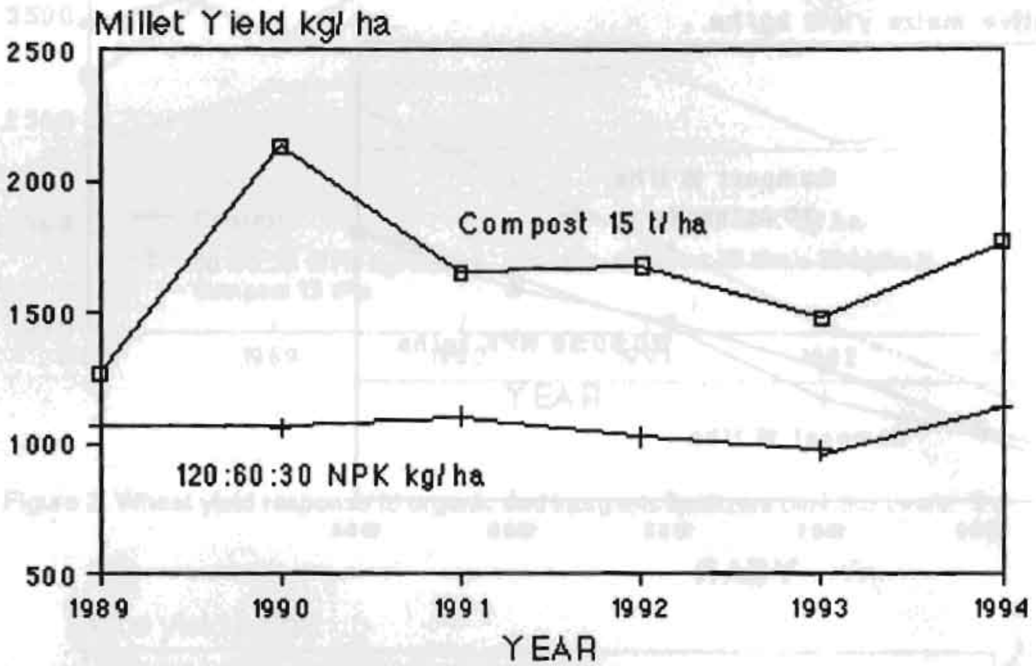


Figure 6. Residual effect on millet of chemical fertilizers and compost applied to the preceding maize crop.

Results of the first five years of long-term experiments on rice-wheat and maize/millet patterns have shown that the combined use of organic and inorganic sources of fertilizer helps to restore soil fertility in the longer term (Tables 3 and 4).

In a rice wheat system, the application of compost has improved the organic matter content, exchangeable calcium, magnesium and CEC of the soil. There is also a strong indication that when chemical fertilizers are applied alone the total exchangeable acidity may increase. There is also an indication of the decreasing availability of DTPA Zn from chemically fertilized plots (Sherchan, 1995).

Under a maize/millet system the lowest pH value (5.3) was found from the chemical fertilizer treated plot and consequently, the total exchangeable acidity was also measured at 1.97 Cmol+/kg. The status of available phosphorus was found to be better when compost and chemical fertilizers (NPK) were applied together. Again, there is an indication of decreasing availability of DTPA iron and zinc from the plots where chemical fertilizers were applied (Sherchan, 1995).

Table 3. Soil properties after 5 years of a rice-wheat long-term trial (mean of three blocks).

Soil pH	5.26	5.15	5.11
Ex. acidity Cmol+/kg	0.69	0.78	0.81
Organic matter %	2.18	1.86	1.94
AVL. phosphorus mg/kg	149.0	78.2	249.0
AVL. potassium mg/kg	65.9	61.9	87.5
CEC Cmol+/kg	9.71	7.28	9.2
Ex. Mg. Cmol+/kg	0.92	0.7	0.96
Ex. Ca. Cmol+/kg	4.54	3.4	4.66
Ex. K. Cmol+/kg	0.06	0.06	0.06
DTPA Extractable			
Iron mg/kg	322.0	218.0	307.0
Manganese mg/kg	28.6	16.1	16
Copper mg/kg	4.7	3.96	4.3
Zinc mg/kg	2.83	1.8	2.4

Source: Sherchan, 1995 (PAC Technical Paper forthcoming)

Note: The initial soil test value of the experiment plot was pH = 5.3, OM % = 1.62, total N = 0.09%, AVL P = 20 mg/kg and AVL K = 78 mg/kg

In the potato+maize systems at high altitude, compost is applied at very high rates; usually not less than 30 t/ha (Gurung, 1991). In order to provide different options to overcome the decreasing availability of plant materials for compost and recognizing that the availability of chemical fertilizers is being increased, an attempt was made to determine the effect on potato tuber yield using a combination of chemical fertilizers (90:60:60 NPK kg/ha, 60:30:30 NPK kg/ha and 30:15:15 NPK kg/ha) and compost/FYM (10 t/ha, 30 t/ha, 50 t/ha and 70 t/ha). Two years of results show that yields were increased by 24, 43, 48 and 49% when 90:60:60 NPK kg/ha was applied in combination with compost at 10 t/ha, 30 t/ha, 50 t/ha and 70 t/ha over the control plot without chemical fertilizers (13.93 t/ha, 15.13 t/ha, 15.28 t/ha and 11.96 t/ha tuber yields). There was an indication that even a small quantity of chemical fertilizers can increase tuber yields significantly but there is no significant effect between various doses of compost (Figure 7).

An alternative to compost is the use of green manures. In the low altitude maize-rice-wheat and rice-rice-wheat cropping systems, *Dhaincha* (Sesbania aculeata), when relayed with maize, increased subsequent rice yields by 23 to 32.5 percent when *Dhaincha* was sown either at the time of earthing up the maize or at the time of hoeing. In both cases, the maize yield was unaffected (Figure 8).

Table 4. Soil properties after 5 years of a maize/millet long-term trial.

Soil Properties	Compost 15 t/ha	120:60:30 NPK kg/ha	60:30:0 NPK kg/ha
Soil pH	5.85	5.35	5.68
Ex. acidity Cmol+/kg	0.63	1.97	0.81
Organic matter %	1.57	1.44	1.6
AVL. phosphorus mg/kg	20.1	12.15	24.18
AVL. potassium mg/kg	62.51	61.87	73.83
CEC Cmol+/kg	12	11.46	12.98
Ex. Mg. Cmol+/kg	1.38	0.96	1.46
Ex. Ca. Cmol+/kg	8.07	6.13	8.25
Ex. K. Cmol+/kg	0.37	0.33	0.37
DTPA Extractable			
Iron mg/kg	103	114.4	87
Manganese mg/kg	123	145	119
Copper mg/kg	2.71	2.62	2.4
Zinc mg/kg	2.96	2.2	1.97

Source: Sherchan and Gurung, 1995 (PAC Technical Paper forthcoming)

Note: The initial soil test values were pH = 5.3, OM % = 1.9, AVL P = 29 mg/kg and AVL K = 116 mg/kg

5. FUTURE STRATEGIES FOR SOIL FERTILITY RESEARCH IN THE HILLS

In the hills and mountains of Nepal, research is often conducted in isolation without paying attention to all the components of the farming system. This type of research cannot be successful. An understanding of the socioeconomic factors affecting farmers' decisions is also essential.

Soil fertility management dynamics are intertwined with components of the farming system. The responsibility to develop an appropriate technology does not rest solely with the soil scientist. Research should be coordinated with all disciplines working to improve the productivity of the overall system. The research agenda would be different, but the goal must be to improve soil productivity.

An analysis of the various biological and socioeconomic factors should be the first priority to identify the factors causing reduced productivity levels or constraining agricultural development. To date in Nepal, base line information on soil resources is not available which has caused difficulties in assessing the levels of land degradation, erosion etc.

Though there has been limited research on soil erosion and nutrient losses in the country, available findings indicate that research to mitigate surface erosion as well as to minimize nutrients loss will be of direct benefit. There is also a need to know the tolerance limit of soil loss under such hilly terrain conditions. Diversity in the geology, soils and climate of the hills in Nepal suggests that erosion studies should be undertaken using a watershed approach (Carson, 1985). Chaudhari and Mahato (1987) have indicated that organic matter content could be one of the parameters to assess productivity. They reported that over an 18 year period, soil organic matter content at the Tarahara Regional Agricultural Research Station fell to 52% of the original level (2.29 to 1.51) and suggested this as a principal cause for the declining productivity of the soil.

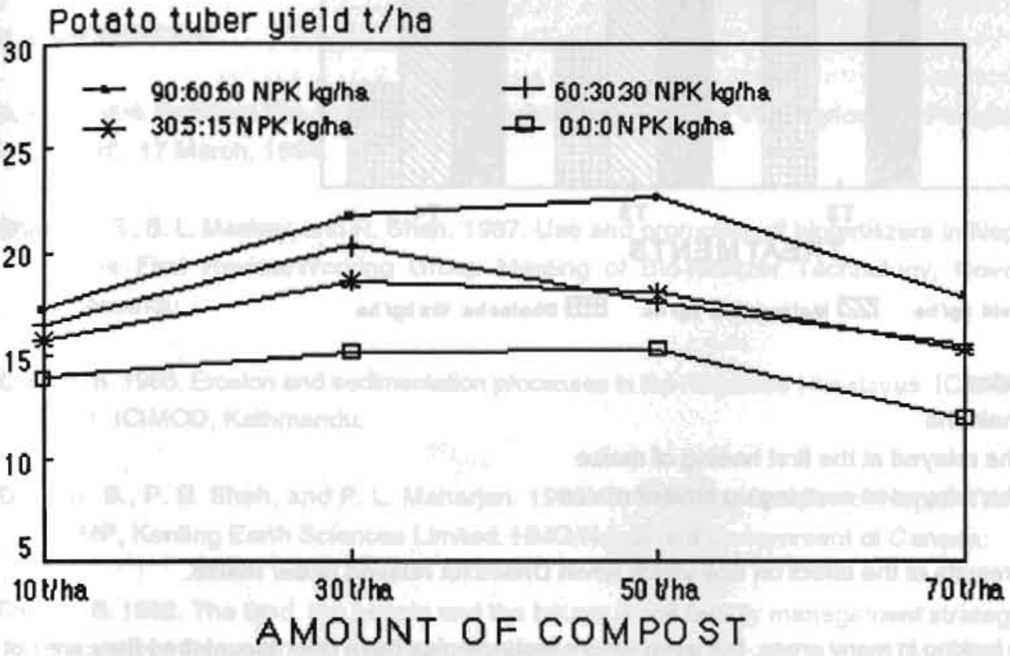
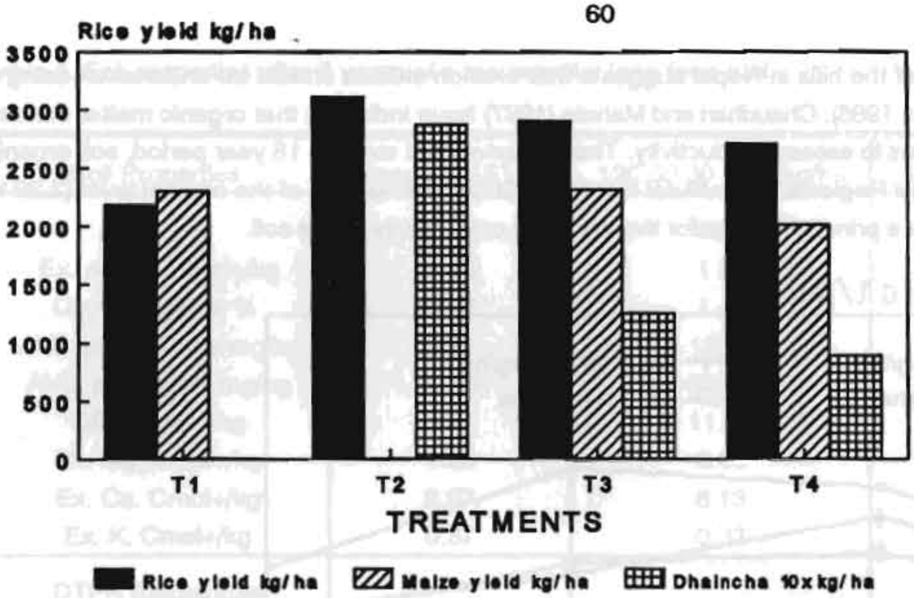


Figure 7. Response of tuber yield to combination of inorganic and organic fertilizers under potato+maize system at high altitude (mean of two years of results).

It has been shown that organic sources of plant nutrients are critical for sustaining soil fertility in the hills. There are two areas where improvements may be made. First, in the supply of farm fodder and forest materials and livestock management systems, and second, in sound production techniques and efficient application of compost/FYM for increasing crop productivity. To achieve this, research should be conducted to gain a better understanding of the dynamics of applying compost alone or in combination with chemical fertilizer. Inconsistent yield responses to Rhizobium inoculum is also an area where research is required.

Identification of research recommendations based on an analysis of biological and social factors is an important area for future work if appropriate research projects are to be developed. Earlier recommendations have been based on altitude differences, namely low (<1100 m), medium (1100 to 1750 m) and high (>1750 m). However, these do not adequately cover the biological and social diversity of the hills.

There is also a need to identify potential areas where the use of chemical fertilizers would bring significant changes in food production by supplying adequate nutrients or correcting deficiencies, or in those areas where favourable soil moisture regimes would allow maximum response to applied chemical fertilizers.



Note: T1 = Sole maize
T2 = Sole Dhaincha
T3 = Dhaincha relayed at the first hoeing of maize
T4 = Dhaincha relayed at earthing up time of maize

Figure 8. Two years results of the effect on rice yields when Dhaincha relayed under maize.

Research findings are lacking in many areas, but even where technologies have been developed they are not reaching the clients. The technology transfer system in the country should be strengthened to ensure that soil fertility management technologies are adopted by the majority of farmers. Until now, soil management technology has been treated as a complementary package of practices to be provided along with plant genetic materials, but evidence is increasingly showing that farmers do not adopt a whole package for a wide variety of reasons. Now is the time to rethink our approach in order to improve the technology adoption levels.

6. CONCLUSIONS

Recent research suggests that both organic and inorganic fertilizers are important for sustaining soil fertility in the hills, but a major emphasis should be placed on improving biologically-based technologies. At the same time, conservation and efficient utilization of natural resources: land, forest and water, are key issues in the research and development process. However, the use of chemical fertilizers cannot be ignored in the present context for meeting high food demand due to a growing population. The human dimension should not be forgotten while designing research strategies. Any strategy should identify the domain where a maximum response to applied inputs, both organic and inorganic fertilizers, can be obtained.

7. ACKNOWLEDGEMENTS

We would like to thank the Director of ICIMOD and the Project Coordinator of the MRM/IDRC Jhikhu Khola project for inviting us to attend this workshop. We are also thankful to our PAC colleagues for their comments and help in preparing this manuscript.

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A Systems Analysis of Soil Fertility Issues in the Hills of Nepal: Implications for Future Research

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1. PERSPECTIVE

Hill agriculture in Nepal is complex and precarious. Hill farming is characterized by a scarcity of arable land, diversified farming, few employment opportunities, market problems and weak institutional support to modernize agriculture. Variations in biological, physical and socio-economic influences have resulted in numerous micro-production localities. As a consequence, subsistence farming systems are highly interactive and dependent upon the forest, livestock and field crops to survive. Rapid population growth has changed the historical pattern of the use of these natural resources. A resultant decline in soil fertility has been noted by both farmers and researchers in Nepal.

Several efforts have been made to understand and address soil fertility problems in the hills (Sthapit, 1988, Subedi, 1989, Shah, 1991, Carson, 1992, Tamang, 1992, Joshi, 1994 and Joshi, 1995). Soil fertility research has been a priority issue at Lumle Agricultural Research Centre (LARC) since 1987, spearheaded by a multidisciplinary Soil Fertility Thrust. A decade of research by LARC has focussed on understanding indigenous soil fertility maintenance systems and utilizing or improving existing soil fertility practices in different agro-ecological zones. Although much work has been done, a thorough investigation of the factors influencing soil fertility was felt necessary in order to develop a future strategy.

This paper presents the findings of a collaborative study between the Soil Fertility Thrust of LARC and the Natural Resources Institute in the United Kingdom, which was conducted between May 1994 and March 1995 and covered nine hill districts of Western Development Region (WDR). The overall aim was to improve the perspectives for sustained agricultural productivity in the hills of Nepal. The specific objectives were to:

- identify, quantify and understand the factors affecting soil fertility in the hills of Nepal,
- identify among representative groupings of households the awareness and attitude to soil fertility related issues and
- formulate a long term strategy for soil fertility research for the mandate area of LARC.

The project was designed in three phases. First, an appropriate framework for soil research activities was established. Secondly, a multidisciplinary analysis was carried out, focussing on the environmental, institutional and socio-economic factors that influence soil fertility across LARC's Research Command Area (RCA) which includes Lamjung, Gorkha, Tanahun, Kaski, Parbat, Myagdi, Baglung and Syangja districts and the Palpa area. The farmers' perceptions and opinions of soil fertility were an integral part of the study and were obtained through surveys of representative houses. In the final phase, a long term strategy for soil fertility research at LARC is to be developed. The project is a relatively long exercise; therefore to limit the scope, this paper presents findings related to the second phase.

2. METHODOLOGY

The focus was on the representative farming systems in the LARC RCA, and covered systems that were locally adapted and representative of most environmental conditions in the area (Bennett, 1994). The land use systems and factors chosen in the analysis were: altitude, rainfall, fertility, management practices, accessibility, differences in proportion of khet and bari soils, population pressure, land fragmentation, *tar* areas, cropping intensity, livestock management systems, soil characteristics, forest resources, number of trees on private land, and outward sloping terraces. Seven study areas were proposed for research activities (Bennett, 1994).

Twenty eight villages within the seven study areas were visited and characterized in terms of all of the important factors in the farming systems. Thirteen sites were selected, and twenty biophysical, socio-economic and institutional factors were used to characterize all major variations in the hill farming systems of the area (Table 1). The study involved a review of soil fertility issues and the compilation of soil analysis results both from this study and previous crop cut surveys.

Table 1. Villages selected for household surveys.

Study area	Districts	Village/VDC	Altitude (masl) (Agro-ecological zone)	Accessibility (Walking distance from road head)	Market	Rainfall	Aspect
Arman	Myagdi	Kimchaur/Arman	1600-2000 (high hill)	poor (13 hrs)	poor	medium	NE
Baranja		Arman/Arman	1300-1400 (mid hill)	poor (12 hrs)	poor	low	NE
Marsyangdi River Basin	Tanahun	Chambas/Bhanu	500-580 (low hill)	good (0 hrs)	good	medium	NE
	Gorkha	Bahrapirke/ Palung*tar*	500-635 (low hill)	medium (1 hr)	medium	medium	W
Tansen Area	Palpa	Nayatola/ Kusumkhola	1100-1450 (mid hill)	medium (0.75 hrs)	medium	low	N
		Deurali/Deurali	1150-1600 (mid hill)	medium (1 hr)	medium	low	W
Dhampus, Tanchok, Landruk	Kaski	Tanchok/Lumle	1800 (high hill)	poor (3 hrs)	medium	high	NW
		Landruk/Lumle	1775 (high hill)	poor (5 hrs)	medium	high	W
Khurkot, Pang, Durlung	Parbat	Kaphalchaur/ Durlung Pang/	1200-1350 (mid hill)	medium (3 hrs)	medium	high	NE
		Pang	800 (low hill)	medium (1 hr)	medium	medium	S
Baidi Area	Tanahun	Tal bari/Baidi	740 (low hill)	poor (9 hrs)	poor	medium	NW
		Khalte/Baidi	240 (low hill)	poor (9 hrs)	poor	medium	S
Pokhara Seti River Valley	Kaski	Hyangja/Hyangja	950 (low hill)	good (0 hrs)	good	high	N

NE - North East; W - West; NW - North West; S - South; N - North

Various group discussions, field observation, RRA and PRA methods were used to collect the desired information. A detailed household questionnaire was administered to forty households within each village irrespective of village size. Within a village, households were stratified into three groups on the basis of food self-sufficiency, and random samples were drawn from each stratum in proportion to the size of the group. A total of 523 households from thirteen villages were involved in the survey. Field staff from District Agricultural Development Offices were trained and involved wherever possible.

The data was analyzed using SPSS PC+. Preliminary investigations were done using descriptive statistics (means, frequencies, graph and cross-tabulations). Further analyses were performed using correspondence analysis on multi-way tables, logistic regression on binary responses and principle component analysis on metric data (the results of the logistic regressions only are presented in this paper).

3. RESULTS AND DISCUSSION

3.1. Soil Fertility Status

The widely held view that soil fertility is declining in the hills of Nepal is based primarily on perceptions and observations with little reliance on quantitative studies. Soils analyzed during a crop-cut survey in 24 Village Development Committees (Extension Command Area, ECA of LARC) in 1991/92 and 1992/93 were examined to quantify current soil fertility status in farmer's fields. More than 300 soil samples were collected of which 70 samples are included in this analysis. It is not easy to generalize the findings in terms of statistical parameters as each specific location will demand distinct explanations due to highly diverse soil environments.

Using the critical levels defined by Landon (1992), 85% of soil samples had low-to-medium nitrogen (N), indicating N as a major limiting nutrient. A large variation in phosphorus (P) levels was found but the majority of soils have medium-to-high phosphorous content and 60% of the K values lay in the range of 0.1 to 0.3 meq/100g soil, indicating low-to-medium exchangeable K status (Table 2).

Table 2. Properties of soil samples.

Soil Property	Mean (n=596)	Rating*	Range	Khet (n=247)	Bari (n=340)
pH (Soil:Water 1:2.5)	5.6±0.02	medium	4.1-7.6	5.54±0.03	5.6±0.03
Organic Carbon (%)	2.94±0.04	low	0.2-7.0	2.59±0.06	3.2±0.06
C/N Ratio	12.78±0.20	-	2.4-56.5	12.77±0.32	12.78±0.25
Total N (%)	0.26±0.004	medium	0.001-0.8	0.22±0.01	0.27±0.01
Available P (ppm)	153±8.0	high	1.3-1698	122.9±9.5	174±13.04
Exchangeable K (meq/100g)	0.37±0.01	medium	0.04-4.64	0.28±0.01	0.44±0.02

* Refers to values given in Landon (1992); samples include RCA and ECA.
Source: Soil analysis of crop-cut survey: 1991/92 and 1992/93.

Bari soils have significantly higher ($p \leq 0.05$) levels of organic carbon (OC), total N, available P and exchangeable K than khet soils. It is generally believed that farm yard manure (FYM) application on bari land is higher due to the nature of crops grown and proximity to homesteads where livestock are kept. This is also to balance nutrient loss from erosion by surface run off which may partially be gained by khet land accumulations of humus and sediments. However, cropping intensity and accessibility to market determine the amount of FYM and chemical fertilizer used.

The use of farmers' classification of soils is widely accepted. Throughout the visited area, *rato mato* (red soil) and *kalo mato* (black soil) are the common soil types. Farmers regard *kalo mato* as fertile soil because it contains higher organic matter and moisture regime compared to *rato mato.* This can be substantiated from the soil analysis report (Table 3) which shows that *kalo mato* has significantly higher OC, N and P ($p \leq 0.05$).

Table 3. Soil properties of *Kalo mato* and *Rato mato.*

Soil property	*Kalo mato* (n=159)	*Rato mato* (n=77)
pH	5.7±0.04	5.6±0.01
Organic Carbon(%)	3.1±0.08	2.9±0.11
Total N (%)	0.27±0.01	0.22±0.01
Available P (ppm)	138±18.59	102.0±19.3
Exchangeable K (meq/100 g soil)	0.39±0.03	0.46±0.05

Source: Soil analysis of crop-cut survey, 1991/92 and 1992/93.

3.2. Fertility Management Dynamics

Interdependence between crops, livestock, forests, fodder and compost are the key issues in hill farming systems in Nepal. The livestock, forests and crops contribute to the synthesis of compost or FYM which are the major sources of plant nutrients. Inevitably, the availability of compost forms the basis for most of the soil fertility regimes in traditional hill farming practices, and fertility dynamics are the result of interactions between existing components of the farming systems.

The traditional soil fertility management in the hills is a dynamic process which adjusts to changes in resource availability, socio-economic and institutional factors. No farmer in the study area reported using `improved' techniques of compost preparation. The PRA investigation shows that FYM is still the dominant source of plant nutrients, although the degree varies across agro-ecological zones (Figure 1). In the high hill and inaccessible areas, the role of FYM is predominant in supporting traditional farming systems, but the use of chemical fertilizers is important in low and middle hill areas where access to markets and inputs is better. Fertilizer use is higher on khet land than on bari land.

In the high hills where in-situ manuring is declining and in the low hill sites where cropping intensification is higher, a shift towards intensive management of khet land has been observed. This is the reverse of the situation 10-15 years ago. Changes in soil fertility management strategies with time are well illustrated by the case of Chambas, a low hill village. Ten years ago, management on bari land was more integrated, but now, the contribution of chemical fertilizer has increased and in-situ manuring is no longer used. It is apparent that management of khet land is becoming more integrated with increases in FYM use along with legume and trash burning. Fallowing, which was the most important strategy in the past, is no longer practised. There are few changes in high hills and inaccessible areas. Pang, a classic case of a low hills system with almost no access to forest resources, has undergone hardships during the protection stage. This has forced farmers to use chemical fertilizers even though they know that the soils are being eroded.

3.3. Farm Yard Manure

The pressure on the resources has also changed the pattern of uses. FYM is still the major nutrient source (Figure 1), and changes in strategies have not reduced its importance. In the high hills, reductions in livestock numbers have induced collection of leaf litters to maintain the quantity of FYM produced. Mid and low hill lands have experienced a decline in the proportion of plant residues due to forest restrictions and labour shortages, although crop residues and remaining twigs of fodder compensate to some extent. This is because byproducts such as straws and twigs are also used for fuel, thatching, fencing and matting purposes.

Traditionally, the majority of FYM went to the bari land. Some 63% of the farmers reported no change in the patterns of distribution between khet and bari. Nevertheless, there is a gap between demand and supply of FYM due to the range of factors discussed above (Figure 2).

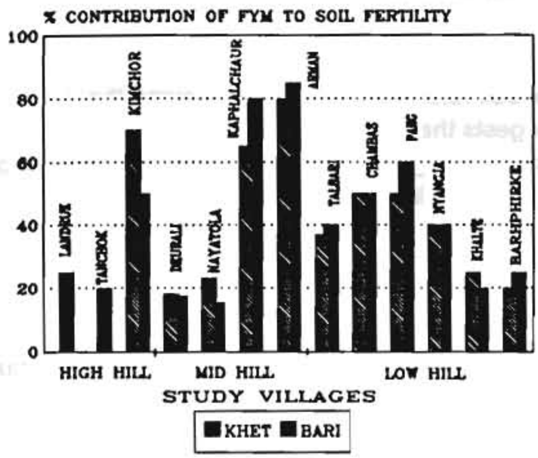


Figure 1. Contribution of FYM to soil fertility in study villages.

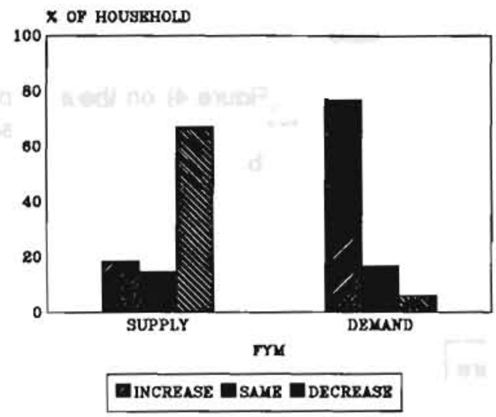
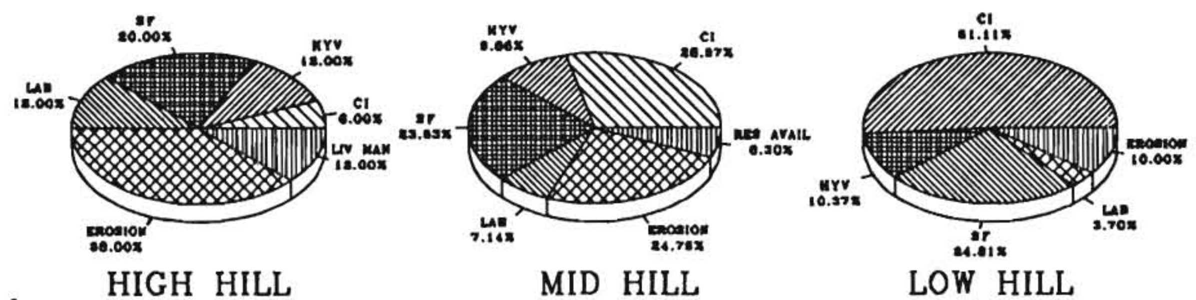


Figure 2. Demand and supply of FYM.

PRA investigation shows that, in low and mid altitudes, FYM is diverted to khet in order to meet the demand of crop intensification. However, Hyangja, Pang and Talbari (low hills) reported a decline in FYM contribution. Chambas and Arman are sites with low forest resources, and they reported increased use of FYM on both khet and bari. Erosion and decline in soil fertility are the major reasons cited by farmers for the increasing demand for FYM (Figure 3). The contribution of soil erosion increases with increasing altitude, while cropping intensity and use of high-yielding varieties (HYV) have contributed in increasing the demand in the low hills.



3.4.

Figure 3. Major reasons for increasing demand of FYM.

Key: CI=Cropping Intensity; SF=Soil Fertility; LAB=Labour; LIV MAN=Livestock Management; RES AVAIL=Resource Availability; HYV=High Yielding Variety

3.4. Chemical Fertilizers

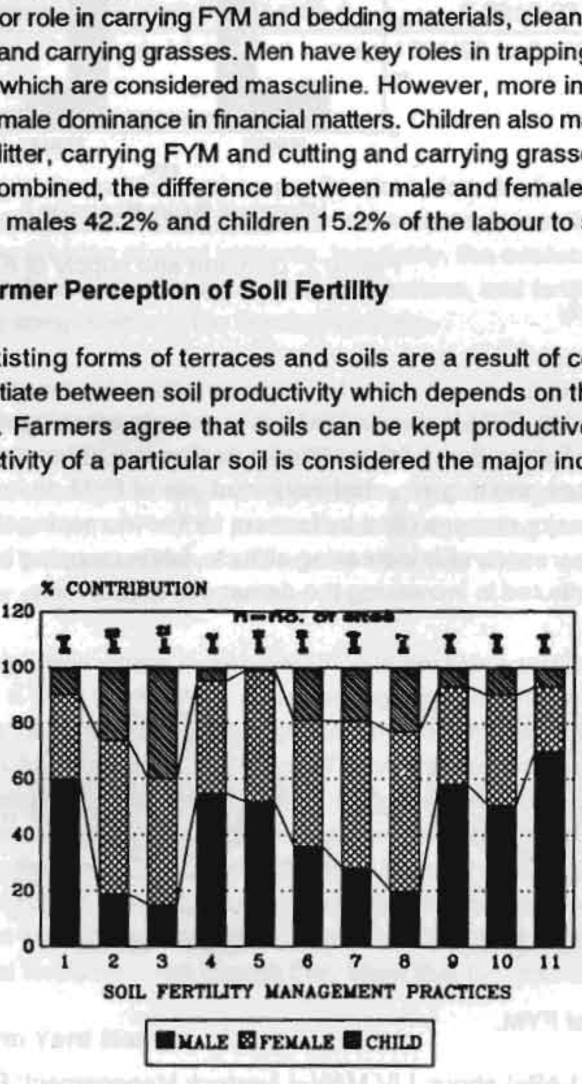
The use of chemical fertilizer is significantly correlated ($p \leq 0.001$) with altitude, accessibility and markets. Overall, 39% of the farmers are using fertilizer, 7% used it previously but stopped using it, 46% never used fertilizers and 8% are occasional users. Of those who use fertilizer, 87% come from the low hills, followed by 19% in the mid hills, and 85% of fertilizer users are located less than two hours' walking distance from the road. Farmers are aware of the negative effects of fertilizers on soil properties. Farmers from Bowa Pokhara in Palpa related declining performance of legumes to the use of chemical fertilizer.

3.5. Gender Roles in Soil Fertility Management

PRA investigations (Figure 4) on the division of labour for soil fertility management showed that there are variations in activities between study villages. Figure 4 suggests that all activities are shared between men, women and children, but the degree of involvement varies according to the nature of the work. Women play the major role in carrying FYM and bedding materials, cleaning animal sheds, spreading FYM on the field, and cutting and carrying grasses. Men have key roles in trapping flood water, turning FYM heaps and work related to *goth* which are considered masculine. However, more involvement of men in purchasing chemical fertilizer shows male dominance in financial matters. Children also make useful contributions, especially in the collection of leaf litter, carrying FYM and cutting and carrying grasses. When all reported activities in the thirteen sites were combined, the difference between male and female contributions was negligible. Females contributed 42.6%, males 42.2% and children 15.2% of the labour to soil fertility management practices.

3.6. Farmer Perception of Soil Fertility

The existing forms of terraces and soils are a result of continuous efforts over many generations. Farmers differentiate between soil productivity which depends on the human-managed status of soil and inherent soil fertility. Farmers agree that soils can be kept productive if sufficient manure and moisture are available. Productivity of a particular soil is considered the major indicator of soil fertility.



Key: (1) work in *Goth* and in-situ manuring; (2) carrying FYM; (3) collection, carrying of leaf litters and trash burning; (4) work in sheep *goth*; (5) application of chemical fertilizer; (6) cleaning animal sheds; (7) spreading FYM on the field; (8) cutting and carrying grasses; (9) turning compost heap; (10) carrying chemical fertilizer from sale depot; (11) trapping flood water.

Figure 4. Gender contribution in soil fertility management practices.

Farmers from Pang also differentiate between soil productivity and soil properties stating that, although crop yields have increased (soil productivity), soil properties have deteriorated (*mato bigrio*), and soils are becoming less fertile (*rukho*). Here farmers increased fertilizer use to compensate for declining FYM output due to changes in the forest resource base and restrictions in forest use. Therefore, FYM or nutrient requirements can be a proxy indicator of soil fertility status.

Farmers use a range of parameters to characterize local soils, such as crop suitability, productivity, water holding capacity, ease of working with the soil, drainage, and assessment of amount of FYM or nutrient requirement as measures of yield. For example, farmers from the Marshyangdi river basin explain that *rato mato* (red soils) are rated poorly because they are difficult to manage due to their depth, and clay loam structure.

3.7. Soil Fertility Trends

Farmers widely support the view that declining soil fertility is a major problem in the hills irrespective of land type (Figure 5). Of the households surveyed, 67% reported a decline in fertility on bari lands and 61% on khet lands. No clear pattern can be seen across the sites, but more problems were observed in the low hills with higher cropping intensification and in higher inaccessible areas.

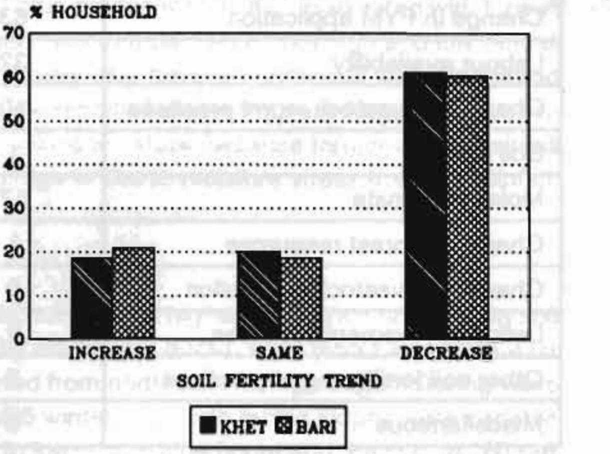


Figure 5. Soil fertility trends on khet and bari.

The farmers' perceptions of the reasons for declining soil fertility are given in Table 4. Perceptions vary across the agroecological zones and between khet and bari lands (Figures 6 and 7).

On bari lands, erosion is regarded as the major factor in decreased fertility in the high and mid hills (Figure 6). In the low hills, the decline is related to reductions in FYM output, and adverse effects such as cost and unreliable supplies of chemical fertilizers. Across the zones, other important factors are dwindling forest resources, livestock management, forest access and FYM demands and supplies.

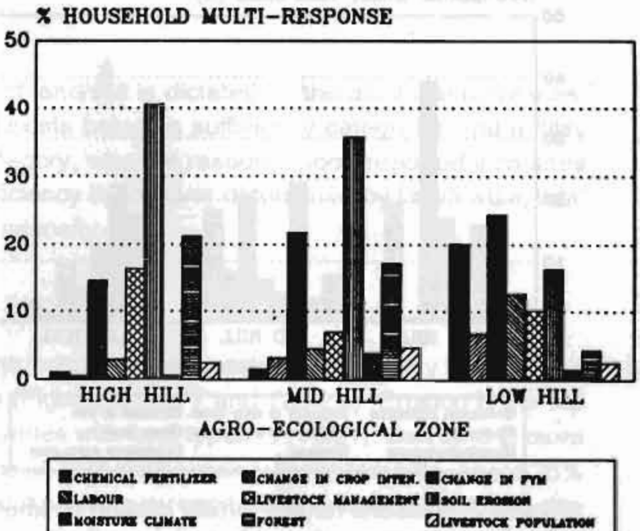


Figure 6. Reasons for soil fertility decline on bari lands.

Khet lands also present a similar picture to bari in the high and mid hills (Figure 7). In the low hills, the khet problem is related to higher fertilizer use due to crop intensification and shortage of FYM. The importance of labour increases with decreasing altitude.

Summer maize, paddy, upland rice (*ghaiya*) and spring maize were taken as reference crops to assess the effect of soil fertility trends in different land use systems. Declining crop productivity in summer maize (60%), paddy (53%), *ghaiya* (53%), and spring maize (49%) was reported.

Association of crop productivity trends with agroecological zone, accessibility, market, rainfall and aspect were tested. All of these factors have significant relationships ($p \leq 0.03$) with soil fertility trends in summer maize, paddy, and *ghaiya* except for agro-ecozone and rainfall on *ghaiya* and for rain on spring maize.

Table 4. Reasons for changes in soil fertility (multi-response frequencies).

Reasons for changes in soil fertility	Soil fertility trend on bari		Soil fertility trend on khet	
	increase	decrease	increase	decrease
Use of chemical fertilizer	26	71	33	77
Change in crop intensity	19	31	28	53
Change in FYM application	63	165	50	114
Labour availability	32	59	17	46
Change in livestock mgmt practices	10	85	2	46
Soil erosion	1	229	0	103
Moisture/climate	17	16	22	19
Change in forest resources	1	102	0	60
Change in livestock population	0	25	0	17
Land improvement practices	2	1	1	0
Other soil fertility mgmt practices	5	0	6	1
Miscellaneous	0	4	0	0

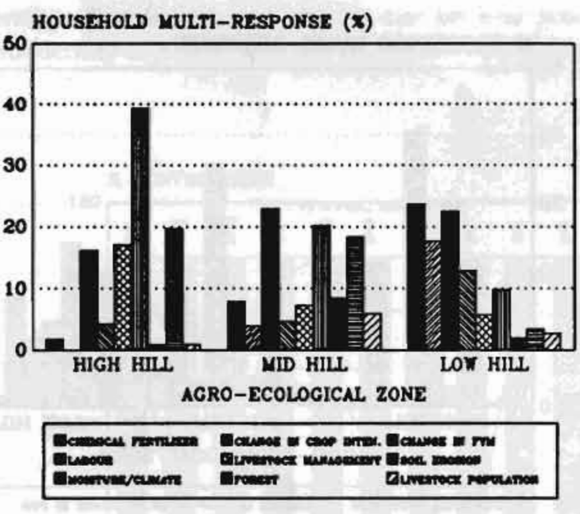


Figure 7. Reasons for soil fertility decline on khet.

Declining productivity of these crops has been mainly associated with change in soil fertility, use of high yielding varieties (HYV), increase in cropping intensity, uncertain climate and moisture stress, adverse effects of chemical fertilizer and its unreliable supply, and FYM supply. However, the emphasis changes as altitude changes. The effects of disease/pests, chemical fertilizer and labour increase in the lower hills. Labour is cited as an important constraint in *ghaiya*.

3.8. Soil Fertility Status Determinants

The issue of soil fertility in an interactive hill farming context is complex because several factors are involved. The fertility trends as discussed below refer to the human-managed level of fertility and not inherent soil fertility. Soil fertility in Nepal can be maintained by management practices, not by inherent properties of soils (Carson, 1992).

3.8.1. AGROECOLOGICAL ZONES

Agroecological zones are synonymous with altitude and sites were classified as high (>1500 m), middle (901-1500 m) and low (<900 m asl) hill sites. A significant relationship ($p \leq 0.001$) exists between fertility trends on khet and bari lands and agroecological zones. Across the agroecological zones and irrespective of land types, over 60% of households report declining soil fertility. However, both on bari and khet, the incidence of increasing and decreasing soil fertility trends are higher in the low hills and more stagnant in the mid hills. Decreasing trends are highest in high hills (74% on khet and 78% on bari).

3.8.2. ACCESSIBILITY AND MARKETS

Accessibility and markets are related to the level of infrastructure, and both influence soil fertility. Fertility in areas with good markets has a higher probability of increasing than in remote areas. Increases in soil fertility along roads (Chambas/ Hyangja) are related to chemical fertilizer use and crop intensification (Table 5).

3.8.3. RAINFALL

Rainfall has a significant effect ($p \leq 0.001$) on soil fertility and crop productivity as it is associated with topsoil erosion. Increases in soil fertility are reported from medium rainfall sites and decrease from high and low rainfall sites in maize, rice and *ghaiya*. Problems of moisture and timely rain have an immense value in rainfed agriculture. An irregular pattern or low amount of rainfall is widely reported especially from Palpa and Myagdi. This has served to mask the importance of soil fertility issues during the study because farmers relate rainfall and fertility to crop productivity. In Palpa, low winter crop coverage is due to moisture stress from low rainfall.

3.8.4. ASPECT

A significant relationship was found between aspect and fertility trends. The highest incidence of declining soil fertility is reported from south facing villages (77%), followed by north-west (69%), west (65%) and north-east (49%). Higher incidence of increasing fertility was also reported from north-east facing villages. During visits in western Palpa, which received almost no rain during 1994/95 winter, the north facing slopes were capable of raising winter crops. North slopes conserve moisture due to lower sunshine hours and Joshi *et al.*, (1994) reported mandarin orchards facing North perform better.

3.8.5. FOOD SUFFICIENCY

A general hypothesis is that the quality of management of land/soil is dictated by the available resources. However the results show that a significant relationship exists between sufficiency categories and fertility trends on bari land ($p=0.03$). Some 54% of the <6 month category, who are resource poor, reported increases in soil fertility while 38% reported constant fertility. Food deficiency is however determined by family size, total cultivable land per capita, area of khet land and cropping intensity.

3.8.6. EROSION

Soil erosion is perceived by the farmers as the largest contributor leading to a decline in fertility both on bari and khet, becoming more important as altitude increases (Figures 6 and 7 and Table 4). Erosion is the top problem for 99% of the high hill farmers, but the problem varies with land types ($p \leq 0.001$). Bari land is more prone to erosion forces (53%). Farmer also reported problems on khet (12%) mainly in the low hills. About 35% of the farmers reported problems both on khet and bari. High hill sites have reported more loss of khet land due to landslides. Women in Kimchor associated increased run-off with degradation of forests, excessive collection of leaf litter and reduced natural regeneration of forests.

Palpa presents an interesting case for soil erosion. Land is on outward sloping terraces with high clay content and low rainfall (<1500 mm per annum). Coarse and stony structure on the surface indicates severe erosion. Fifteen to thirty centimetres of soil is lost every year from the top edge of the terrace leaving behind a barren sub-soil. The barren top edge is normally covered by ground grasses and fodder material. Farmers often plant *Khar* grass (thatching grass) as a last resort. Significant areas of land have been abandoned 50-70 years after the start of cultivation.

The erosion has resulted in a steady decline of crop productivity. Ploughing also causes soil movement on sloping terraces. Traditionally large terraces are symbols of social prestige and associated with ease in ploughing. High clay content in the soil in the region can cause waterlogging and slumping of terraces (Carson, 1992) if bench terraces are made. The explanation partly lies with return to investment where terrace improvement will hardly make any difference without irrigation and other inputs. Even *tars* were turned into khet terraces soon after irrigation was available.

Table 5. Summary of categorical factors affecting soil fertility on khet and bari.

Factors	Categories	khet (n=513)			bari (n=397)		
		Increase	Same	Decrease	Increase	Same	Decrease
Agro-ecozones	high hill %	6.1	19.7	74.2	12.1	10.3	77.6
	mid hill* %	3.7	31.5	64.8	11.1	44.8	32.2
	low hill* %	30.7	14.1	55.1	24.4	15.1	60.5
	Chisq p	<0.001			<0.001		
Accessibility	> 2 hrs %	17.8	11.8	70.4	39.5	24.1	52.8
	0 hr %	51.6	16.1	32.3	41.3	23.8	35.0
	< 2 hrs %	7.3	29.1	63.6	8.1	23.7	68.2
	Chisq p	<0.001			<0.001		
Market	good %	41.3	23.8	35.0	51.6	16.1	32.3
	medium* %	7.3	20.1	72.6	6.1	25.9	67.9
	poor* %	17.6	8.2	74.2	24.8	10.5	64.8
	Chisq p	<.001			<.001		
Rainfall	high %	18.4	24.0	57.6	16.8	23.9	59.4
	medium %	24.5	17.9	57.6	19.7	14.7	65.5
	poor %	4.3	18.6	77.1	18.9	20.4	80.7
	Chisq p	<0.002			<0.001		
Aspect	NE %	23.9	27.0	49.1	20.9	24.3	54.8
	NW %	24.1	7.4	68.5	14.5	9.2	76.3
	S %	14.9	8.1	77.0	7.7	5.1	87.2
	W %	9.8	25.0	65.2	11.7	15.0	73.3
	Chisq p	<0.001			<0.001		
Food Sufficiency	> 12 months	15.2	15.2	69.5	10.5	14.0	75.4
	6-12 months*	17.9	22.2	59.9	12.8	19.5	67.7
	< 6 months*	23.2	21.4	55.4	21.6	16.2	62.3
	Chisq p	0.239			<0.030		

Note: % = row percentage, n = no of respondents, NE = North-East NW = North-West, S = South, W = West, * = level is significantly different (<0.05) for both khet and bari from reference category in logistic regression

3.8.7. LIVESTOCK SYSTEMS

Total livestock units were calculated using the formula published by Rajbhandary and Pradan (1989) for each household across the agroecological zones. The study involved cattle, buffalo, goat and sheep. Unit numbers do not vary significantly (p=0.08) across the agroecological zones, but the actual livestock numbers do (p=0.007). For example, higher numbers of cattle per household were found in the low hills whereas buffalo numbers were higher in the high hills.

The change in livestock population across agroecological regions in last 15 years is shown in Figure 8. The livestock population has decreased by 46.6%, but the number of households keeping livestock grew by 3.0%. About 4.5% of the households do not have livestock. The high hills had the highest potential to keep larger herds, but: (1) a sharp decline in transhumance, (2) in-situ manuring in the high hills, (3) an emphasis on strengthening private land resource, (4) a scarcity of labour, (5) an increase in number of school children, and (6) a change in livestock management can explain the change.

Surprisingly livestock units and livestock numbers do not influence soil fertility. Instead, caste and markets influence livestock numbers (p=<0.001).

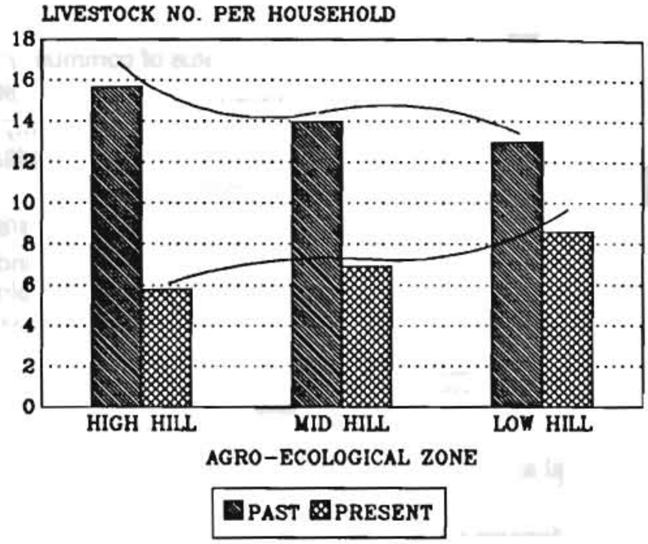


Figure 8. Trend of livestock no. per household in past and present across agro-ecological zones.

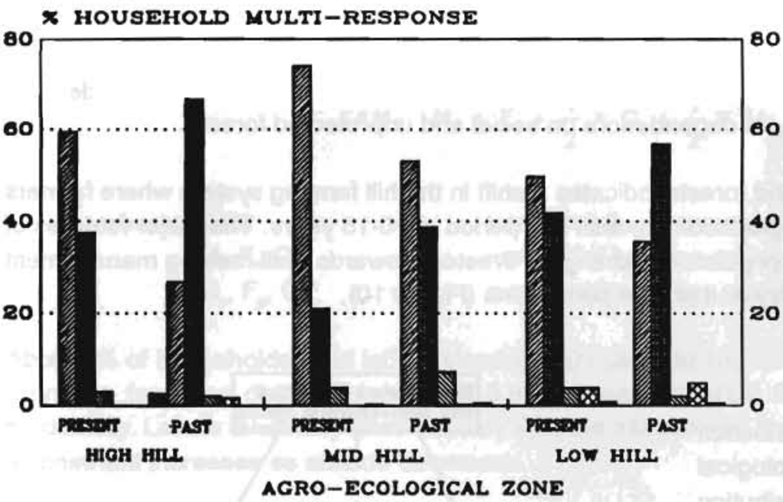


Figure 9. Livestock management practices in past and present across agro-ecological zones.

Note: SF in mon.= stall-fed in monsoon; SE in win= semi-extensive in winter.

There has been a marked shift in livestock management in the hills to respond to changes in the resource base. Six major types of management systems have been reported: stall-fed, semi-extensive, *goth*, *goth* + stall-fed, stall-fed in monsoon, semi-extensive during winter and kharka (Figure 9). On average there is a 31% increase in stall-feeding, 36% decrease in semi-extensive feeding, a slight increase in *goth* and an almost disappearance of the transhumance (*Kharka)* system. Stall feeding is more popular in mid hills, but around 50% of the livestock in the high and low hills is managed under the semi-extensive system. It is not the number of animals kept which is important from a soil fertility point of view but the management of manure. The increase in stall feeding has apparently increased manure collection and consequently the amount of FYM available despite decreases in livestock.

3.8.8. FOREST RESOURCES

Promotion of community forestry has brought positive changes across the region as it shifts authority to the local user. In many cases, although the status of community forest has not yet been attained, local people and traditional institutions prevailing in the Nepalese hill society enforce regulations to maximize social welfare, protect natural resources and maintain their cultural integrity (Vaidya, 1991). However, in Chambas (low hills), this has not been possible due to demographic and politico-social problems. Bowa Pokhara Thok in Palpa reported protection in 1967/68 and has experienced an increase in livestock population as an effect. Landruk and Tanchok in the Annapurna Conservation area are experiencing strong conflicts with wildlife causing considerable damage to crops. Pang in the low hills is undergoing hardship due to restricted access.

Deforestation has an indirect effect on soil fertility. Forests have contributed to declining crop productivity from 4% to 40% on bari and 3%-20% on khet lands. Dependence on forest resources increases as altitude increases which suggests the interdependence between forest, livestock and crops becomes less as elevation decreases. This is possible because land can be managed with reduced FYM at lower elevations due to biophysical and institutional advantages such as fertiliser and green manures.

Only 25% farmers across all domains reported an increase in availability of forest resources, 38% reported a decline and 20% were unchanged. There is a significant difference on the state of social and community forestry across the agroecological zones ($p \leq 0.001$). Highest increases after the declining phase (51%) were reported from the mid hills. The increases reflect the positive effect of social/community forestry and indicate that the system is recuperating even though the declining trends in the mid and low hills show sustained pressure on forest resources. No change in the availability of resources was reported by 48% of high hill respondents, and 37% reported increasing availability after a decreasing phase. It is interesting to note that 98% of cases reporting no access to forests came from the low hills signifying greater pressure on forest resources. In response, more trees are being planted in the low hills (49%) followed by the mid hills (30%), though it is not statistically significant. Farmers in the lower hills depend on private farms for fodder and bedding materials whereas high hill farmers depend more on social and unprotected forests.

The preceding discussion on livestock and forests indicates a shift in the hill farming system where farmers have modified the system to arrest the degradation process in a period of 10-15 years. The major features of the shift are a drastic reduction in livestock population, a change of livestock towards stall-feeding management and more emphasis on community forestry and private plantations (Figure 10).

3.8.9. ETHNIC GROUP

There is a significant variation in the distribution of ethnic groups across the agro-ecological zones ($p \leq 0.001$). A clear pattern of distribution can be observed in the study area, with Brahmin and Chetries concentrated in the lower hills and valleys with better farming prospects and Gurung and Magar in higher mountains. Middle hills are often inhabited by mixed communities. Occupational castes are an integral part of any society.

Ethnic group also influences the fertility status of both khet and bari ($p \leq 0.01$). Decreasing soil fertility on bari is associated more with Brahmin/Chetries (31%) and Gurung/Magar

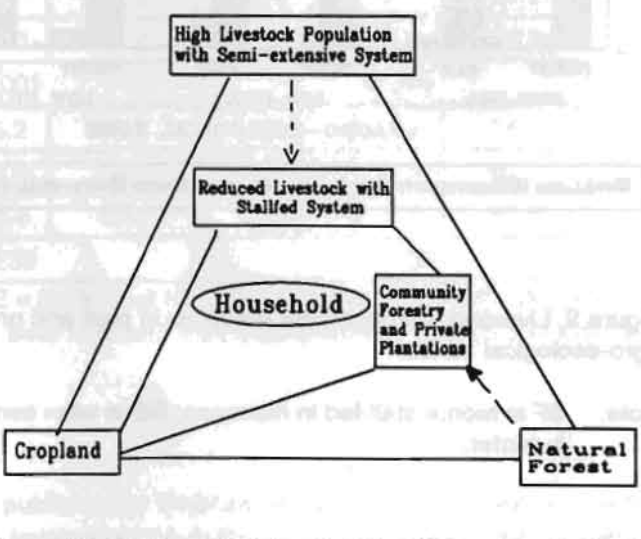


Figure 10. Shifting triangle of hill farming system (adapted from Joshi, 1994).

(39%). Only 14% of households from occupational castes reported declining soil fertility. A similar trend was evident on khet.

3.8.10. LAND HOLDINGS

No association between land fragmentation, distance to fields from homestead and size of holding with soil fertility was evident. Given that hill farming is essentially subsistence in nature with low opportunity cost of farming activities and very low land holding size in the hills (0.68 hectare per household in the study area), it can be argued that management will not be influenced by these factors. Similar explanations also work in Tanchok and Landruk where households have pension and tourism incomes.

The size of land holding is certainly related to ethnicity and agroecological zones ($p \leq 0.001$). Brahmin/Chetri and Gurung/Magar have larger holdings compared to occupational castes. About 61% of occupational castes own less than two ropani (0.1 hectare) of total cultivable land. The size is inversely related to altitude; however, the mid hills are densely populated which reduces the land per household. No association with soil fertility could be found.

3.8.11. LABOUR

Hill farming is traditional and labour-intensive. Therefore, total able manpower within the household, labour supply in the market during peak season, migration and opportunity cost of labour (market wage) affect farming activities as a whole. The increasing number of school children, positive impact of family planning, and tourism opportunities are reported to have affected the labour available for hill farming in the study area.

Total available manpower affects number of livestock reared ($p=<0.001$) but does not influence productivity on khet or bari. The total available manpower is defined as follows:

$$TAM \quad M_f + F_f + \frac{1}{2} \times C_f + \frac{1}{2} \times (M_p + F_p + C_p)$$

where: TAM	=	total available manpower
M_f, F_f, C_f	=	number of full-time males, females and children respectively
M_p, F_p, C_p	=	number of part-time males, females and children respectively

About 8% of households cited labour shortages (household and hired) as a reason for declining soil fertility. From the foregone discussion (section 3.8.7), it was apparent that livestock numbers do not influence productivity. Labour availability does not vary with the altitude and food sufficiency levels. However, labour as a constraint increases as altitude decreases.

3.8.12. LAND TENANCY

Land tenancy is expected to influence soil fertility management practices (Regmi, 1976; Tamang, 1993). Zaman and Regmi (1976) discussed lower output per unit area from tenant-cultivated land compared to owner-cultivated land. In the study villages, 26% of farmers are involved in land tenancy arrangements. Almost 90% of farmers who rent-in land are from the <6 months category (46%) and 6-12 months category (43%), while the majority of farmers from the >12 months category do not hire-in land ($p=<0.001$). Similarly 49% of those who rented-out came from the >12 months category ($p=<0.001$).

The majority of tenancy land is under a share cropping arrangement (57%), others being contract (14.5%) and various combinations depending on land types. There is 51% tenancy under unassured tenancy, 21.5% mortgaged land kept until a loan is repaid and 21% ranging from one season to five years. Tenancy applies to all crops in 73% of cases and 19% reported that it applies to rice only. Tenancy is found equally both on khet and bari. Over 80% of farmers do not discriminate between owner-cultivated land and tenant land. Manure application is primarily the responsibility of the tenant (80%), in 11% of cases both tenants and owners apply manure and in 5.5% of cases only the landowner reported responsibility for manure application.

It is believed that tenants try to maximize output, and it could be argued that fertility management is compromised. Hill farmers are cautious about long term management of soils and are particularly concerned about degradation in soil properties related to chemical fertilizers. In Chambas, landlords make an agreement with the tenant that chemical fertilizer will not be applied in return for which the landlord agrees to contribute FYM. In Mustang, where tenancy arrangements are skewed in the tenants favour, farmers reported relaxation of fertility management towards the end of the contract (Joshi, 1994). However, the study failed to detect any relationship between land tenancy and trends in soil fertility on bari and khet.

A shortage of labour was reported by 74.5% of households as the main reason behind renting out land, while 20% mortgaged their lands because of indebtedness. Other reasons were a shortage of manure, excess land, physical inability and distant land parcels.

4. PREDICTION OF SOIL FERTILITY DECLINE

Soil fertility is the effect of several factors within and outside the farming system including state policies. Deforestation and demographic pressures leading to environmental degradation have brought a series of changes in patterns of resource usage which eventually impact soil fertility. Assuming an influence on the parameters under study, a logistic regression model was prepared taking households as the unit and using several key factors acting in hill farming systems which are expected to influence soil fertility trend on bari and khet. The independent variables used to predict soil fertility trends were food sufficiency category, ethnic group, sex of respondent, livestock management, total FYM output, total FYM going to bari and khet, forest index (indexed from fodder sufficiency, availability of resources in community forest, fodder from private land and trend in natural forest), fodder ratio (public: private source), total livestock units, livestock and management index (livestock unit and management combined), khet:bari ratio, market, rain, aspect, accessibility, agroecological zones, area and parcel of cultivable land and tenancy arrangements.

This model includes both categorical and continuous variables. A forward step method was used. For categorical variables, the reference category set for food sufficiency was the >12 months group, for ethnic groups, Brahmin and Chetri, for market, good, for respondent sex, male, for rain, high, for livestock management, stall-fed, for agro-ecozone, high hill, and for land tenancy arrangement, share cropping. The dependent variable has two values, 1 which means increasing or the same and 2, decreasing. For analysis purposes, increasing is considered as zero.

4.1. Model for Declining Soil Fertility on Bari

The model takes only six variables to predict soil fertility trends on bari (Table 6). These are food sufficiency, amount of FYM per unit bari land, forest index, market, rain and agroecological zone. Regression coefficients suggest that the <6 month category has more chance of increasing soil fertility than the 6-12 month group. Forest index has a larger effect than FYM. Locations with poor markets will have a chance of severe fertility problems. Medium rainfall is likely to favour increasing fertility than low rainfall. The chance of increasing soil fertility is greater in the mid hills than the low hills.

This model classifies 76% of responses correctly. Partial correlation shows a greater influence of market and agroecological zone on soil fertility trends. Using regression coefficients, the probability of decreasing soil fertility can be calculated for any particular household using the following equation:

$$\textit{Prob (decreasing soil fertility)} = \frac{1}{1+e^{z}}$$

where: z = 3.489+[0 or (-0.875 x category 2) or (-1.09 x category 3)]
+ (-0.015 x bari FYM) + (-0.35 x forest index)
+ [0 or (2.146 x medium market) or (2.617 x poor market)]
+ [0 or (-1.025 x medium rain) or (1.39 x poor rain)]
+ [0 or (-2.5 x mid hill) or (-0.824 x low hill)]

Table 6. Parameter estimates for logistic regression model on bari.

Variable	Regression coefficient (B)	Sig	Partial Correlation (R)
Food sufficiency category		.035	.089
Category 2 (6-12 month)	-.878	.028	-.091
Category 3 (<6 month)	-1.086	.015	-.107
FYM per ropani on bari	-.015	.013	-.110
Forest index	-.350	.010	-.120
Market		.000	.184
Market (medium)	2.146	.001	.160
Market (poor)	2.617	.000	.197
Rainfall		.007	.130
Rainfall (medium)	-1.025	.097	-.047
Rainfall (low)	1.390	.012	.113
Agro-ecozone		.001	.179
Agro-ecozone (mid hill)	-2.505	.000	-.194
Agro-ecozone (low hill)	-.824	.205	.000
Constant	3.489	.005	

4.2. Model for Declining Soil Fertility on Khet

The model takes only six variables to predict soil fertility trend on khet and classifies 70% of responses correctly (Table 7). This model explains a similar probability trend of selected variables as on bari. Logically, the forest index is lower on khet than on bari but more important than total compost.

5. CONCLUSIONS

1. The study was based on farmers perceptions, intensive visits to the study area and discussions with farmers. Although these findings may not provide the accuracy that direct measurement would have, given the resource and time constraints, information generated should be an adequate basis for the final phase of the project which is to produce a long term strategy for LARC soil fertility research.

2. Although farmers have often been blamed for resource degradation the results suggest that they have contributed towards reversing the process by adjusting various components of farming systems to the new resource base.

3. Soil fertility decline both on bari and khet has been widely reported. Major reasons cited for the decline in soil fertility are due to a decline in FYM supply, erosion, change in forest resources and problems associated with chemical fertilizers.

4. Logistic regression shows the effects of market and agroecological zones on soil fertility which are associated with accessibility. Lower hills with access to inputs have a greater chance of increasing soil fertility. This creates two distinct soil fertility domains, one with a greater potential of increasing productivity using external inputs such as chemical fertilizer and pesticides, and the second, inaccessible areas away from markets where traditional methods will continue as fertilizer use may not be feasible or practical.

Table 7. Parameter estimates for logistic regression model on khet.

Variable	Regression coefficient (B)	Sig	Partial Correlation (R)
Food sufficiency category		.048	.076
Category 2 (6-12 month)	-.603	.086	-.051
Category 3 (<6 month)	-.993	.015	-.105
FYM per ropani on bari	-.291	.020	-.097
Forest index	-.022	.022	-.095
Market		.001	.162
Market (medium)	1.986	.003	.140
Market (poor)	2.641	.001	.178
Rainfall		.001	.189
Rainfall (medium)	2.356	.001	-.174
Rainfall (low)	.803	.126	.031
Agro-ecozone		.006	.133
Agro-ecozone (mid hill)	1.955	.001	-.152
Agro-ecozone (low hill)	-.196	.722	.000
Constant	2.710	.017	

6. RECOMMENDATIONS

1. As a result of the study, thirteen villages have been identified in seven study areas. The framework for research using existing farming systems and identified study villages can be used for future research activities.

2. Upgrading the necessary data bases and developing recommendation domains around study villages should be a priority.

3. FYM is the output of a farm where all components of the farming system contribute as well as socio-economic and institutional factors. Nevertheless, understanding why farmers do not accept improved methods of compost preparation is as important as improving quality, minimizing the loss of nutrients and increasing efficiency. FYM has crucial role in high and inaccessible areas. Therefore understanding nitrogen and carbon dynamics for this domain is important.

4. Problems of erosion in the high hills and on outward sloping terrace call for immediate research and extension attention. The extent of erosion problems on khet land reported by farmers requires further investigation.

5. A high response related to negative effects of fertilizers shows a lack of research and extension about the correct use and combination of fertiliser. In the light of the envisaged encouragement of fertilizer use in the Agricultural Perspective Plan, the issue deserves more attention. A knowledge of long term fertility dynamics in different land use systems will contribute improved productivity using external inputs without injuring soil health. Integrated management of fertility has relevance in this context.

6. The null effect of either livestock management, livestock units or their combination on soil fertility changes has come as a surprise from the study and requires further investigation.

7. Wider changes in the system are also a result of policy and socio-cultural practices beyond the scope of soil fertility research. However, the study underlines the influence of farmer category, land tenancy, deforestation, and community participation in forest management which needs to be considered to guide future research.

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Capacity Building in Community Forestry Management

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1. INTRODUCTION: WHY BUILD CAPACITY?

Whenever opportunities and constraints are discussed in the forestry sector, the need for training is invariably mentioned. Many authors have described Nepal's foresters' lack of basic social and technical skills and their poor education qualifications which affect the sector's ability to realize its true potential. Other authors have focused on the skills needed by diverse forestry user groups as they begin to manage their recently received forests for the development of their communities. Donors in the forestry sector continuously receive requests from rangers, district forest officers, and Kathmandu officials for long and short term, national and international training opportunities, indicating a continued interest in training and self improvement.

A recent as yet unpublished report by David Sowerwine, a consultant working with the World Bank and other donors, estimates that Nepal could realize a net present value of NRs 92 billion per year through intensive management of its forestry resources (Sowerwine, 1994). This sum is approximately ten times the annual amount of Nepal's foreign exchange borrowing. Sowerwine notes that if such a management regime is adopted, Nepal will need 4,500 additional trained foresters ten years from the regime's inception. This figure is approximately 50% of the present staff numbers in the Department of Forests. Capacity building is desperately required at all levels to upgrade the knowledge of people working in community forestry.

The law pertaining to community forestry in Nepal, the Forest Act 1993, defines a community forest as a "*national forest handed over to a user group..... for its development, conservation and utilization for collective benefit*". As of December 1994, around 2,800 user groups had received forests under the provisions of this Act. Many more user groups exist but are not counted until the complex process for obtaining a forest is complete. First, the user group must register itself and then submit a constitution and an operational plan on how to manage the forest in question. These user groups range in size from 13 to 588 households, and their forests cover areas of between 1.04 and 2,885 ha. (CPFD, personal communication). Community forestry management in Nepal takes place exclusively through such user groups, and geographically is more or less confined to the 51 predominantly hill districts, although the Act applies equally to Terai districts as well.

This paper will first attempt to describe the present capacity of the main actors in community forestry - user groups, forest guards, rangers, DFOs, and the central administration in Kathmandu - to manage community forests sustainably under the terms of the Forest Act (Figure 1, point a). The focus will be on in-service training for government employed foresters, such as that offered by the Community Forestry Training Project. Certain training issues which have arisen through implementation of CFTP will be discussed. Finally, the paper will present a vision of what point b on Figure 1 might look like.

2. PRESENT CAPACITY: COMMUNITY FORESTRY EDUCATION IN NEPAL

2.1. User Groups

No comprehensive study has been undertaken to allow one to characterize the forestry education standards of the thousands of user group members. Dahal (1994) has some illustrative data from user groups formed in eastern Nepal. The few respondents he examined had literacy rates ranging from 64% to 100%, but females were mostly illiterate. The majority of members had schooling only at the 1-5 grade levels. The better educated members were predominantly male Brahmins who came from those groups close to the bazaar areas. This typology of generally poor education levels among user group members both male and female is especially the case amongst poor females. The exception to this is high caste males who generally have higher educational qualifications as borne out by anecdotal evidence across the Kingdom.

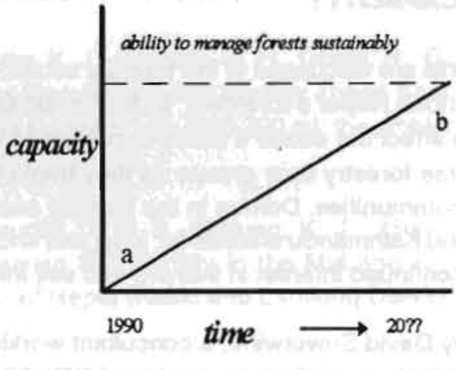

Figure 1. Capacity building in forestry.

2.2. Forest Guards

Forest guards form the largest group of the estimated 9,000 individuals employed by the Department of Forests. While forest guards in the Terai spend most of their time protecting the resource, in the hills they are slowly assuming community forestry tasks. CFTP views forest guards as having tremendous potential to promote and facilitate community forestry. On average, each hill district has around 30 forest guard positions, although frequently many of these are not occupied. Most forest guards are now recruited with at least some level of literacy, but there are many guards from older times who are still unable to read and write. Forest guards may, at some time in their career, receive a "Basic Training" which qualifies them for more responsible duties and somewhat greater remuneration, but district budgets often restrict the number of postings for these more qualified individuals. The "Basic Training" curriculum has been revised recently, and now covers, in a two month course, such community forestry topics as extension, surveying and mapping, nursery techniques and appropriate silviculture. CFTP, which has trained 638 guards over the past 18 months, estimates that only 10-20% have received basic training, but that a further 30% may not be trainable because of age or low literacy levels.

2.3. Rangers

Each hill forest district has on average 12 ranger positions, but as with guards these positions are often unfilled. Rangers fall into two categories with regard to education: those with an ISc and those with a BSc. ISc (Intermediate Science) certificates are given by the Institute of Forestry, which has two campuses in Nepal, at Hetauda and at Pokhara, and involve a two year course of study focusing on the basic sciences with some forestry taught from an academic stance. Those passing an ISc may then continue towards a BSc, which involves a further three years of study. Competition for the 30 or so places a year for BSc students at IOF is fierce: this year over 500 aspirants planned to take the entrance exam. IOF has recently revised their forestry curriculum so that it concentrates more on community forestry and extension, but the change began only this year and no rangers currently employed in government service have been through it. CFTP has observed that technical standards, even for rangers with BScs, are low. Dahal (1994) writes that rangers had no knowledge of biomass, were unable to identify tree species and were ignorant of policy in their field. While CFTP believes that 50% of all rangers are capable of implementing community forestry, only 20-30% are both capable and willing.

2.4. District Forest Officers

Since 1984 when IOF began graduating BScs, the recruiters of HMG forestry officers have taken people who have studied within Nepal. Prior to this date, students would normally attend the forestry school at Dehra Dun, in India. Consequently, around half of the current DFOs are Indian-trained, while half are from IOF. DFOs' technical education is supplemented by brief courses at Nepal Administrative Staff College. Increasingly now DFOs are being selected for overseas courses, some at the Masters level, in aspects of forestry. Many of the Masters graduates have taken courses in social and community forestry in the Philippines, the UK, Australia or the USA. Low pay, a conservative bureaucracy, frequent transfers, and low morale all combine, however, to reduce the productivity of this group once they return to work in Nepal. CFTP still encounters DFOs who have a mediocre understanding of the philosophy behind community forestry, perhaps on account of poor policy communication between Kathmandu and the districts.

2.5. Central Administration Kathmandu

Class I officers, and senior class II officers employed in Kathmandu have invariably taken overseas Masters degrees, and sometimes even PhDs. Many of them have also been on study trips to other countries. Most of the administration has at least an academic understanding of community forestry, and whenever individual officers have been exposed to field conditions they have been able to make impressive contributions to the development of sound community forestry policy. Once again, however, bureaucratic demands on their time restrict the scope for making contributions.

3. COMMUNITY FORESTRY TRAINING PROJECT

The evolution of the Community Forestry Training Project began with a joint World Bank-DANIDA appraisal mission which visited Nepal in November 1988. The mission presented its findings in a Staff Appraisal Report which outlined IDA support to what is now termed the Community and Private Forestry Division of the Department of Forests in the areas of research, forest resource management, institutional support, and training. DANIDA decided, on the basis of the appraisal, to give support to the training component. While the development objective of CFTP is to conserve and expand the forest resources needed to sustain traditional farming systems and livelihood in the hills, its immediate objective is the improved technical and managerial capabilities of both DOF staff and communities involved in community forestry to undertake community forestry in the hill districts. CFTP works now in 38 of the 51 hill districts. The project has established five Regional Training Centres across the country which deliver and fund training at the district and regional levels. Currently, CFTP organizes around 500 training events a year, reaching around 5,000 trainees, mostly at the district level. Table 1 lists the type of district level training supported by the project for the current fiscal year. Similar courses are offered in non-CFTP districts under a variety of different funders. Figure 2 shows the proportion of trainees by group.

3.1. CFTP Strategy

Recognizing the limitations imposed upon it by the low educational standards in Nepal, CFTP developed a strategy to support HMG's community forestry program. This strategy acknowledges that the primary resource managers are women and men from the communities, but that they need the support and understanding of HMG foresters. Furthermore, the project views DFOs as managers of their district's forest resources and facilitators of the handover process. Their training needs lie more in business management, monitoring and evaluating progress, and planning and budgeting activities than in technical skills which the project believes should be taught primarily to rangers. All HMG staff should be re-orientated towards participatory management ideas. User group needs are diverse and, in some districts where many community forests have been created, overwhelming. The project reaches only very few user groups directly through study tours and awareness creating events. Support to user groups must come through ranger and forest guard field work, or through other well-established groups, perhaps under the rubric of user group federations. CFTP recognizes that the potential for non governmental organizations to work in community forestry is enormous. Finally, inherent in the project's approach is the belief that long term investment in training in community forestry is justified by both economics and equity considerations, for there is the potential that vast amounts of forest equity will come to reside in village elite groups at the expense of poorer villagers unless the implementors of HMG's community forestry policy understand the technical and social issues involved.

Table 1. District level courses, seminars, study tours and workshops currently offered by CFTP.

Forest Guard Community Forestry Orientation
Nursery Management Course
District Level Community Forestry Orientation
Range Post Community Forestry Seminar
User Group Member Community Forestry Management
School Teacher Community Forestry Seminar
Women Community Forestry Seminar
User Group Networking Workshop
User Group Member Study Tour
Women Study Tour
Within District User Group Member Study Tour

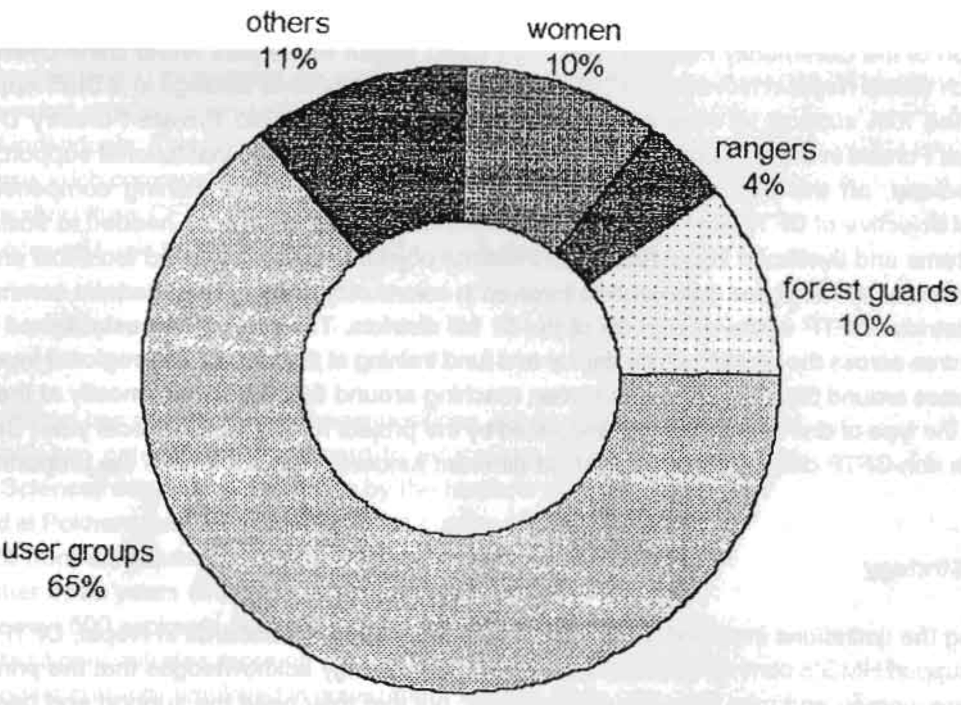

Figure 2. CFTP trainees served by trainee group 1993/4.

4. TRAINING ISSUES

Over the course of the project's five years of experience, certain issues have arisen. The project makes no claim to have solved these questions but notes that any future capacity building exercise will have to face these issues sooner or later.

4.1. Technical Versus Social Content of Training

Is community forestry an art or a science? How much social content should enter into any course, and how much technical content? CFTP has conducted large numbers of re-orientation courses in the past, and the project estimates that 80% of the ranger cadre have taken such a course. However, if the rangers are later assigned forest protection duties, they may never get the opportunity to practice their social skills, which necessitates re-emphasizing them in subsequent courses. Many foresters maintain that there are scientific aspects to community forestry management which must be taught, implying more of a technocratic approach. Others maintain that communities typically have sufficient indigenous knowledge to enable them to manage forests, and the task of a ranger or forest guard is to tease out this knowledge, but how much of this skill can be taught in short training courses?

4.2. Lack of Skilled Trainers

There is a dearth of trainers in Nepal, especially those skilled in participatory training techniques. It is generally accepted that people trained in the traditional lecture type format, in which a "professor" instructs students, will tend to deliver lectures to user group members in the same manner. Most community forestry projects are moving away from this pedagogy and are instead focusing on encouraging discussions among trainees. The role of a trainer is seen more as a facilitator. Unfortunately, however, both high school and university courses taught in Nepal invariably use the more traditional approach, which means that projects have to re-educate trainers before launching training programs. Changing trainers' attitudes may take longer than the project life.

4.3. Monitoring and Evaluation

Monitoring and evaluation of training programs could be improved. Evaluating the impact of any training program is difficult since so many outside variables have to be considered. If a district has handed over forest to apparently solid, sustainable user groups, who appear to be actively managing the resource according to a sound Operational Plan, is that happy state of affairs due to training, or is it due to the leadership of the DFO, or his motivated staff, or the state of the resource at handover, or to the proximity of emerging markets for forest products, or the user groups' homogeneity, or...? Conversely, if a district is not doing well with regard to community forestry, how much of the blame lies with a poor training program? Most of the evaluation of CFTP impact must therefore be based on qualitative evidence gained from interviewing field practitioners. This methodology has obvious drawbacks, since given the acknowledged incentive value of training and the desperate need for it, very few people are likely to be critical of a training project. How much resources should be devoted to evaluation of these types of training programs?

4.4. Trainers' Career Path

Little consideration has been given to the career path of training officers in the Department of Forests. The Regional Training Centres were established with support from DANIDA CFTP in the early 1990s. In February 1990 they were staffed by class III HMG officers. If a class III officer wishes to progress to class II status, he has to leave the RTCs and seek a class II DFO position. Only then, having served time as a DFO, can he hope to be transferred to one of the few class II training positions in Kathmandu. Training staff is an important but comparatively minor part of any DFO's work, especially in the forest protection areas of the Terai. Thus the present system ensures that the few ambitious trainers available to the DOF will sooner or later leave to posts where their skills will become rusty through lack of use, and that they will be replaced by comparatively inexperienced trainers who will not be able to deliver, administer, or monitor training effectively.

4.5. Trainee Selection

Selection of people to be trained, especially from among user group members, is haphazard. This is particularly true for study tours, in which the tendency is to choose participants who come from already active user groups. Selection is viewed as a reward for their work. The effect of this is to dilute the impact of study tours, which are really intended to encourage adoption of community forestry management practices in groups not yet active. Bunch (1982) makes the point that people chosen for training should agree to train others, and thus spread the technologies far beyond the contact group of an extension worker. There are no such preconditions set in CFTP.

4.6. Incentive Value of Training

In an ideal training project one might expect that trainees would value training opportunities to such an extent that they would be willing to invest time and money in attending classes. It is only at the user group level that CFTP has seen this situation - a few members have attended training without any remuneration, and one user group has even organized its own study tour without any support from the project. All HMG staff, from the central administration down to forest guards, expect some kind of "training allowance" before they attend training, and these allowances are often set well above the costs involved in attending training. HMG staff see training as an opportunity to bolster a meagre income, and expect "compensation" for time spent. This uneconomic, artificial situation creates pedagogical problems in projects, and selection problems in the districts, since one is never sure who is genuinely interested in training and who attends training only for the allowances. Should CFTP now proceed to cut training allowances?

4.7. "Untrainables"

There are many constraints to community forestry implementation which cannot be addressed through a training program. CFTP refers to these items are "untrainables". Untrainables have generally to do with the rigidity of the HMG bureaucracy as well as the lack of development in the Nepalese hinterland. They are low pay levels for staff, general lack of incentives to perform quality work, frequent transfers of staff from one district to another, budgetary restrictions on field allowances, poor housing conditions, lack of facilities in the more remote districts, and general isolation. Can and should a training project address these "untrainables"?

5. SUMMARY: COMMUNITY FORESTRY AT A CROSSROADS

Community forestry in Nepal has reached a crossroads. The signposts point to a utopian vision of user groups managing and harvesting forests and investing their profits in rural development. This is the high road promoted by donors which can only be reached with a sustained investment in human resources, including training, at both government and community levels. Travel on the high road and one comes immediately to the "untrainable" barriers which must be somehow crossed. Branches from the high road lead to user group federations, private forestry, NGOs, and marketing coops. Another signpost points to the low road, which skirts the untrainable constraints, yet allows some measure of community forestry to proceed by dint of the legislation and policy initiatives. This road passes through several serious resource conflicts, as some community groups realize that they have been cheated out of their rightful share of a diminishing resource. On the low road training is still very much in evidence, but its impact is weakened because of low morale among the government foresters, and the lack of time for training caused by the sheer volume of work to be done.

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Local Forest User Groups and Rehabilitation of Degraded Forest Lands

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1. INTRODUCTION

There has been a major concern about the impact of natural processes and human activities on degradation of the fragile mountain ecosystems in the Hindu Kush-Himalayan Region. Deforestation is one of the key issues in the region because of its impact on biodiversity and on poor farmers whose livelihood depends on this resource. Within Nepal, the relationship between the forest and the livelihood of mountain farmers is well documented (Mahat, 1987; Yadav, 1992; Eckholm, 1976). Degraded forest lands exist throughout the heavily populated middle mountains of Nepal.

As a result of global perceptions in the 1970s and 1980s, efforts to rehabilitate degraded lands in Nepal tended to concentrate on creating green vegetation cover. Such efforts have been relatively successful in increasing forest cover in some areas such as the Jhikhu-Khola Watershed. Forest cover in this watershed increased by 10% between 1972 and 1990 after an overall loss of 24% between 1947 and 1981 (Tamrakar, 1991). The establishment of pine plantations by the Nepal Australia Forestry Program was the main impetus for this change. However, a more detailed analysis has shown that the forest cover increase has been mainly on the intermediate slopes rather than on steeper slopes, and that the utility of pines for farmers is lower than mixed broad-leaved forests (Shah, 1994; Schreier, 1994). This illustrates a need to move from a "greening first" approach to a "community first" approach, in which the needs of the communities are emphasized and the community is involved in forest management.

The National Forestry Plan (Kayastha, 1991) has promoted the return of control of accessible forests to local Forest User Groups (FUG) under the assumption that local communities can better manage their forest resources. The Kavrepalanchok and neighbouring Sindhupalchok districts were pioneer districts in the evolution and implementation of community forestry programmes. Government legislation has been partially effective in handing over the control of the forest. However, there appears to be much less emphasis on active rehabilitation after the communities took control. For example, an ICIMOD team reported that in the Kavrepalanchok District (1993) only 21% of forest area handed over to the communities was subject to enriched planting. Between 1980 and 1988 less than half of the targeted community forests was replanted. The study also points out that most forests that have been handed over to the communities are degraded forests.

It has also been observed that conservative silviculture, which emphasizes resource conservation rather than optimal use, appears to be dominant in community management of forests. This conservative approach is appropriate under favourable conditions where native regeneration of degraded forests is possible. However, in severely degraded lands, the challenges are firstly to get the communities involved in protection, and secondly, to promote active rehabilitation work.

ICIMOD's rehabilitation programme is examining the issues of resource degradation in the Hindu Kush-Himalayan Region through participatory action-oriented research. The research programme, which is funded by IDRC (Canada), focuses on community level rehabilitation. It is being carried out in test areas in China, India, Nepal and Pakistan.

The Nepal site was established in 1993 and is located in the Kavrepalanchok District. Two forest user groups (FUG) from "Bajrapare ko ban" and "Dhaireni Pahka ko ban" are participating in the project with ICIMOD and the District Forest Office (Kavrepalanchok). This paper discusses the experience and findings of the rehabilitation work between 1993 and 1995.

2. PROJECT SITES AND ACTIVITIES

Both Dhaireni and Bajrapare sites are situated in the Jhikhu Khola Watershed, where the "Mountain Resource Management Project" (ICIMOD/ UBC/ IDRC) has been studying the resource dynamics over a considerable period of time. The two sites are located on red soils in similar agro-ecological zones, but differ in size, accessibility and composition of the Forest User Groups. These areas were identified by the District Forest Office as very degraded and in urgent need of rehabilitation. Some of the important biophysical characteristics of the two sites are summarised in Table 1.

Table 1. Selected biophysical characteristics.

		Site I	Site II
o	Name	Bajra Pareko Danda	Dhaireni Pakha
o	Area	6.76 ha	15.93 ha
o	Altitude	925-1150 m.a.s.l.	900-1000 m.a.s.l.
o	Climate	Sub-tropical (sub-humid)	sub-tropical (sub-humid)
o	Rainfall	1000-1200 mm	1000-1200 mm
o	Temperature	Min. 0°C; Max 35.5°C	Min. 0°C; Max 35.5°C
o	Slope	15°-25°	10°-25°
o	Aspect	South facing	South facing
o	Soil	Red; clay loam. Poor in organic matters and low infiltration; gully erosion prominent	Red; clay loam. Poor in organic matters and low infiltration, gully erosion prominent
o	Existing Vegetation	- Chirpine (*P. roxburghii*) Plantation in 1986 - amla (*Emblica officinalis*), pithouli (*Rhus parviflora* Roxb.) bushes, sal (*Shorea robusta*), khar (*Cymbopogan microtheca*)	- Chirpine Plantation in 1973 - pithouli, khar

The project is carrying out various planting activities in collaboration with the FUGs, and these activities are summarized in Table 2. Strengthening of these FUGs is a major goal of the project. This action-research project aims to improve the production of biomass and produce a range of other useful products from the degraded forests by integrating traditional and new technologies in the activities of the FUG's. The project also

aims to demonstrate the usefulness of planting nitrogen fixing plants, hedgerows and grass strips as a way to conserve soil moisture and improve the productivity of the forest. Demonstration of water harvesting techniques, research on soil erosion, species performance and natural regeneration are some of the main activities of the project. Since the implementation of the Rehabilitation Project, plant seedling production was initiated in the FUG nurseries, and various indigenous and exotic species were planted in the forests. In 1993 and 1994, a total of 2.5 ha was planted at Bajrapare and 5.05 ha at Dhaireni, which includes 1908 m of hedgerows at Bajrapare and 3318 m of hedgerows at Dhaireni.

Table 2. An overview of project activities.

Challenges	Options followed by the project	Research Components
a) Human activities i) Free grazing: increasing biomass depletion, decreased regeneration, increased soil erosion through ground cover losses and trampling ii) Uncontrolled resource extraction: low regeneration, biomass degradation	i) stop free grazing ii) Controlled extraction, encourage private production of such resources	i) Monitoring of impacts on natural regeneration and biomass production
b) Management constraints i) New settlements, therefore no consensus on protection ii) Lack of options/ information	i) Consensus building through regular meetings. Meeting space provided at Dhaireni. ii) Training/ Visits	i) Monitoring of participation and other socioeconomic variables
c) Natural constraints i) Soil: poor nutrient levels, highly erodible, crusts easily, low infiltration ii) Climate: high rainfall during monsoon, hot and dry other times thus high water losses iii) South aspect: Warmer/less rain iv) Deep gullies	i) Nitrogen fixing species, erosion controlling hedgerows ii) mulching in dry seasons, drought tolerant species iii) water conservation through hedgerows/ mulching iv) Check dams constructed	i) Species performance: biomass production etc. Rainfall/ soil erosion monitoring

Table 3 shows that the Dhaireni location is ethnically more diverse than Bajrapare, which has implications on the social organization, especially on the collective social action to protect the forests. The population/forest area ratio is higher in Bajrapare (19.2:1) than in Dhaireni (16.3:1) and this could affect the feed supply for animals.

Table 3. Household (HH), population and ethnic composition of project sites, 1994.

	Bajrapare	Dhaireni
Total Household (HH)	18	259
Total Population	130	1667
Average Persons/HH	7.2	6.4
Ethnic Composition	Brahmin and Chettries	Brahmin and Chettries 34% HH, Newars 29% HH, Danuwars 21% HH, Sarki, Kamis and Damai 11% HH, Tamang 4% HH, Magar 1% HH

The comparisons in Table 4 suggest that, on average, most farming households own between 0.5 to 1.5 hectares of land. If we assume that land holding is the primary determinant of wealth, then comparatively more households are poor in Dhaireni than in Bajrapare.

Table 4. Comparison of land holdings at Bajrapare and Dhaireni with district averages.

Land Holding Categories (LHC)	Kavrepalanchok District Average (%HH)	Bajrapare (%HH)	Dhaireni (%HH)
Landless	0.4	0	2
<0.5 ha	37.7	39	59.2
>0.5-1.5 ha	55	61	30
>1.5ha	6.4	0	8.8

3. COMMUNITY INVOLVEMENT IN REHABILITATION

In 1993, the District Forest Office (DFO) in Kavrepalanchok 'handed over' the forest lands to the local User Groups in Bajrapare and Dhaireni. This was preceded by extensive discussions with the local communities and the DFO and followed the norms and regulations of the DFO. The project started in April 1993, following the signing of a tripartite agreement between the FUGs, DFO and ICIMOD. Formal clearance from the respective village development committees (VDC) was also obtained. Highlighted below are some of the issues that have emerged and approaches that were followed by the project during field implementation. These are considered relevant for participation of local communities in rehabilitation of degraded forest lands.

3.1. Obtaining Consensus

Agreement among the FUG, VDC, DFO and ICIMOD to carry out rehabilitation work was very important in the project implementation. One of the major challenges was at Dhaireni where the FUG households live in ten different settlements. Initially, the main Forest User Group Committee members came largely from one settlement. Meetings were organized in each settlement to clarify the aims and objectives of the project and to start a process of continuous discussions within the communities. Members were chosen by each community to represent them in the FUG committee, which has ensured a continuous dialogue among local communities.

At both project sites, the participation of the local communities in project activities has been very encouraging. An indication of the local community support is that, despite a lack of fencing, the plantations have been very well protected from grazing by domestic animals. The plantations at both sites probably represent the first plantation in the district without any fencing (Mr A. R. Sharma, District Forest Officer, personal communication).

Assisting local communities with other identified needs such as drinking water supply has promoted greater participation. Water supply in the village of Bajrapare has made it possible for the FUGs to produce their own seedlings in nurseries, and it has encouraged production of vegetables in the bari land (non-irrigated fields) near their houses.

3.2. Investment in Rehabilitation Activities

The investment by the project has been an important factor. Contributions by the local communities have been mostly in terms of `participatory' wages (charging less than market wages for work done on forest land) and also in supplying planting materials (seeds or plant cuttings). Our experiences suggest that communities are unlikely to make direct investments into rehabilitation of degraded forests due to a variety of reasons, the first being that investment in rehabilitation work in very degraded sites represents a risk. In comparison, natural regeneration is encouraged simply through community control over grazing and incurs little direct cost. In contrast, afforestation work requires investment. Very degraded and unproductive sites do not offer a means of income generation. Even with the FUG investment in rehabilitation, drought, very heavy rainfall or a single incursion by a stray domestic animal can destroy the efforts. There is a large element of risk involved in such an investment, and the benefits take a long time to realize. Community forests, being common property resources, have inherent problems with free riders (many non-contributors to rehabilitation enjoy the benefits) which also discourages investment.

3.3. Tenure Security

Since ownership of the forest still resides with the government, many FUG members privately expressed reservations in participating. They feared that the government would annex control following their efforts to rehabilitate. If communities are not convinced that their tenure is secure, they are unlikely to invest in rehabilitation even if they have resources. Although tenure security can only be changed by a new law, significant progress has been made through a continuous dialogue between the DFO and the FUGs. Regular meetings have reassured the local communities that their rights and interests will be looked after.

3.4. Initiative by the District Forest Office

There is no doubt that with favourable policies that promote the handover of forests to local FUGs, the DFO has been able to achieve participation of local communities in the project. Initiative by the DFO to identify a suitable area and in handover has been critical for project implementation.

3.5. Continuous Consultation

Regular contacts with the District Forest Office, such as tripartite planning/ review meetings in which DFO, ICIMOD and FUG members participate, have helped to build confidence between the FUGs and DFO. For example, FUGs are now more likely to seek help from DFO in seed acquisition than they were a year earlier. A newly established field office has also made it possible for project staff and the FUGs to hold continuous dialogue and discussions. This, again, has been crucial in promoting trust and cooperation between the project and the FUGs. This has been particularly important in promoting the participation of women in project activities. For example, because the field staff have established a very good rapport in the village, the women were confident enough to ask for organization of a `women only' field trip to Godavari.

4. IDENTIFYING APPROPRIATE TECHNOLOGIES

For community involvement in rehabilitation work, understanding the perceptions of the local FUG is essential. A severely degraded area with gullies and a thin layer of top-soil is very difficult to rehabilitate, especially if the soil characteristics and climate are also unfavourable. For example, at both project sites, which are on red soils, even natural regeneration has been difficult in some areas due to crusting of the soil. There was scepticism on the part of many FUG members that anything could grow in such area given the long dry and hot period.

4.1. Field Visits, Training and Demonstrations

The project first demonstrated that technologies were available to assist rehabilitation. Various field visits to successful rehabilitation sites were organized (Terani, Dang), to convince leaders that rehabilitation efforts are worthwhile and possible. The examples of successful plant growth and natural regeneration at project sites have also convinced people that rehabilitation is possible.

4.2. Selection of Species

Selection of species was mostly done by the FUGs, but some exotic species were included for trial purposes (e.g. Tephrosia candida, from China). In the forestry sector, emphasis is placed on planting tree species on degraded lands. However, as seen at Bajrapare for example, the priority of the villagers is on fodder production. Thus planting of fodder species, including grasses, provides an alterative to tree-only plantations. The FUGs have been very impressed by the performances of certain species such as NB21 grass, *Tephrosia*, sissoo (*Dalbergia sissoo*), lapsi (*Choerospondias axilliara*), bakaino (*Melia azadiracta*) and badahar (*Artocapus lakoocha*). In fact, the FUGs were so impressed by these results that they were reluctant to cut and use NB21 grass but wanted to keep it to show others. Introduction of such species shows visible changes over a short period and is very important to sustain the interest of the FUGs.

4.3. Introduction of Innovative Technologies

After many discussions the project personnel managed to convince the FUGs that a modified Sloping Agricultural Land Technology (SALT) could be an appropriate method of rehabilitation (Partap, 1994). Selected FUG members were trained in hedgerow establishment and the concepts of SALT. The use of hedgerow technology in forestry has been tried in many countries with great success (eg. Vetiver in Thailand, Board on Science and Technology for International Development, 1993). However, in Nepal, the project sites in Kavrepalanchok probably represent the first case of the technology being tested on forest land.

4.4. Encouraging the Use of Indigenous Knowledge

Along with the introduction of innovative technologies the use of indigenous knowledge and local innovation must be fostered and encouraged. Emphasis on indigenous knowledge, through the incorporation of indigenous species and practices, can increase the participation and commitment of local communities by providing an opportunity to contribute. This is encouraged by the project at both sites. The collection and planting of local materials could also reduce costs and thus investment risks.

5. REPLICABILITY OF THE PROJECT EXPERIENCES AND ACTIVITIES

Many of the experiences are very site specific and the choice of species is largely determined by soil and climatic conditions. However, even within the Jhikhu Khola Watershed, large degraded areas on similar soils with similar climates exist, thus providing scope for replication. Red soil areas in other regions of Nepal have also been identified as being of special concern, with estimated erosion rates of up to 200 tons per hectare per year (Biot, 1990). Other countries in the region such as China have also identified areas (Zhang, 1991). Thus there is potential for replication of the project experiences under similar biophysical conditions in many different places.

The hedgerows and species trials are only two years old, and data analyses are still underway. However, the initial results have shown encouraging signs. The establishment of plantations with hedgerows requires more material and labour than the standard afforestation carried out by the District Forest Office. For example, at Dhaireni, 3.55 hectares planted in 1994 required approximately 40,000 seedlings (Chalise, 1994), whereas the DFO would normally plant 5680 plants (at 1600/ha). Therefore, a large scale replication of this technology is neither feasible nor desirable. However, there is considerable scope for targeting specific problem areas for replication of this technology.

We believe, however, that the approaches taken by the project, which involve the local FUGs in active rehabilitation, provide some useful examples. It has been shown that communities are able to organize themselves if some outside agents play the role of catalyst. It also shows that communities are able and willing to learn new technologies and approaches and can, with initial encouragement, benefit by participating in a national programme such as the community forestry programmes. It has also been shown that with proper investment and encouragement, local communities can work on rehabilitation of very degraded lands.

6. CONCLUSIONS

The experience gained from ICIMOD's "Rehabilitation of Degraded Lands in Mountain Ecosystems" project suggests that rehabilitation of forest land through Forest User Groups is possible. To be successful it needs favourable policies, combined with initiatives, appropriate technological innovations, and active participation of local people. Extensive plantations without fences and hedgerows, which include fodder trees, are first attempts towards a successful rehabilitation program.

The project has also shown that initiatives by the DFO have facilitated the `hand over' of the forest. They helped clarify to the local people their rights and obligations. Collaboration with other facilitators such as NGOs can also help in the process of `take over' by local communities, even if the land is very degraded. Further research is needed on innovative approaches to be carried out to strengthen the FUGs as viable and capable institutions. Long term support and involvement in such work will be necessary to guarantee that these issues can be dealt with effectively. For active rehabilitation work, initial investment is essential. The need to invest in management of common property resources has also been highlighted by a number of other researchers (Jodha, 1990). Through commitment to support the activities of the FUG financially and visible collaboration with FUGs, the VDC and DFO have generated positive participation by the local communities.

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"Invisible" Farmers?: Hill and Mountain Women of the Himalaya

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1. INTRODUCTION

Since the advent of planned "development" which was conceived as a way for developed countries of the North to assist in the modernization of post-colonial societies of the South, we have witnessed a continual decline of resources in rural areas. The call for increased food production through the use of modern agriculture technology, such as in India's Green Revolution, resulted in the wealth of a few farmers and the further impoverishment of the poorer ones unable to afford the required inputs. As the push for "economic growth" desired by development planners became more acute it became clear that as countries which developed cash crop production for export became more dependent on western technology, investments and the international markets. The growth that has occurred has not made a dent in the accelerated process of impoverishment that has left the world with a greater percentage of poor people than ever before (Karl, 1991).

Many argue that the development process has contributed to the growth of poverty by increasing the economic and gender inequalities and the degradation of the environment, which further diminishes the means of livelihood of poor people. This is particularly the case for poor women who are more affected by these processes (Braidotti, 1994.). The growing recognition of the linkages between the environmental crisis and the development crisis broadened the intellectual discourse to include social aspects in the pursuit of sustainable development models. In the 1970s, women's role began to be considered, and a call was made for their integration into development in an attempt to rectify previous neglect by development planners.

Yet this move for integration ignores the general failure of development theories to bring about improvements in the lives of the Third World poor after four decades of trials. Despite the postulated crisis in development, the concept itself has remained intact. For mainstream development models, development has meant the integration of Third World countries into the international market systems whereby growth was to be manifested solely in increased economic production. Therefore, women's involvement in development has been measured by their employment in a market economy, making them "invisible" in rural subsistence-based societies. As women comprise 60-90% of the agricultural work force, and produce 44% of all food worldwide, why is it important to only speak of income-generating projects, as are often proposed by development agencies? (Anand, 1991). Is it not better to recognize women's current productivity and the value of their work in supporting subsistence production systems, which are now suffering because government and market pressures are focused on crops for markets, rather than home consumption? Has this development process, which is now being promoted for women, been beneficial to the majority of men?

The modernization of agriculture often leaves women producers worse off. With the best land under cultivation for cash crops, women must work harder as they produce cash crops on the better land and use the smaller plots on poorer land to produce the food for their own consumption needs. The already heavy work loads of women farmers increase commensurately with the addition of market-oriented farming ventures while their work is simultaneously devalued in an increasingly monetized economy. New information on inputs, techniques and machines is usually accessible only to men who generally are the targets of training and technologies for improved agricultural production. Even women of the same household often are unaware of the new knowledge provided to their menfolk, as it is not shared with them.

Due to their social and economic roles, poor rural women have a close association with natural resources from which they must provide water, food, fuel and income for their families. Yet despite their traditional roles as agricultural and natural resource managers, and the extensive knowledge they possess that enables them to shoulder these responsibilities, they have been almost completely marginalized from processes that seek to formulate strategies for the use and management of these resources. In the process, by losing access to resources and decision making, they have further lost status and power as well as control over their labour and knowledge.

The special difficulties that women face are the consequences of the sexual division of labour, double work burden, and unequal distribution of resources which stem from their inferior status and lack of control over productive resources (including land) and cash. Against this backdrop, women's lives are very much affected in ways different than men by the environmental degradation which is occurring in the Himalayas as well as other regions of the world (Venkateswaran, 1992).

2. WOMEN'S ROLES IN AGRICULTURAL AND NATURAL RESOURCE MANAGEMENT IN NEPAL

2.1. Agriculture

Farming in Nepal occupies 81% of its citizens. Primarily a subsistence-oriented system, it is labour intensive, relying on the inputs of 91 % of the country's females and 75% of the males. Women contribute between 50-80% of the total agricultural labour force, depending on socio-economic and geographical variations. Gender involvement in farm production activities does vary from the Terai to the Hill/Mountains, with hill women taking on more responsibilities. This can be attributed to three factors: higher migration of males from hills and mountains, socio-cultural restrictions of orthodox Hindu women mostly in the lowlands and traditional sharing of work amongst men and women in the highlands. Women in high income families are involved indirectly as managers of agricultural production, in middle income families as unpaid family labour, and in marginal and landless families as wage labourers. Ethnicity also affects the division of labour with members of the Tibeto-Burmese groups most involved time-wise and in decision-making. Education, family size and livestock holdings also affect the women's level of involvement (Bajracharya, 1994).

The allocation of labour and responsibilities between men and women is affected by many factors with a high degree of variability even within a small region, but there is no activity in which women are not involved. Even ploughing, which is almost always performed by men, has been observed to be done by women on some farms where men are absent and hired labour is not available. Several studies carried out in Nepal indicate a domination of women's labour in such tasks as planting/sowing, compost and manure carrying, transplanting, weeding, harvesting and post-harvest activities for cereal crops, pulse, legume and oilseed crops and even vegetables (Bajracharya, 1994). Women also play the predominant role in animal husbandry, contributing more than 73% of the labour required for their care.

2.2. Forests and Pasturelands

The indispensable role of forests in the farming system makes any decrease in its resources a major concern for the women who are primarily responsible for the collection of its products to provide fuelwood, fodder, leaf litter, herbs for medicines and income sources. Households in the hills of Nepal contain an average of five goats and two cattle or buffalo for which 2-3 loads of fodder are required daily (Gurung, 1988). Studies indicate that an average of one extra hour of time is necessary for the collection of fodder in areas subject to severe deforestation. In the highlands, 66 % more time is required to collect a standard load of fuelwood in sites of greatest deforestation than in sites of lowest deforestation (Kumar, 1988). This extra labour requirement is often met through the allocation of more work to children, usually girls. Collection of fodder leaves and grasses, as well as fuelwood, is largely done by women; they contribute 72% of this work, spending on an average 2.5 hours a day averaged over the year. It has been estimated that the increased hours required for collection in degraded areas has led to a reduction in women's input into agricultural production by one hour per day. The implications of deforestation are twofold: the workload is increased, and the labour input per hectare of agricultural lands is reduced which has probable adverse effects on yields (Kumar, 1988).

2.3. Water Management

Hill and mountain women's traditional roles in the collection and provision of water to household members and livestock is well-known; they are the principal carriers of water and also make decisions on its use and storage for which they hold knowledge related to its conservation and quality. It should be noted that women of the Terai spend only a fraction of the time spent in the hills in water collection due to more plentiful supplies and easier accessibility (Pradhan, 1990).

3. IMPACTS OF THE CHANGING SCENARIO ON WOMEN

Even the largely self-sufficient, independent and isolated communities of the mountains are gradually giving way to become members of the "global village". Externally-driven changes are more and more affecting even remote mountain societies through market forces, government development interventions, political movements, tourism - even internationally broadcast TV. Urban centres and international markets are increasingly consuming natural resources which require greater extraction from mountain regions. Commercial agriculture is being introduced to supplement subsistence systems, and local economies are becoming monetized. Out-migration of males is a well-recognized phenomenon that will only increase as farming becomes less sustainable and profitable. In-migration of lowlanders, unfamiliar with strategies for proper management of mountain farming and survival, is bound to cause environmental damage. Education and employment opportunities elsewhere are distancing youth from the land and setting in motion a process of "class differentiation" (Mehta, 1990).

3.1. Cropping Patterns

Increased pressures on natural resources, brought on by both internal demands of a larger population and exploitation pressures from outside, make it impossible for farmers to continue with the subsistence strategies which have worked in the past. Traditional agricultural practices that require long fallow periods and extensive support lands for supplies of biomass such as fodder will soon no longer be feasible. New marginal lands may be brought into production, but these will be distant and more fragile, requiring significant labour inputs to make them arable. The quest for cash brings new cash crops which place added labour demands on women's time without bringing them a fair share of the profits. At the same time, their primary role in subsistence agriculture is losing status and value (Gurung, 1994).

In India, where the commercialization of agriculture has moved at a faster pace than in Nepal, the shift from a subsistence to market economy has affected women in several ways. The Green Revolution, which focussed on technological interventions, greater mechanisation and higher capital investments, entailed a shift from human to technical inputs. This process has marginalized women's knowledge and inputs, resulting in a shift from them being agricultural managers to mere labourers. It has increased their workload by reducing the availability of crop fodders; high yielding varieties introduced by the Green Revolution have a low percentage of straw which can be used for feed. The availability of food for household consumption has been affected as grain is now directly transported to the market from the field, leaving women little control over its usage.

Previously, women could use the grain for exchange for other commodities. Women's opportunities to earn cash or barter from other activities, such as threshing grain, have been curtailed through the introduction of machines usually owned and operated by men.

The introduction of cash crops in mid-western Nepal has decreased the amount of time men spend in agricultural activities and resulted in greater amounts of time being spent in training sessions and market activities. Meanwhile, their womenfolk have increased their time in agricultural activities and reduced the amount of time previously spent on child care and household work. Perhaps of greater loss than the time is that of the loss of status, decision-making power and control over the products of their labour (Paolisso, 1992).

The overall greater importance is attributed to men through wages and access to training and resources; the focus of modernisation affects the proportion of income for family maintenance as well. It is well-documented that where women control cash income, a larger percentage is spent on nutritional needs for the family (Venkateswaran, 1994).

3.2. Monetized Economy

Although in the past women were accorded lower status relative to men, there was greater parity in the sexual division of labour based on each sex's contribution to the domestic and agrarian economy. As the village has become increasingly interwoven into the cash economy; however, new sets of values and expectations have widened the gap. Since agriculture cannot ensure even a minimum subsistence in most areas of the hills and mountains, households are forced to use migration and other strategies to provide cash to cover an ever-growing array of "needs" and "wants". Men's seasonal or permanent withdrawal from agricultural work results in added burdens for women. The higher level of male participation in the market economy (a function of their greater mobility, education and socialisation) has increased women's dependence on men as earners of income and intermediaries to the "outside" world. Those who command access to remunerated activities are now accorded a value and prestige that far exceeds that attached to activities which appear to be unconnected to the market (and which are largely performed by women). Because of the obscured link between women's responsibilities and the market value of their work, women's roles as managers of agricultural production are undermined and invisible to both householders and development planners (Mehta, 1990).

3.3 Migration

Agriculture alone does not provide sufficient returns to support hill households; the great majority of households suffer from some months of food deficiency and must rely on remittances from outside to support even a basic level of survival. Many households have at least one male member who is employed outside of the community at least on a seasonal basis, but the current trend is for increased numbers and man-months of male migration leaving women as de-facto heads of households. However, this status has not brought them access to land titles, credit or even agricultural extension services from the governments of the region. With their menfolk absent, women are left to make important decisions themselves in areas where they may have little experience or exposure (i.e. in the public sphere) and must manage the farm under increasingly difficult conditions with fewer labour resources than before (Gurung, 1994). Female-headed households are known to be the poorest group in every country as was documented in a study of 74 developing countries (Bajracharya, 1994).

3.4. Environmental Degradation/Reduced Access to Common Property Resources

Common property resources, which are of particular importance to women as sources of water, fodder and fuelwood, are becoming degraded, privatized and made inaccessible through protection schemes of government forestry programmes. Women's traditional rights to community lands have been lost as such lands have become privatized and land titles given to men.

Protection schemes or acts of forest officials under the guise of forest protection have bypassed local management systems that prevented their over-exploitation and may have allowed women a voice in their management (Venkateswaran, 1992). Even community managed schemes, such as those being widely promoted in India and Nepal, have not increased the accessibility of women to forest products. Because women are rarely truly represented on forest management committees, their rights to the benefits of forest protection and needs for forest products are usually overlooked by village men (Sarin, 1994). Simply closing off nearby forest lands, without allowing for management on a sustained harvest basis, has created additional hardships for women who are forced to walk the extra distance to more remote forests.

As distances to agricultural and forest lands increase and the daily business of searching for and carrying fuelwood, animal fodder and water becomes more difficult, women's workloads are significantly increased, leaving families no choice but to detain their children from attending school to assist with the chores. Most often, it is the female children who are held back, thereby missing out on an education and perpetuating the cycle of inequity.

3.5. Dairy Development

As farmers in the hills face deteriorating soil conditions, fragmented landholdings and a heavy reliance on chemical fertilizers no longer subsidized by the governments, many are increasingly turning to livestock raising as their primary source of income. In communities in Lalitpur District of Nepal, farmers are rapidly purchasing buffaloes whose milk can be sold for quick profits through the guaranteed markets established by the Dairy Cooperative. Since 1980, buffalo raising, encouraged by loans given by the Small Farmers Development Project, has resulted in significant cash generation plus increased crop yields due to manure inputs. However, there has been a high cost to women of the communities who are the main caretakers of the animals, and therefore, a negative impact on the gender roles and relations within households that cross class and ethnic lines. Besides the extra effort necessary for fodder collection, women and young girls must cook feed, clean stalls, milk and bathe the animals, consuming an average of three extra hours of work per day. These responsibilities have brought about restricted mobility, little or no leisure time, increased drop-out rates from school for girls and earlier marriages in households with too few daughters. While acknowledging the economic benefits gained by households as a whole, these women state that they have seen little or no personal gains, although their workloads have increased tremendously as families strive to keep six buffaloes (one buffalo consumes two loads weighing 160 lbs. of fodder per day). A frequent comment by the women was "I received two saris a year prior to raising buffaloes, and I receive two now."

Men's involvement has been peripheral, except in the buffalo purchasing and carrying and selling of milk. Gambling and alcoholism have become community concerns. However, now that the financial stakes are high, some men, particularly younger ones, are slowly becoming involved in fodder collection (Bhatt, 1994).

3.6. Reduced Energy Availability

It is clear that the impact of decreasing availability of biomass from the forests is borne disproportionately by women who are responsible for its collection and use. The drudgery and increased workload of fuelwood and fodder collection are only one aspect of the impact; another very important one is that the health and nutrition of the family, and particularly the females, are affected. Reduced energy supplies have been shown to affect the number of meals cooked per day and even changes in diet from traditional grains to cereal staples which require less cooking but have a lower nutritional value (Venkateswaran, 1992).

In societies where women are the last to eat from the pot, reduced caloric intakes by the household members who carry the largest part of the workload could result in long term health deficiencies which endanger the welfare of the entire family. The frequency of pregnancies and length of lactation cycles also affect women's health status.

3.7. Irrigation

Irrigation schemes have brought previously marginal lands into crop cultivation, affecting sources of fodder and fuelwood for women of landless or small landholding households. These lands were also relied on for grazing by livestock. Irrigation can affect family nutrition as subsistence crops are substituted by cash crops, and the derived income is not necessarily invested in better food (Venkateswaran, 1992).

3.8. Cooperative Arrangements/Organisations

In the wake of these changes in hill and mountain communities, local people have not been able to organize themselves to adequately manage their own resources and to make their voices heard in order to orient development initiatives to their own advantage. Their resiliency to outside forces has broken down as old traditions, local institutions and culture are challenged by the new religion of materialism and consumerism (Mehta, 1990). Traditional forms of organization are breaking down in the face of new forms promoted by development organizations, banks and governments. Women's roles in informal institutions controlling water and forest resources, for example, may be undermined by new forms of more formalized and centralized organizations where representatives of government agencies may attend meetings and insist on a hierarchial structure which effectively renders women's participation infeasible (Gurung, 1994).

Shared labour arrangements have traditionally been an important coping strategy for hill farmers, particularly women. Labour-intensive tasks that must be completed in a timely manner are undertaken by groups of women taking turns on each others' fields. However, this form of reciprocal exchange is no longer as common in India where farmers want to maximize time on their own cash crop land. A shortage of time has placed those with insufficient labour resources in the difficult position of not being able to reciprocate if they request assistance from their neighbours. The erosion of this type of social network has resulted in a loss of an important forum for women to share knowledge and concerns and provide a support system (Mehta, 1990).

4. ACCESS TO AND CONTROL OVER RESOURCES

Despite the predominant roles that women play in managing the agricultural, forest and water resources required by rural households throughout the hills and mountains, they have been almost completely marginalised from extension, training and access to productive resources related to their responsibilities.

4.1. Land

By far, the most important resource is land. Under most traditional patterns of property ownership and inheritance, women exercise limited or no control in their own right. Most farm women throughout the world do not own the land they till. A study done in Nepal, India and Thailand showed that less than 10% of female farmers now own land (Jacobson, 1992). Without ownership of land to offer as collateral, farmers cannot access credit, improved inputs, market incentives. etc which are necessary to increase production, diversify crops, and participate in cash crop operations. Land reforms and the breakup of communal lands have invariably rewarded land titles to men, thus robbing women of the customary rights they had to manage common lands.

4.2. Markets

Although there is some variation, women's access to markets outside of those in the village itself (such as haat bazaars) is limited. Many women complain that they never see the money that is earned from the fruits of their labour as the market transactions are conducted by household males, such as in the case of the men who carry milk to the depot. A set of unspoken rules also bars women who do go into markets from sitting at teashops or lingering after their work is completed thus denying them access to information about the outside world (Mehta, 1990).

4.3. Extension and Training

Women are seldom the targets of agricultural training and extension services. In Nepal, a mere 5.1% of all trainees in eastern Nepal were female (Bajracharya, 1994). The inherent assumption in not targeting women as trainees is that the new information would filter down to them from training provided to men of the households. In fact, this rarely happens (Venkateswaran, 1992), so those to whom the information would be most relevant are left unaware of its existence. Most rural women are reluctant to interact with male extension workers due to socio-cultural constraints and low levels of confidence. Male workers usually choose to interact with the males out of habit and sense of ease.

Even where government directives have attempted to establish female leader farmers in India, achievements have been poor. This is partially due to socio-cultural factors that make it hard to formally recognize women leader farmers in households that have men farming as well. More importantly, however, is the extremely low percentage of female extension workers. Nepal has a total of 45 female Junior Technicians/Junior Technical Assistants working for the Department of Agriculture (Bajracharya, 1994); across India, although varying according to state, the overall figure is .025% of the extension staff are women . This is partially due to the low numbers of females who enter the agricultural schools and universities. Many of those women who are hired as extension workers do not focus on female farmers (Venkateswaran, 1992) .

There are even fewer females working in the very male-dominated field of forestry. In India, there are almost no female range officers, block officers or forest guards in the territorial divisions of forest departments. A few women have entered into the Forest Service but at officer levels where they do not interact with village women (Sarin, 1992 b). The enrollment of women in Nepal's Institute of Forestry has been raised to 15%, but even many of those few graduates are unable to find employment that allows them to work with village women; some are unemployed, while others are kept in headquarter offices by their bosses. Female foresters are not always accepted by their male colleagues and face the difficulties of opposition from their families for joining a field-based profession.

Extension services for women must take into account the various limitations of women and adjust their training services accordingly by scheduling sessions and meetings in places near their homes and fields at times suitable to them. The illiteracy of most women requires that all new information be demonstrated and reinforced through diagrams and other forms of communication without the use of the written word. Government extension schemes are usually without the flexibility and resources to adjust to the special needs of women.

4.4. Technical Inputs

Most technological improvements, whether they be "advanced" or "appropriate", are introduced almost exclusively to men. Men are the recipients of training and access to machines, tractors, harvesters, improved ploughs and irrigation systems in spite of the fact that women are the major food producers. In water supply, men are trained to construct and use pumps, pipes and faucets in spite of the fact that women have traditionally been in charge of supplying water needs. Small technologies could do much to decrease women's workloads, but most planners tend to overlook these possibilities because they do not consider these tasks to be work and undervalue the contributions women make to the household, community and country (Karl, 1991).

5. CONCLUSION

Given the high inputs of time, knowledge and labour, it is difficult to understand how women can be considered "invisible" actors in agriculture and natural resource management in the hills and mountains of the Himalayan region (one study in Nepal in 1984 showed that Agricultural Development Officers were of the opinion that women make a limited contribution to agriculture). It seems that in the last two decades planners have recently "discovered" women and now speak of them as some "vast, untapped resource" to be integrated into, or maximized for rural development. In fact, women are already managing, or "holding up the sky" for the subsistence-based and cash crop-oriented farming systems of the region. Rather, it is the biases and attitudes of development planners which have caused the distortion of the data which then makes women's work and value obscured. Women are invisible only to those who have been trained not to see.

As the access of women to resources continues to dwindle, their responsibilities and the demands on their time and energy will increase while their status and decision-making roles decline. What choice do they have in this scenario but to rely more and more on the labour of their children over whom they have some degree of control? The increasing tendency to keep female children out of school assures the continuation of the poverty cycle for another generation. The only viable strategy at the household level is to produce more children as a source of status and security.

Rapid population growth within subsistence economies compounds environmental degradation and poverty, leading to the unsustainable escalation of soil fertility losses, deforestation, water shortages, etc. The state of health of women and girls most affected by the decline worsens. What is called the "population trap" is population growth triggered by misguided government policies which have contributed to environmental neglect or abuse. However, rather than confront the gender bias that has led to population growth, planners focus on women's reproductive capacity to the exclusion of their roles as producers. They encourage women to control their family size as the best way to solve economic and social problems, pouring more money into family planning schemes than those to improve their health and productivity. But without dramatic changes in the theory and practice of "development", these programmes cannot reduce poverty or remedy the growing conflicts between human populations and the environment (Jacobson, 1992).

The slogan of "sustainable development" has become commonplace since the advent of Our Common Future and the Rio Earth summit. But given the failure of conventional development strategies to address poverty, equity and the environment, it is imperative to ask "development for whom? With resources from whom?" Improving the status of women (and therefore the prospects for humanity) requires a drastic reorientation that increases women's control over resources, improves their productivity and increases their social and economic choices.

Women of hill and mountain areas are themselves asking for literacy classes and information on technologies and practices that can reduce their workloads, improve productivity of subsistence crops and bring them cash income. Women themselves must identify their critical economic, social, cultural and psychological needs, but for this they must have opportunities to organize and attend meetings, increase awareness, achieve literacy and gain financial security. In most cases, these opportunities will not become available until workloads are diminished and women are exposed to new knowledge from the outside which points to possibilities for change. Experience in the region has indicated that once women are organized and empowered to take collective actions, they can articulate their common problems and themselves determine and voice their demands so that modernization and development will be adapted to meet their needs for production and not women be adapted for the purposes of modernization as is happening today. Only then will truly sustainable development be a possibility for humankind.

6. RECOMMENDATIONS

- Develop gender sensitive data bases on women's knowledge and experiences of management and conservation of natural resources, the impact of environmental degradation and impact of commercialisation on women, and analyze linkages between gender relations, environment and development.

- Undertake programmes to reduce the workload of women and promote provision of environmentally sound technologies designed and developed in consultation with rural women.

- Facilitate access to all forms of resources: credit, property, training and information.

- Establish and promote women's groups for collective action.

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Community Forestry for Rural Development in Nepal: Some Prospects and Problems

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1. INTRODUCTION

Achieving socio-economic change and development in a country like Nepal has been a formidable challenge and also one with an imperative of "reconciling development and conservation" (Ives, 1989). Nepal's status as one of the least developed countries in the world is often attributed to historical, physical, socio-cultural and economic factors and processes. For the past 40 years, various plans, projects and programs have attempted to improve the fate of the country and its people by setting one or more targets such as to increase the agricultural productivity, controlling population growth, conserving and improving the environment, poverty alleviation, rural development, meeting the basic needs of the people, and so on. While such goals have generally been laudable, the approaches and strategies adopted to achieve them have not always been appropriate. There are exceptions, and community forestry is one example of a viable approach to promote conservation or environmental protection as well as rural development in the Hills of Nepal. In a country where only about 10% of the total population lives in urban areas and where more than 90% of the country's economically active population is engaged in farming activities (CBS I992), "rural development" and "meeting the basic needs of the people" are critical issues.

The purpose of this paper is to discuss some of the potentials and problems in the context of community forestry as a strategy for rural development in Nepal. Our discussion in this paper is based mainly on our field observations in Sindhu Palchok and Kabhre Palanchok; the prospect and problem of Community Forestry as a strategy for rural development may hold true for most parts of Nepal where these programs are being implemented.

2. BACKGROUND

The importance of forests and forest products for the rural people in Nepal cannot be overstated. Forests provide fuelwood, construction materials, fodder for livestock and other products needed by rural communities on a day-to-day basis. The linkages between farming, forestry, animal husbandry and human society and the importance of forests are sufficiently understood by the rural communities of the hills of Nepal (Chhetri, 1993, I994, Chhetri, 1992, Mahat, 1987), but the fact that forests and forest products could generate income and employment in these rural communities and that community forestry could be a viable strategy for promoting sustainable rural development has yet to be fully appreciated by both villagers and professionals.

Today, progressive policies and legislative provisions of community forestry favourably promote rural development. For instance, one of the objectives of the Government's latest five year development plan (1992-1997) is to "increase income and employment opportunities from the forestry sector for small and marginal families" (HMG/NPC, 1992). The plan further adds that "forests will be raised on marginal lands in all the areas and emphasis will be placed on forestry-based occupations "(HMG/NPC, 1992). Policy statements like these and the priority given to community forestry in the overall forestry development program for Nepal have opened up opportunities for generating income and employment for the forest user groups from their community forests.

Figure 1. NACFP project area.

3. COMMUNITY FORESTRY: SOME CHANGES

In 1992, a seminar was organized by ICIMOD on Himalayan Community Forestry which brought together professionals and representatives from donor agencies, NGOs, INGOs and Government Organizations. At that seminar, it was noted that Nepal had taken a very liberal legislative approach to community forestry and that the "liberal approach of Nepal in turning 100 percent of forestry benefits to local communities amazed Indian participants" (ICIMOD, 1993a). Although the community forestry program in Nepal has had a history of ups and downs, HMG's commitment to the program is reflected in changes in focus that have occurred while implementing the program at the field level.

Ever since the introduction of the Community Forestry Program in Nepal in 1978, some noticeable changes have come about in the practices related to forestry development. For instance, there has been a change in emphasis from centralized management of forests by the Department of Forests (DoF) to decentralized management by communities. Community Forestry originally involved heavy emphasis on plantation activities, while today the focus is more on natural regeneration of forests and protection and management by user groups. The DoF field staff, whose role at one time was patrolling and protecting the forests, are now technical advisors to the communities, helping them to undertake forestry development. These days, DoF staff are not expected to control and punish the people, but rather, they are expected to act as facilitators. Since the forest user groups are now given authority to manage their community forests and sell and distribute forest products independently, villagers no longer have to wait for permits (purji) to obtain timber. All of these are encouraging signs of a progressive forestry development program being followed in Nepal today.

4. THE NACFP EXPERIENCE

The Nepal Australia Community Forestry Project (NACFP) has been assisting HMG in the implementation of community forestry in Sindhu Palchok and Kabhre Palanchok Districts in the Hills of Central Nepal since 1978 (Figure 1). Initially a high priority was given to establishing plantations during the second phase of the project since "the forest resource was so impoverished that little could be done to protect it until additions through new planting began to relieve the pressure" (Griffin 1988). Planting has continued to date, although at a slightly relaxed rate compared to the peak in the mid-1980s. To date more than 20,000 ha of plantations have been established in the NACFP area through the participation of the communities who will own the forest resources once the forests are handed over to them.

Towards the mid-1980s, the need for improving the management of existing natural forests and plantation resources saw a search for identifying appropriate organizations to undertake protection and management of these forests. For almost a decade, beginning in the late 1970s, forests were being handed over to Panchayats (now Village Development Committees) as community and protected forests. Although the intent of the government's policy to hand forests back to the people was commendable, the selection of the politico-administrative unit such as the Panchayats caused a lot of confusion and conflicts at the local level. By the mid-1980s, the forest user group (FUG) was identified and recognized as better suited for undertaking protection and management of forests in their proximity. The first handover of a community forest to a FUG was approved in 1988 in Kabhre Palanchok. By the end of 1990, the total number of FUGs in the project area was 60, while by the end of 1994, the total was 266. The formation of FUGs and the handover of community forests appears to be gaining momentum.

5. SOURCE AND NATURE OF INFORMATION

The observations and discussions in this paper have emerged as a result of dialogue between the authors and the local people in Sindhu Palchok and Kabhre Palanchok over a period of more than three years. Some case studies as well as anecdotal information have been used to support the emerging arguments in this paper. The results of some of the field-level discussions with the villagers using Participatory Rural Appraisal and Participatory Action Research methodologies have been presented as internal reports at NACFP. Table 1 below summarizes some of the data available in records kept at the districts and the project offices.

Table 1. Total user groups, community forest area and user households in Sindhu Palchok and Kabhre Palanchok (March 1995).

District	No. FUGs	Total CF Area ha	Total FUG HHs	Average CF Area/FUG	Average CF Area/HH	Beneficiary HH %	Average # FUG HH
Sindhu	156	6228.53	20026	39.9 ha	0.31 ha	38.95	128
Kabhre	125	2762.78	13522	22.1 ha	0.20 ha	23.38	108
Total	281	8891.31	33548	32.0 ha	0.27 ha	30.36	119

Source: Project Record, NACFP, HH=Household

Table 1 shows that the natural and plantation forest area handed over to 28l FUGs in Sindhu Palchok and Kabhre Palanchok covers 8991 ha. The average size of the forest handed over to FUGs comes to about 40 ha in Sindhu and 22 ha in Kabhre. A rough calculation, based on the average household size and the total number of households in the two districts at the time of 1991 census (ICIMOD, 1993b), reveals that over 30 percent of the total population in the two districts have been exposed to the Community Forestry program. This is a substantial achievement given the fact that the first FUG-based CF handover was in 1988.

A note on the average CF area and the average number of FUG households is necessary to give a better picture of the field realities. While many CFs and FUGs may be closer to the averages shown in Table I, in reality there are wide-ranging variations. The largest FUG in the project area has 590 user households while the smallest has only 8 households. The size of the community forests handed to FUGs also varies. The largest CF in project districts is 250 ha while the smallest one is only 0.5 ha. Such wide variations in the size of FUGs and CFs along with other variables like the condition of the forest and species composition may raise questions regarding equity as well as self-reliance among the FUGs.

6. CASE STUDIES

6.1. Pine Plantations in Chaubas and Pipal Danda

Chaubas and Pipal Danda VDC are respectively located in Kabhre Palanchok and Sindhu Palchok Districts. Both sites have large areas of semi-mature plantation established on previously degraded sites. About 480 ha of plantation have been established in the Chaubas area and 439 ha in the Pipal Danda Area. In Table 2 some of the characteristic features of the two sites are presented. In both Chaubas and Pipal Danda, plantations were established in response to requests from local people. Many elderly people confess today that in the late 1970s and early 1980s (when the first plantations were established in the area), they were quite sceptical that forests would grow out of the tiny pine seedlings. These days, people in the areas are happy with the new developments in forestry because shortages of firewood, leaf litter and timber have been alleviated. However, at present, in both areas grass and grazing areas are in short supply (Table 2). These changes over time suggest that development efforts in regard to natural resources need to recognize dynamics.

Table 2. Some basic features of Chaubas and Pipal Danda.

Features	Chaubas area (Kabhre Palanchok)	Pipal Danda area (Sindhu Palchok)
Plantation	480 ha	439 ha
Management	Community Forest	Community Forest
Previous Condition	Grassland	Grass/shrubland
Previous Problem	Shortage of fuelwood/timber	Shortage of fuelwood/timber
Access	Remote: No motorable road.	Accessible: Motorable road.
Condition	Pine plantation	Mixed forest
Present situation	Plentiful forest products, excess timber and grass shortage	Plentiful forest products, excess timber and grass shortage
UG Aim	Utilize products for income and employment generation while maintaining the natural ecosystem values through sustainable forest management	Utilize products for income and employment generation while maintaining the natural ecosystem values through sustainable forest management

The plantations in both sites have been handed over to local user groups as community forests. The user groups have been undertaking silvicultural operations like pruning, singling and thinning to meet subsistence needs. However, because the users are only harvesting forest products for subsistence needs, the vast resources created in these areas are being under utilized. How to utilize forest product surpluses for subsistence needs, generate cash income and create employment are critical issues for CF. In both areas, users have been seriously considering establishing user group-managed sawmills to utilize the new resources.

Chaubas is a relatively remote site, the closest motorable road is more than four hours distant. Pipal Danda has a motorable road. The Pine plantations in Pipal Danda have approximately 50% stocking of regenerated broad-leaf trees. The people in Pipal Danda think that sometime in the future they can gradually change the structure of their forest from a pine plantation to a mixed natural forest. They plan to favour Chilaune (*Schima wallichi*), Kafal (*Myrica esculenta*) and other multi purpose broadleaf species by selectively removing pine. One old man in Pipal Danda claims that this will be achieved in the next 60-70 years.

6.2. Natural Forest Management in Nala and Tukucha Area

There are several forest user groups in Nala and Tukucha area of Kabhre Palanchok district today. Most of these user groups have been protecting and managing natural forest areas with some technical support and advice from the project and district forest office staff. Two such forests, Nala ko Thulo Ban and Tukucha ko Sano Ban and their user groups will be discussed briefly. Both of the forests have had their own history of indigenous management before formal handover took place. The user households of these forests come from several settlements or villages from five different Village Development Committees

Nala ko Thulo Ban (meaning Nala's big forest) is a single forest with a total area of more than 100 ha. Local people report that an indigenous system of protection and management was present here until it was designated as Panchayat Protected Forest in 1984..In 1989, the forest was handed over to three forest user groups under written Operational Plans in accordance with the new practice of User Group approach to community forestry.

Tukucha ko Sano Ban (meaning Tukucha's small forest) has an area of about 80 ha of natural forest and about 40 ha of pine plantation. This forest was also handed over to three user groups in 1988 and 1989.

Each of the forest user groups have divided their Community Forests into smaller blocks based on geographical features. Such blocks are not necessarily identical in size, but they fulfil the objective of ensuring product availability over a defined period while accommodating an annual harvesting program by the users. Regular harvesting of forest products has been taking place in these community forests by the respective user group members. The user groups have made income from the sale and distribution of forest products as well as from other sources. The funds thus collected have been used to undertake such local development works as improvements to the drinking water supply system for the users, electrification in the villages, construction of roads to connect the villages to the local market centres, fabrication of furniture for the local schools and restoration of a village shrine.

7. SOME PROSPECTS FOR RURAL DEVELOPMENT

Today the supply of forest products from the CFs of many FUGs in the project districts far exceeds the local demand to meet the subsistence needs of the users. If such surplus is utilized properly, many FUGs can earn large incomes. A recent study has estimated that 130 ha of well managed 12 years old pine plantation could generate an annual net income of almost 1 million rupees to the concerned FUGs from the processing and sale of surplus timber (Jackson, 1994). Another recent report estimated that 227 FUGs "accumulated net funds of about Rs 97,000 (about US$ 19,400) during the year, after spending an equivalent amount on development and afforestation activities" (Jackson, 1994). Figures such as these suggest that farmers in the hills of Nepal cannot satisfy their own basic needs through participation in the Community Forestry program, but may also contribute to the national development and economy by undertaking small local development projects.

The potential for the FUGs to generate funds and use such funds to provide for their own local level development such as improving the drinking water supplies, constructing roads/trails, schools, etc., may have wider implications for the process of rural development in the country. Once FUGs start undertaking such local development projects, the government may shift expenditures to larger national level development projects. Instead of spreading the funds thinly over a large number of micro-projects, the funds at the centre could be spent in ways that would benefit a wider public.

People in some rural areas of the hills may prefer pine plantations on degraded broad leaf sites if they can generate income from marketing pine timber. The FUGs in Chaubas and Pipal Danda are examples of this. What is more interesting is to see that some farmers in the project area have also planted pine in their private lands since these trees grow faster and provide quick returns.

Farmers have a strong interest in the management, sustainability and use of the forest resources in their proximity because they depend on such resources for their survival. Thus, when forest resources are depleted, it is the hill farmers who suffer the most. They understand this very well. During a recent visit to Jajarkot, the senior author had an opportunity to attend the opening day of a Community Forestry workshop for village women. When a ranger began to talk about the importance of conservation, forest and natural resources for the farming community, an elderly lady in the audience stood up, interrupted the ranger and said: "We already know all this. Could you please tell us something new?".

The new potential for the rural farmers could be in linking opportunities for income and employment generation with protection and management of natural resources. Employment opportunities created at the village level may have implications on the social and demographic process, too. It could mean a reduced rural to urban movement of people. This, in turn, will not only retain able-bodied human resources in the villages (retain more farm labour) but will also reduce the pressure on urban areas where socio-economic problems associated with overcrowding are becoming more acute every day.

One of the best things to happen is that local level development decisions are made at the local level since FUGs or villagers themselves fund them. Such decisions are likely to be more appropriate and the resultant development process will probably be effective and efficient ensuring people's participation and sustainability.

In some parts of Sindhu Palchok and Kabhre Palanchok, FUGs have chosen to use their funds as a rotating credit fund from which user group members can obtain short-term loans at interest rates they themselves have fixed (Chhetri, 1995). People see this type of fund management as useful since loans can be obtained easily to meet household expenses of any kind. Furthermore, when FUGs are located far away from banks, the rotating credit fund as a way to manage income appears to be suitable.

Also, a potential exists for FUGs to undertake income generating activities by utilizing non-wood forest products like medicinal plants, fruits, Sal (*Shorea robusta*) leaves, lokta, etc. Some of these products are collected by individuals and/or contractors and supplied to the market. Perhaps FUGs could be provided with the necessary support to collect, process and market locally available non-wood forest products. If marketing activities are done by FUGs as a group, the resultant benefits will go to everyone in the group rather than to some individuals only.

As noted above, the FUGs have the potential to reduce the cost of rural development to HMG. This is happening in many ways. One good example is a reduction of the cost of protection of the plantations and natural forests. Forest user groups have been growing seedlings in their own nurseries, undertaking plantation activities and protecting the forests by adopting protection methods that are suited to their local conditions.

8. EXISTING AND EMERGING PROBLEMS IN COMMUNITY FORESTRY

As discussed above, the potential benefits from Community Forestry for rural development are many. However, some problems or bottlenecks are still there while others are likely to emerge in the future. One of the main problems is that some CFs might be overutilized, and that local elites and unscrupulous people may try to capture the benefits. Overutilization could result in the degradation of forest resources. Equity problems will also occur if care is not given to the way funds are shared or used, particularly if benefits are captured by the elites among the FUG members. The elites from urban areas and district headquarters and high-ranking government officials (other than those from the Ministry of Forests and Soil Conservation) tend to disregard or overlook the tenureship rights of FUGs in their respective CFs. There have been some isolated cases of this nature. This needs to be controlled.

More recently, DoF field staff are finding it difficult to handover forests that run across more than one district or in cases where forest users come from two or more districts. Field staff may need to do a careful investigation in order to identify CFs that are spread across district boundaries.

Other obstacles to a smooth implementation of CF in the hills of Nepal are the target orientation of the DoF, inadequate levels of support available to FUGs (because of the shortage of field staff), frequent transfers of the field staff and inadequate records keeping systems at the field level.

9. CONCLUDING REMARKS

The following conclusions emerge from the above discussion:

1. The developments in Chaubas and Pipal Danda clearly suggest that solving one set of problems today may give rise to another set of problems and issues tomorrow. An observational/evolutionary process towards development is better than the one that looks at development as an end product.

2. The real empowerment of the FUGs is to make them self-reliant which is also contingent upon a better co-ordination between various organizations within HMG.

3. A potential exists for Community Forestry and User Groups to contribute to rural development in Nepal. What can be a more sustainable approach to rural development than letting the rural people themselves carry out local development works on their own by mobilizing local resources?

4. Through participation in community forest protection and management, FUGs have reduced the cost of forest protection (i.e. no cost to hire watchers) for HMG.

5. Community Forestry can generate funds that can be spent on local development, reducing the burden on the government to undertake local development works.

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Local Knowledge for Mountain Biodiversity Conservation at the Cajamarca Pilot Project in Perú

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1. INTRODUCTION

The Andes are a continuous mountain ecosystem that includes the territory of seven different South American countries, from Venezuela in the north to Argentina in the south. It extends over 2 million square kilometres, and it has an estimated population of about 20 million inhabitants. The land used for agriculture ranges from 1,500 to 4,200 m in elevation which gives rise to many different agro-ecological zones, particularly in the Central Andes (Colombia, Ecuador, Perú and Bolivia) where even tropical high mountain conditions are found. In the Andes, the more extensively populated area in the world is typically located above 3000 m elevation. Large cities, such Quito, Ecuador, and La Paz, Bolivia, have more than 1.5 million inhabitants each, and medium size cities like Huancayo, Cusco, and Puno in Perú and Oruro and Potosi in Bolivia have more than 100,000 habitants.

Agriculture in these mountains is possible because frost-resistant plants were domesticated to adapt to high altitude, such as the so-called "bitter potatoes" (*S. juzepzukii* and *S. curtilobum*), other "native" potatoes, the small Andean grain "cañihua" (*Chenopodium pallidicuale*) and the small highly nutritive root "maca" (*Lepidium meyenii*). The conservation of these crops has been possible only because the local communities have maintained their cultivation and use during the last few centuries. Also, at altitudes of 3,800 to 4600 m, two important ruminants, the llama and alpaca, were domesticated to produce meat, fibre, leather and manure and graze on more than 20 million ha of native pasture in Perú and Bolivia.

It is also important to remember that these areas have been utilized by humans over the past 10,000 years, and important cultures as the Tiahuanacu and Chavin, and finally, in the 11th century, the Incas, built up what was considered the largest empire in the New World before the arrival of the Spanish. The Incas heritage of domesticated plants and animals and agricultural technology from the previous cultures gave the population an advanced social organization. As a result, biodiversity conservation and appropriated technologies were the keys in a sustainable agricultural system which was quite advanced for the time.

It is now well recognized that, at that time, food production could support the Inca's empire population which was similar in number to the population today. Nevertheless at the present, the Andean rural population has one of the lowest standards of living in South America with serious problems with food supplies and environmental degradation such as soil erosion, loss of soil fertility, inadequate use of water and loss of biodiversity. This is resulting in low crop and livestock yields.

Several attempts to control the process of degradation have been initiated, but the results were often controversial with many negative effects. A general review of the principal constraints on Andean rural development projects is presented for the Peruvian "Sierras", and a case study is presented where a holistic approach is used to analyze and integrate the different components of development to provide alternatives to the current management of the Andean ecosystem with emphasis on soil and biodiversity conservation.

2. AGRICULTURAL DEVELOPMENT IN THE PERUVIAN MOUNTAINS OVER THE LAST TWO DECADES

Agricultural development in the Peruvian Andes has been the main focus of national institutions and international organizations. In many cases, the approach has been to transfer models and techniques that are based on intensive energy and investment systems such as the use of high yielding crop varieties, the use of high levels of chemical fertilization and pesticides and the introduction of new breed livestock systems with emphasis on artificial insemination rather than forage production.

One of the main problems has been the assumption that the high Andean Mountains are a uniform and stable environment. Based on findings by Troll (1950), Pulgar Vidal (1946), Tapia (1990), and Torres (1992), the high Andean mountains in Perú are highly diverse and cover a wide range of environments that greatly influence agricultural production. These range from warm conditions at lower altitudes, such as the **yunga zone** (1000-2000 m) to the template zone known as the **quechua zone** (2000-3200 m), **suni zone** (3200-3800 m) in the central and south part of the Andes in Perú, **jalca zone** (3000-3800 m) and **puna zone** (>3800 m) . Each of these zones are highly influenced by latitude as well as exposure either on the Amazonian side to the east, the Pacific side to the west or the intermountain location. Also physiographic factors such as topography can have a drastic influence on the farming systems. Therefore, an appropriate agro-ecological zonation should not only consider altitude but also temperature, volume and distribution of rainfall, evapotranspiration and more localized conditions such as soil texture, depth, water retention and nutrient content. Mountain agro-ecological zonation is recognized as a complex entity as well as a key aspect in understanding the potential and restrictions of high altitude environments.

An agro-ecological zonation for the Peruvian Andes has been proposed by Tapia (1990), based on geographical studies by Troll (1950) and Pulgar Vidal (1948) as well as botanical studies by Weberbauer (1945) and ecogeographical work by Cabrera (1967) and Brack (1991). This agro-ecological zonation classification considers three hierarchical levels. At the first level, the mountain ecosystem is divided into physiogeographic zones. At the second level, climate is used to arrive at six different sub-regions, each with different agro-ecological conditions. Crops and livestock species and varieties are different in each agro-ecological zone as well as the levels of production. The third level of zonation considers the soils and alternative technologies to be used as the main factors which influence production.

3. THE PERUVIAN ANDEAN AGRICULTURAL SYSTEM

Considering the agro-ecological zones as the main units for environmental differentiations, it is quite important to realize their influence on biodiversity evaluation as well as on the characterization of the distribution of agricultural systems (Table 1).

Crops are dispersed, and some of the chenopods, grains, roots and tubers are adapted to low temperature conditions. Maize is the best indicator of temperature but can be grown up to 3400 m in the absence of frost and up to 3800 m in special micro-climate environments such as the islands on Lake Titicaca. Other crops that have adapted to different altitudes are quinua that can be grown from sea level to close to 4,000 m and beans that can be produced from sea level to 3300 m.

Livestock production systems are mainly concentrated in the upper zones and bottom of the valleys since most of the better cultivated pasture can be adapted to more humid conditions or irrigation.

Table 1. Agricultural systems in the Peruvian highlands.

Agricultural Systems	Agro-ecological Zone and Altitude Range (m.a.s.l.)	Species Livestock	Crops
High altitude	Janka 4500-4800	llamas alpacas	camelids
	Puna 3900-4500	alpacas llamas sheep, cattle	bitter potatoes maca, kaniwa barley
	Jalca 3200-3700	sheep, cattle potatoes, oca olluco, mashua	barley, oats
Middle altitude	Suni 3500-3900 hill sides	sheep, cattle	potatoes, oats oca
	Suni 3800-3900 high plateau		barley, pasture olluco, mashua, quinua
Bottom of the valley	Quechua 2300-3500 varying from sub arid to sub humid	dairy cattle goats, sheep	maize, potatoes amaranths quinoa, beans
Temperate	Yunga 500-2,300 maritime	dairy cattle goats	fruit, maize beans, vegetables
	Yunga 1000-2800 fluvial	cattle, goats	maize, fruits

4. CAJAMARCA PROJECT

Cajamarca is one of the 24 Peruvian departments within one of the 13 political provinces. In 1991, a micro watershed location, named La Encañada, was selected as a site to start a pilot rural development project in the northern Peruvian Andes in the province of Cajamarca (ASPADERUC, 1993). The Encanada is located 45 km north east of the capital city of Cajamarca and includes 27 "caserios" composed of 30 to 60 families each. At the present 1,200 families are involved in the project. The agricultural development activities include the following components:

- participatory diagnosis
- soil and water conservation
- agriculture improvement
    - crops and biodiversity in situ conservation
    - pasture and livestock

forestry production
- agro-industry and marketing
- peasant enterprise organization

The pattern of action for the project was characterized as:

- multi-institutional participation by five different institutions, involved in activities ranging from soil and water conservation (Pronamachs) to crop and livestock improvement (INIAA) and agro-industry (ITDG), coordinated by the Agriculture Research Department at the University of Cajamarca (ASPADERUC) and the stakeholders, the local Agriculture Producers Association;

- interdisciplinary activities included social studies, soil sciences, agronomy, in situ biodiversity conservation, animal production, forestry, agro-industry, economics and interactions; and

- intensive local participation: from the beginning of the project, the local people were involved not only in the task definition, but, in the design of programs and activities, with emphasis on the "organized group work" which includes 12 to 20 families with the experience to work together and freedom to start soil and biodiversity conservation actions. By the third year of the project, 90 different groups were formed and they dedicated at least one day a week to work on terrace building, raise field borders, drain channels, work on irrigation, participate in forestry activities, help in germoplasm evaluation and seed production and improve forage conditions. The entire family participates in these processes.

4.1. Results of Biodiversity Conservation

From the diagnostic analysis, a close link was identified between soil erosion and loss in biodiversity due to inadequate hillside agricultural practices and market effects which have mainly restricted sound local agricultural development. As a result, special emphasis was placed on the establishment of different soil conservation practices that encourage crop biodiversity.

4.2. Soil Conservation

For each soil conservation practice, the number of working days needed to conduct the work were calculated (Table 2). The peasants in the area dedicated more then 450,000 days to work in soil conservation. A total of 880 hectares of hill side now show the process of terrace building. Some 24 kilometres of land were fenced, and 300 km of trenches were made for humidity collection. All of these activities have improved the crop productivity in the area, and it was estimated that, during a regular rainfall year, production increased at least 25 %. These adaptations to the environment and market were considered as essential interventions to promote biodiversity conservation.

4.3. Crop Improvement

The Andean region is well known for its large biological diversity, including a flora of rich genetic material for many different crops that have been domesticated and are still being cultivated (Fries, 1985). Many peasants grow up to 12 different crops and as many as 20-50 varieties of potatoes (Tapia, 1994). These crops are adapted to be cultivated at different altitudes, and in the case of the Encanada project, more than 14 different crops contribute to the diet of the peoples (Table 3).

Table 2. Number of work days per each soil conservation practice.

Practice	Work days
Terrace construction, earth, side slope, per ha.	720-780
Terrace construction, stones, side slope, per ha.	700-1100
Trench for infiltration, drainage, per ha.	400-480
Fence, earth made, per ha.	270-330
Fence, stone made, per ha.	405-495

Table 3. Altitudinal adaptation of the crops in the Encañada Project in Cajamarca, 1994.

Crop	Scientific name	Altitude (m)
Native species		
Potatoes	*Solanum andigenum*	2800-3500
Oca	*Oxalis tuberosa*	3200-3500
Olluco	*Ullucus tuberosus*	3200-3500
Mashua	*Tropaeolum tuberosum*	3200-3500
Maize	*Zea mays*	2700-3200
Quinua	*Chenopodium quinoa*	3000-3400
Chocho	*Lupinus mutabiles*	2800-3300
Coyo	*Amaranths caudatus*	2800-3000
Arracacha	*Arracacia xanthorrhiza*	2700-2800
Introduced species		
Barley	*Hordeum vulgare*	3000-3500
Wheat	*Triticum sativum*	3000-3300
Faba bean	*Vicia faba*	3000-3300
Arveja	*Pisum sativum*	2700-3100
Lenteja	*Lens esculenta*	2700-3100

Potatoes are cultivated on about 30 % of all agricultural land; therefore, special emphasis was placed on improving its production. One of the important factors is seed quality. In previous diagnostic surveys, the lack of seed storage facilities was identified as a factor seriously affecting seed sanitation and quality. More than 50 new tuber seed store facilities were built with a total storage capacity of more than 140 tons of seed.

The organization of the "seed fairs" was essential in the process to promote in-situ conservation of the genetic material for variety selection as well as publicize local information on the different characteristics and uses of the local land races which have been preserved by the local peasants for centuries. During the last five years, more than twenty "seed fairs" have been organized. The process involves the selection of a day that is dedicated to organization. A formal invitation is distributed to all leaders of the "caserios" so that the local authorities are informed of what was to be documented and how the seed presentation was organized. A central site was selected by the peasants each year, and the participants and their produce were selected well in advance of the fair. Each fair on average involves between 30 to 60 participants and the presentation of more than 20 crops and 1,200 ecotypes.

During the seed fairs, an individual registers the material presented and notes information about its characteristics, so evaluation and selection of the "exposition winners" price are facilitated. Not only the number of varieties are counted but also the quality of the material, knowledge of the producer and utilization of the land races are considered. One important finding was that women had the best knowledge about indigenous agriculture and were particularly knowledgeable about the uses of different crop varieties (Tapia, 1994). For example, campesina Mrs. Rosa Abanto could identify 56 different varieties of potatoes and knew the pattern of growth, insect and disease resistance, use, time of cooking and taste of each. More than 30 varieties of oca and olluco tubers have also been identified. Through the participation of peasants, six new varieties of potatoes and three varieties of oca were selected and are now being produced in larger quantities. Another peasant displayed 27 different coloured seed beans, and his wife knew the use of each one in different dishes and the altitude range where the main varieties were best cultivated.

Arriving at high seed quality production was one of the objectives in the project. About 40 to 50 varieties from six different crops were seeded each year within the peasants fields and these included selected materials presented at the seed fairs. This assured a sufficient supply of genetic material for distribution.

Native and commercial variety potato trials were carried out by interested peasants. A revolving fund was established, and at the moment, half of the total potato seed requirements in the area is obtained from these fields. Also, other tubers such as oca, olluco, grains and quinua were selected to improve the seed quality.

The second successful step in biodiversity conservation was the initiative to discuss the maintenance and proper use of germoplasm. Peasant workshops, which encouraged the participation of conservationists, "seed fairs" winners and interested peasants, were found to be most effective in promoting new efforts that addressed the cost of germoplasm maintenance, labour availability at the time of seeding and harvesting and in organizing a "yunta credit system" in order to get oxen to plough the land.

In a second workshop, issues relating to soil and weather effects on the germoplasm conservation were discussed and, as a result, the "peasant germoplasm bank" was established where each of the campesinos can deposit 1 to 2 kg of tubers and 100 g of grains to be maintained in the bank and seeded in rotation in peasants fields. The peasants can obtain the material that they lost in a specific year due to climatic events.

Finally, a third workshop will to be organized to investigate the relationship between crop diversity, conservation and the market. The goal is to organize the marketing of local native crop varieties.

5. CONCLUSION

Plant genetic germoplasm, in-situ conservation and proper use of local crop varieties should be important components of any research and development project. It should be noted that local domesticated crops have been influenced by numan activities and are now part of the natural environment. These crops have a great potential to contribute to sound ecosystem management.

Mountain conditions, such as those found in the Himalayas and Andes, are typically rich in plant genetic resources, and a methodology is required to involve local people in long term evaluations of local crop varieties, including both major and minor crops. Plant genetic resources are key in the development of cropping strategies for agricultural production in a world which is subject to dramatic changes in climate, land use and surface conditions.

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PART 2

THE JHIKHU KHOLA WATERSHED PROJECT

Introduction to the Watershed Project: Issues and Overview

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1. OVERVIEW OF THE WATERSHED STUDY

Given the lack of long term information on land use, resource degradation, sediment transport and soil fertility in Nepal, in 1989 the Jhikhu Khola watershed was established as the key research area for a long term monitoring program. With the support of the International Development Research Centre (IDRC), we focussed our research on documenting climatic conditions, soil erosion, sediment transport and redistribution, stream flow, irrigation, deforestation, agricultural intensification, soil fertility, socio-economic conditions and population growth in the watershed. After the first three years, we initiated a number of smaller projects which attempted to translate our gained knowledge into development efforts. These activities included the construction of a suspension bridge, upgrading of rural water supply systems, reclamation of degraded areas, electrification of three houses with solar-powered photovoltaic cells, and introduction of a water-conserving trickle irrigation system. Computer technology was used in monitoring as well as in data organization, and a PC-based Geographic Information System (GIS) was used as the main tool for data integration and modelling.

No standard methods exist to examine resources in an integrated and interdisciplinary manner, so we focussed our efforts on trying to gain a better understanding of the intensification of biomass production and environmental consequences. A watershed approach was used, involving an interdisciplinary team, and relied on GIS for data integration. The papers compiled for these workshop proceedings are intended to inform other researchers and NGO's about the Mountain Resource Management Project (MRM), highlight the most important findings and discuss directions for ongoing research activities. The project attempts to address all relevant issues associated with the development of a rural watershed. Much of the initial efforts were spent on building a comprehensive resource database. In 1991, we held the first workshop, entitled: "Soil Erosion and Fertility Issues in the Middle Mountains of Nepal", and this workshop resulted in a status report on the most pressing resource and socio-economic conditions in the watershed. These second workshop proceedings are intended to provide a better understanding of the key resource degradation processes with emphasis on cause and effect relationships and rehabilitation options.

The gaps in our understanding of these processes are still large and what we present is our modest contribution to understanding the dynamics of land use and management in this very intensively used Middle Mountain watershed. The conditions for intensive biomass production are far from optimum, and the population pressure is such that it raises the question of whether the current resource use will maintain the long term productive capacity in the watershed. The issues and processes are complex, and innovative solutions and successes are few. The input and constructive suggestions by all participants during the workshop are greatly appreciated and, with the proceedings, we hope to foster dialogue between disciplines, researchers and resource users concerned with the deterioration of resources and environmental quality in this watershed.

2. GENERAL INTRODUCTION

Rapid population growth and resource constraints are putting severe pressure on the subsistence economy in the Middle Mountains of Nepal. Claims about massive deforestation, soil degradation, accelerated slope instability, and losses of the productivity base for agriculture are widespread. Unfortunately little quantitative information shows the rate and magnitude of these changes. In the absence of such information, predictions of the possible long term consequences of the current land use intensification and the use of marginal lands are difficult to make. To stimulate future development, initiate conservation programs, and point the way towards sustainable resource use, bio-physical and socio-economic processes must be better understood. It is the aim of this research project to address the issues of food, animal feed and firewood sustainability in the Middle Mountains of Nepal and to document the changes that have been taking place over the past 40 years. This information will be used to arrive at development scenarios which include the consequences of resource degradation and alternative development options.

3. BACKGROUND, PROJECT JUSTIFICATION AND AIMS

3.1. Background and national resource issues

Nepal has resource constraints that are somewhat unique in the developing world. These constraints include extremely high rates of natural erosion, marginal terrain conditions for biomass production dominated by steep slopes, a distinct dry season, very rapid population growth, and no room for population migration. To answer these challenges, Nepalis have converted their hill slopes into a multitude of terrace systems that are under double and triple annual crop rotations. The introduction of short growing season crop varieties and the use of an intricate network of irrigation systems have made it possible to increase food production levels, but shortages are still widespread. Given the remoteness, lack of infrastructure and difficult topography, questions have been raised as to whether such intensive cropping systems are sustainable given the naturally high rate of erosion and the relatively low availability of inputs.

The world's press has devoted much attention to the claims that rapid deforestation in the Nepali Himalayas are in part responsible for the recent devastating floods in the Ganges Lowland of India and Bangladesh. Little scientific information is available to substantiate the claims that human activities are influencing the frequency and magnitude of lowland flooding. Additionally, the multiple annual crop rotations are a relatively recent phenomenon (last ten years), and the effects are becoming apparent as the intensification proceeds and the inputs decrease. Very little long term data on land use, soil fertility maintenance, erosion and sedimentation processes are available for this part of the world, and the project was initiated to fill this important information gap.

There are many international development assistance programs in Nepal, but neither the aid organizations nor the recipient government agencies have been able to successfully translate this assistance (which is substantial) into improving the local economy or the subsistence level of the mountain farmers. The issues of long term sustainability are rarely addressed by these programs.

The recent introduction of democracy to Nepal has been hailed as the way towards development, but it is increasingly clear that changes are slow and difficult to initiate because of a lack of experience in the democratic process and a government infrastructure that is unable to cope with the demands and aspirations of its people. This is aggravated by the very marginal environments in which the people in the mountains live. These mountain systems are not as resilient and productive as the lowlands, and the issues of sustainability are far more challenging with consequences that reach far beyond the boundaries of the headwaters regions.

The Land Resource Mapping Project (LRMP, 1986), which was conducted between 1978 and 1984, represents the first systematic inventory of the soil, forestry and agricultural resources in the country. The information obtained by this survey provided the basis for the development of the Forestry Master Plan

(HMGN/ABD/FINNIDA 1988), the Master Plan for Irrigation Development (HMGN, 1989), and the Master Plan for Horticultural Development (ADB, 1991). More detailed evaluations were carried out for food, feed and fuelwood resources by Schreier et al. (1991), and Smith et al. (1993). From these studies it became evident that animal feed was the most critical resource in 1981 with 57% of all districts reporting feed deficits. The overall food production was estimated to exceed the demand by 25%, and fuelwood was considered the least critical resource at that time (Schreier, 1991). Using the human and animal population growth rates between 1980 and 1986, projections were made to the year 2000 using the assumptions that the resource base is not changing and the production capacity obtained in the early 1980's can be maintained. The results from these calculations indicated that by the year 2000, animal feed would be insufficient in 74% of Nepal, and food deficits would occur in one third of the country. While these calculations are highly speculative, they do provide a general indication of priorities and the magnitude of the resource problems. It became evident that inventories are essential to obtain a status report of the country, but, unless we monitor rates of change, we will have great difficulties arriving at a better understanding of the resource dynamics, production performance and degradation. This puts future plans for conservation, maintenance of carrying capacity and improvement of biomass production into question. Because of the lack of information on resource dynamics, resource demands and degradation processes, a detailed watershed study was justified.

3.2. The Jhikhu Khola Watershed Project

3.2.1. BACKGROUND

The Jhikhu Khola watershed, which is one of the most intensively used Middle Mountains areas of Nepal, was chosen for the project because all of the problems commonly associated with population growth, agricultural intensification and deforestation in a marginal environment are present in this watershed. The watershed has all of the infrastructure and make-up of a typical Middle Mountain valley. What sets it apart is that the watershed can be reached by motorable road and the Arnica highway which connects Kathmandu with Tibet passes through the centre of the watershed. This road can be reached from the most remote village by a five-hour walk, and the distance to Kathmandu is about 40 km. This watershed provided a number of advantages since it allows us to examine how traditional subsistence agriculture can be modified to a more market-oriented economy. In some ways this makes the Jhikhu Khola a futuristic Middle Mountain watershed and should allow us to document possible development opportunities that may be applied to other watersheds within the Middle Mountain region.

The watershed is located in the Kabhrepanalchok district some 40 km east of Kathmandu (Figure 1) and covers 11,141 ha. The elevation ranges from 750-2,100 m, and the watershed is subject to a monsoonal climate with an extensive dry season from October to May. A 1:20,000 scale topographic base map was produced as part of the project and served as a basis for all resource inventories and GIS analysis. Historic 1972 aerial photos were available, and new aerial photos were obtained in 1990. These photographs served as a basis for the historic analysis of land use, and the 1990 cover was also used for the soil survey study. Both set of photographs were enlarged to 1:5,000 scale and became the basic planning tools for the socio-economic survey and determination of population trends since each individual house could be identified on the enlargements.

3.2.2. JUSTIFICATION OF PROJECT

The reasons for the selection of the Jhikhu Khola watershed as the study site are manyfold but the most important ones are:

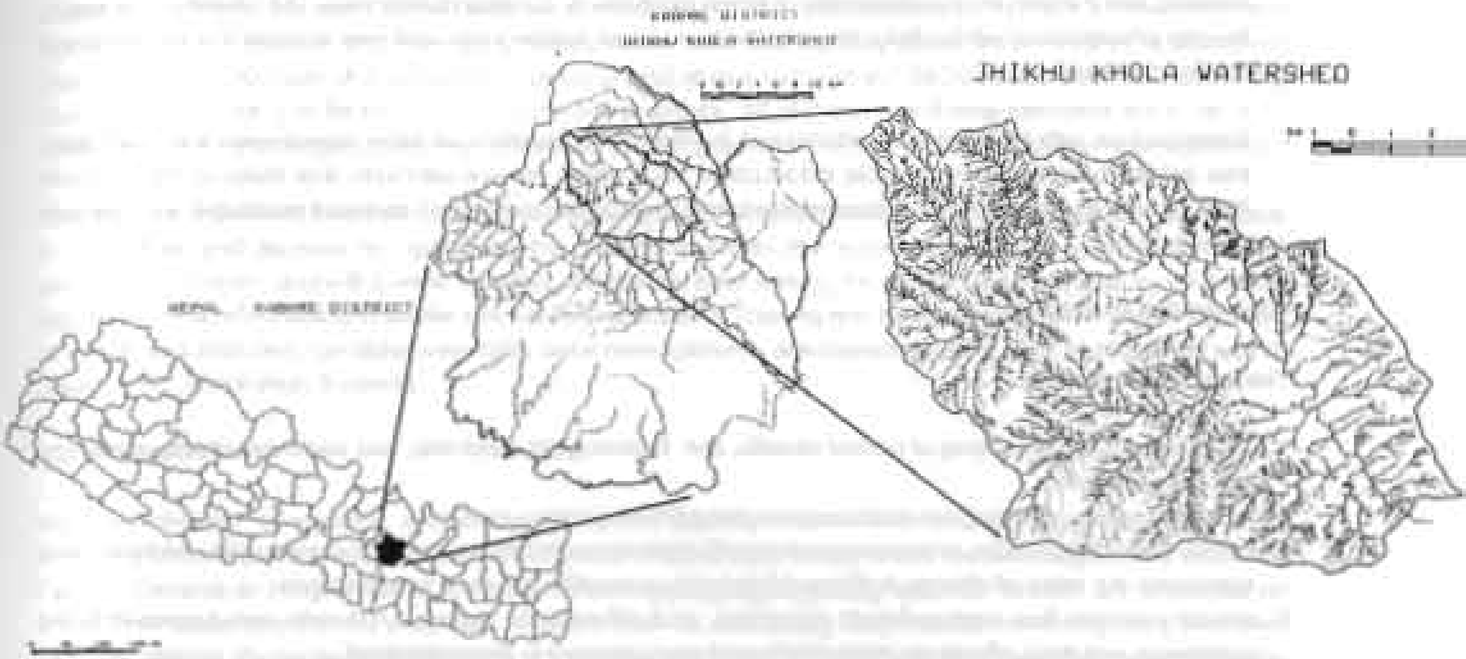

Figure 1. Location of Jhikhu Khola watershed.

- Hydrological processes in the Himalayas are substantially different from those in more temperate regions, yet little good scientific data is available to document these differences. This is particularly critical in view of the fact that the Middle Mountains represent one of the most modified human landscapes in the mountains of the world. The hydrological processes also need to be better understood in view of the extensive hydro-power potential that is constantly advertised by Nepal and aid agencies. The philosophy of building large hydro-dams is still prominent in spite of recent concerns about environmental stability and economic viability.

- Agricultural intensification is putting into question the long term sustainability of the productive capacity of the mountains, and in this context soil erosion, soil fertility maintenance, and irrigation are the key issues.

- In order to progress from a subsistence economy towards a market system, transport is a basic necessity. Having a road infrastructure which is currently being upgraded, and having growing market access in the capital city which is within 40 km of the watershed, provide the essential footings for introducing additional cash crops into the agricultural system.

- Historic aerial photographs (1972 and 1979) and land use change evaluations are available to provide historic land-use dynamics which are required to document rates of degradation and levels of sustainability.

- The watershed has a very active afforestation program, the Nepal-Australia Community Forestry Project (NACFP), and their staff expressed interest in obtaining better resource information in exchange for supplying vital historic information about forest management practices and afforestation efforts.

- Successful tree planting programs have been introduced at the community level by NACFP, but until now, little attention has been paid to soil fertility issues. The forests are losing nutrients by fodder and litter removal, and the long term sustainability of forest productivity is being questioned. The existing community forestry infrastructure will facilitate the introduction of new fodder trees and new approaches for forest soil fertility management.

- Relationships with local farmers established in Phase I will facilitate on-farm experiments such as fodder tree establishments and vegetable introduction. As a result, we are optimistic that many of the research findings can be translated into development that has a better scientific basis and points the way towards sustainability.

3.2.3. AIMS OF PROJECT

The main aims were to:

1. produce a detailed inventory of current climatic, soil, hydrological, land use, and socio-economic conditions in the watershed;
2. determine rates of change in land use over the past 40 years;
3. identify major degradation processes such as soil erosion, sediment transport and soil fertility declines, and determine the rates of change in these processes under different land use practices;
4. quantify stream flow and sediment dynamics, and differentiate between naturally and human-induced processes and their effects on productivity and management in the watershed;
5. identify successful land use practices (traditional and introduced) that can be used as a model to improve land use, productivity and management in other parts of the Middle Mountains;
6. develop GIS techniques that facilitate the integration of resource information, assist in quantitative modelling of processes and serve as effective communication tools in educating farmers and managers about carrying capacity and sustainability and
7. provide suggestions on how the scientific information can be used for development and translated into actions leading towards more sustainable resource management in the watershed.

4. RESEARCH PROGRAM AND TEAM COMPOSITION

4.1. Research Components

During the first three years, a basic resource inventory was conducted which included the generation of a general geological map, detailed soils map, current and historic land use maps, topographic map and detailed drainage system map. All of these maps were digitized into a PC-based GIS system and have formed the basis for our integrated analysis. Part of this inventory also included a number of socio-economic surveys, and all of the houses used in the interviews were georeferenced and incorporated into the GIS system.

The second component included setting up a detailed monitoring network and an intensive monitoring program. A large effort was made to establish a climate monitoring program which consisted of five automated tipping bucket rain gauges, about fifty manual 24-hr rain gauges, and five stations equipped with manual and automated air temperature monitors. Erosion monitoring was conducted at five erosion plots located in upland bari fields. Seven hydrometric stations were selected, staff gauges were installed in all of them, and four were equipped with automated pressure transducers to measure stage height on a continuous basis. A flow and sediment monitoring program was carried out from 1990 to 1995. During the pre-monsoon and monsoon season the monitoring effort was particularly intensive, allowing us to monitor most of the important storms each year. In addition to these networks, twelve forest plots were selected for a very detailed analysis of soil and biomass conditions in 1989, and these sites were resurveyed in 1994 to determine biomass and soil fertility changes. Similarly, ten agricultural fields were selected in 1989 and resurveyed in 1994 to determine soil fertility changes. A socio-economic survey conducted in 1989 was partially repeated in 1993/94 to document changes. Finally, 200 agricultural fields and grazing land sites examined in 1993/94 were used for monitoring changes in biomass, soil fertility and management practices. All of these monitoring networks were set up to determine rates of changes in the key processes affecting biomass production and land use management.

The third component involved community development projects where we attempted to assist local communities and farmers in upgrading the infrastructure in the watershed. These activities included constructing bridges, upgrading water supplies, introducing solar energy for electricity and irrigation, reclaiming degraded lands, and training in fodder tree nursery operations. Training and technology transfer were important activities and included computer use, data base management, automated logging, data transfer and use of Geographic Information Systems.

4.2. Research Team

Multidisciplinarity, integration, and enthusiasm were the key themes that characterized the team which consisted of three groups: local farmers, the ICIMOD/MRM & UBC teams and a number of graduate students. Farmers became an integral part of the field monitoring program. Typically up to 40 farmers are employed on a part-time basis to carry out a number of tasks such as measuring daily rainfall, collecting daily sediment samples, making discharge measurements, monitoring erosion plots and assisting in reclamation work. Many of them allowed us to use their fields as a research laboratory, and all participated in the socio-economic surveys.

The MRM team was made up of a core group consisting of a soil scientist, geologist, geographer, and hydrologist. Additional members, participating on a contract basis, included an agronomist, land use specialist, engineer and several assistants with various backgrounds. The UBC team provided expertise in GIS training, hydrology, soils, land use and socio-economic analysis. Finally, the graduate students came from many different areas and had experience in forestry, agronomy, soils, hydrology, economics, and geography.

We also interacted with the National Agricultural Research Council (NARC), Soil Science Department, Topographic Survey, Department of Meteorology and Hydrology, National Planning Commission, Forestry Department, Soil and Water Conservation Department and the Nepal/Australia Forestry program.

5. RESULTS TO BE HIGHLIGHTED IN THE WORKSHOP PROCEEDINGS

Not all of the results of the research have yet been analyzed and completed, but the key components that were highlighted in the workshop cover the following topics: population and socio-economic profiles of the farmers in the watershed, land use dynamics and intensification, soil erosion, hydrology and sediment dynamics, soil fertility in agriculture and forestry, processes leading to degradation of soils and biomass, indigenous knowledge in soil classification and irrigation, experiences in rehabilitation of degraded land, community projects, use of GIS techniques to model future scenarios, communicating science for development and lessons learned and mistakes made.

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People, Community Dynamics and Perceptions in the Watershed

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1. INTRODUCTION

The main hypothesis behind the socio-economic research is that resource degradation occurs within a social and economic context. To understand why farmers choose different management and cultivation practices it is necessary to appreciate the intricacies of the system within which they are operating. The surveys were conducted as a learning exercise to compile information from the farmers about their constraints (social, economic and physical) and their aspirations (individual, household and village-wide). A semi-structured interviewing approach based on the Rapid Rural Appraisal methods (Khon Kaen University, 1987) was utilized. Informal discussions were conducted with farmers to encourage a free speaking environment. The main purpose of the interviews was to gather information about the farming-household system, thus, the selection of respondents was biased towards the decision-makers within the farm household and towards equal representation of men and women farmers. Simultaneous and separate man / woman farmer interviews were conducted to account for the typical division of labour between men and women farmers and to incorporate a cross check system. In most cases, the interviewing was conducted at farmers' homes with the women (female Nepali interviewer and the woman farmer) holding the discussion indoors and the men (male Nepali interviewer and the man farmer) talking outside in the courtyard. Discussions with key informants and group interviews were also conducted.

A number of questionnaires were conducted between 1988 and 1994 (Table 1). The focus of the questionnaires included farming systems, soil fertility, indigenous knowledge, irrigation systems, agricultural practices and forestry. The Panchkhal, Rabi-Opi and Baluwa regions were surveyed in 1988/89 and again in 1992. The 1992 vegetable production survey re-interviewed 31 families and questions from the 1988/89 surveys were incorporated. The 1994 household survey conducted in Bela-Bhimsenthan region again repeated many of the questions from the 1988/89 surveys. The location of all households surveyed was denoted on the aerial photographs and transferred into the GIS system so that spatial relationships could be determined.

This paper will concentrate on the surveys related to farming systems in the Panchkhal, Rabi-Opi, Baluwa, Dhulikhel and Bela-Bhimsenthan regions (Figure 1). Population dynamics, non-farm activities, agriculture, livestock and forestry, and farmers' perceptions and expectations will be discussed.

2. POPULATION DYNAMICS

A population survey was conducted in the watershed for 1947 and 1990 by counting all of the houses on the available topographic maps and aerial photographs. The 1990 population was determined by counting all houses on the enlarged 1:5,000 scale aerial photographs and multiplying the number of houses by the average family size determined for each village through surveys and interviews. The population for 1947 was obtained from the number of houses on the original topographic map and the average family size determined from historic census data (HMG). The population dynamics between 1947 to 1990 are shown in Figure 2. The estimated population has increased from 8,971 people in 1947 to 32,956 people in 1990. This represents a 3.1% growth rate per annum or a doubling of the population every 25 years. However, this number should be interpreted with caution since increases in the population in the past 10-15 years are likely greater than changes 40-50 years ago.

Table 1. Questionnaires conducted between 1988 and 1994.

Focus	Location	Date	# Respondents
Farming Systems	Bela-Bhimsenthan	1994	85 households (men & women farmers)
Soil Fertility	Bela-Bhimsenthan	1993	230 farmers
Indigenous Soil Classification	Bela-Bhimsenthan	1993 1992	11 farmers 15 farmers
Irrigation	Bela-Bhimsenthan	1992/93	41 farmers
Soil & Water Management	Bela-Bhimsenthan	1992	21 farmers
Vegetable Production	Rabi-Opi Panchkhal Baluwa	1992	16 households (men and women farmers) 24 households (men and women farmers) 24 households (men and women farmers)
Household	Dhulikhel	1990	631 households (50 detailed)
Forestry	Dhulikhel	1990	136 farmers
Agriculture	Dhulikhel	1990	119 farmers
Farming Systems	Baluwa Rabi-Opi	1989	31 households (men and women farmers) 31 households (men and women farmers)
Farming Systems	Panchkhal	1988	33 households (men and women farmers)

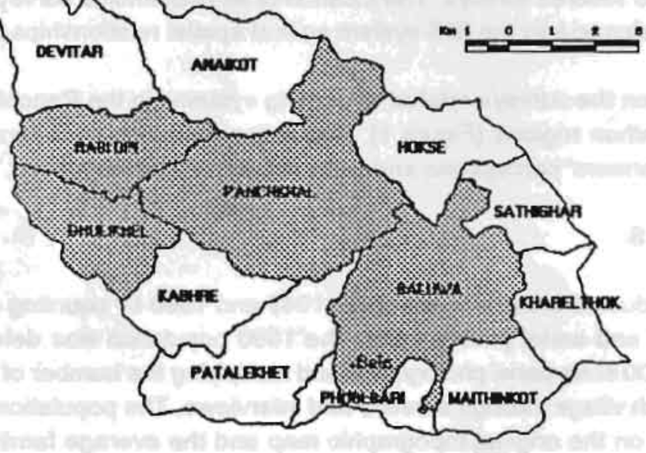


Figure 1. VDC map showing regions surveyed.

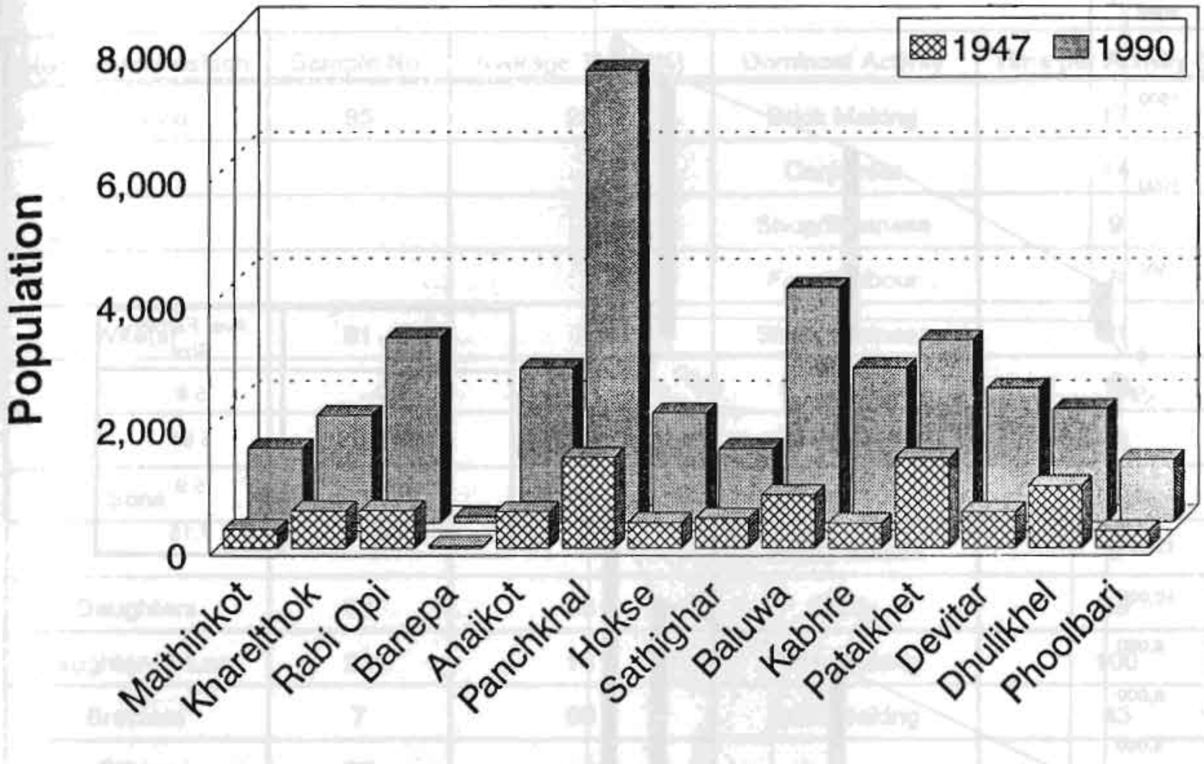
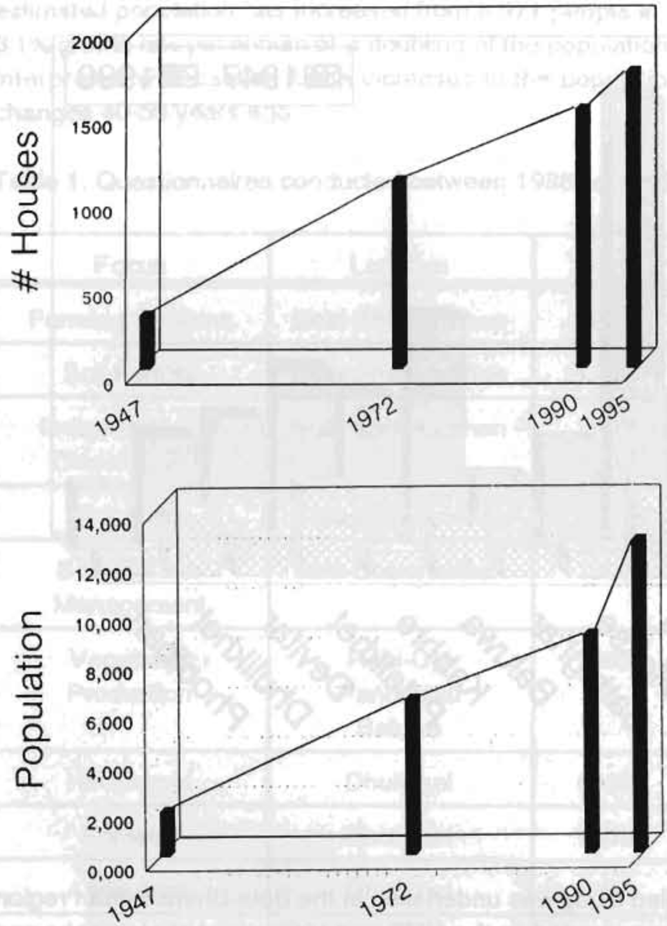


Figure 2. Jhikhu Khola population dynamics.

To evaluate the recent population dynamics a detailed study was undertaken in the Bela-Bhimsenthan region for 1972, 1990 and 1995. The number of houses were counted on the 1972 and 1990 aerial photographs and were compared to the number of houses observed in the field in 1995. Population numbers were calculated from the number of houses and the average family size, determined from census data and field surveys. The number of houses in the region increased from 1516 in 1990 to 1723 in 1995 (Figure 3a).This increase is due to both population growth and immigration; a number of young families from nearby communities are currently building houses in the region. The average population growth rate was 1.9% per annum for the 1972-1990 period and 7.4% per annum for the 1990-1995 period (Figure 3b). This growth rate is likely overestimated due to the larger family size obtained by recent household surveys.

3. NON-FARM ACTIVITIES

Non-farm activities are an important source of family income. Non-farm activities in the Bela-Bhimsenthan region in 1994 are shown in Table 2. The average person in the region spends thirty-five percent of their time in non-farm activities. Husbands typically spend 20% of their time off-farm and the dominant activities are brick making / masonry (17%) and carpentry (14%). Wives usually spend less time off-farm (7%) and the main activities are shop / business and household labour. Sons and daughters spend a large portion of their time studying, but brick making / masonry activities are also noted. The daughter-in-laws involved in off-farm activities all worked in brick making, and 43% of the off-farm activities of the brothers was also brick making / masonry work. This contrasts the 1988 Panchkhal survey where 52% of the respondents worked as farm labourers and no brick making activities were noted. There were only 35 brick making units in 1981/82 in the Kathmandu valley but 142 in 1991/92 (Mishra, 1995).



Year	Ave. Family Size
1947	5.8
1972	5.68
1990	5.9
1995	7.15

Figures 3a and 3b. Population dynamics 1972-1995 Bela-Bhimsenthan region.

4. AGRICULTURE

4.1 Land

The main agricultural assets of farmers in the area are land and livestock. The amount of khet and bari land owned by the households vary dramatically both across and within ethnic/caste groups. For example, in Panchkhal (1988) the average amount of khet land farmed is 8.6 ropani per household, but the distribution across different size categories of land farmed by the sample households (Table 3) clearly indicates that access to khet land is unequally distributed. Fifty-one percent of the households cultivate only 8.5% of the khet land, with holdings of four ropani (ha) or less. Only 15.1% of the sample households farm 54.2% of the khet land and have holdings between 17 and 47 ropani (ha).

Land ownership is also unequally distributed by caste/ethnic groups. For example, in the Bela-Bhimsenthan region (1994) the average khet land per household is 4.8 ropani, while the average bari holding is 16.1 ropani (Table 4). Land holdings vary by caste from 0 to 6.1 ropani of khet land, and 8.2 to 25.0 ropani of bari. Brahmin, Newar and Tamang families have the largest holdings. Ninety-four percent of the households sampled own bari land, while only 76% own khet land.

Table 2. Non-farm activities in the Bela-Bhimsenthan region, 1994.

Household Position	Sample No.	Average Time (%)	Dominant Activity	Time per Activity (%)
Husband	85	20	Brick Making	17
			Carpenter	14
			Shop/Business	9
			Farm Labour	6
Wife(s)	91	7	Shop/Business	31
			Household	15
			Farm Labour	15
Sons	112	62	Study	78
			Brick / Mason	5
Daughters	83	56	Study	99
Daughter-In-Law	23	14	Brick Making	100
Brothers	7	60	Brick Making	43
Others	26			
Average		35		

Table 3. Khet land farmed by parcel size in Panchkhal, 1988.

Parcel Size (ropani)	Amount Khet Land (ropani)	% Khet Land	# Households	% Households
0 - 4	24	8.5	17	51.5
5 - 8	42	15	6	18.2
9 - 12	19	6.7	2	6.1
13 - 16	44	15.6	3	9.1
17 - 47	153	54.2	5	15.1
Total	282	100	33	100

4.2 Production

Farmers were asked if the land that they farmed generated enough food and income to meet their family's basic needs. The results shown in Figure 4 indicate that 21 to 50% of the households surveyed reported that they were not sufficient, with the Panchkhal region being the most sufficient and Rabi Opi the least. In the Bela-Bhimsenthan region, 42% of households sell crops and 46% buy additional food.

Table 4. Land ownership by ethnic/caste group in the Bela-Bhimsenthan region, 1994.

Caste	Sample No.	Average Khet / Household (ropani)	% Owning Khet	Average Bari / Household (ropani)	% Owning Bari
Brahmin	46	6.1	85	18.8	100
Newar	13	4.5	77	12.6	100
Tamang	7	6.1	71	14.3	100
Danuwar	9	1.7	67	8.2	89
Chhetri	5	0	0	9	90
Others	10	2.4	100	25	100
Average	85	4.8	76	16.1	94

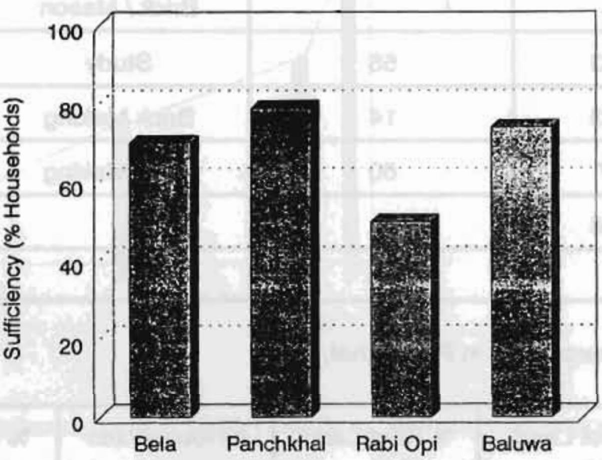


Figure 4. Food sufficiency for four districts.

Farmers were also asked: "What is the biggest problem preventing you from increasing your yields?" The results shown in Table 5 consistently list irrigation as a constraint. The 1994 survey in the Bela-Bhimsenthan region found that uncertainty related to the timing and input requirements of new cropping sequences was a significant problem. Fertilizer (availability, type and cost) and disease problems were also important.

5. LIVESTOCK

Livestock play an integral role in farming systems in Nepal. Every household surveyed owned some livestock. The typical mix (for families with abundant livestock) is a bullocks (oxen), a cow (and possibly a calf), a female buffalo (possibly a calf,) a few goats and a few chickens. Bullocks are used as draught power for land preparation. Cows are kept primarily for cultural / religious purposes and manure production. Female buffalo are kept for milking purposes and for manure. Male buffalo are not used for draught power due to the small terraced plots in the area but are raised and sold for meat. Many families require goats for religious sacrificial purposes. Goats are also sold for meat. Poultry is raised for meat and eggs; however, Brahmins have traditionally not eaten eggs or poultry. A few households raise pigs and ducks.

Table 5. Production constraints.

Region	Constraint	% Responses
Bela-Bhimsenthan	Cropping Pattern	44
	Irrigation	34
	Chemical Fertilizer	12
Panchkhal	Irrigation	57
	Inputs	22
Rabi Opi	Irrigation	36
	Disease	30
	Fertilizer	10
Baluwa	Irrigation	37
	Fertilizer	35
	Disease	12

Source: Male Farmers

The livestock holdings for the Bela-Bhimsenthan region for 1989 and 1994 are shown in Figure 5. There has been an overall 18% decrease in the average number of animals per farm in the last five years. This may be related to difficulties in obtaining fodder and reduced communal grazing areas. Fifty-five percent of farmers reported fodder shortages in 1994, and 98% of those were in the winter. The fodder situation, shown in Figure 6, indicates that the majority of fodder comes from crop residues (51%) and terrace risers (26%), while purchasing fodder (11%), private trees (7%) and community or government forests (5%) provide additional sources. Seventy percent of households responded that it was significantly easier to obtain fodder from all sources five years ago, especially from the forest.

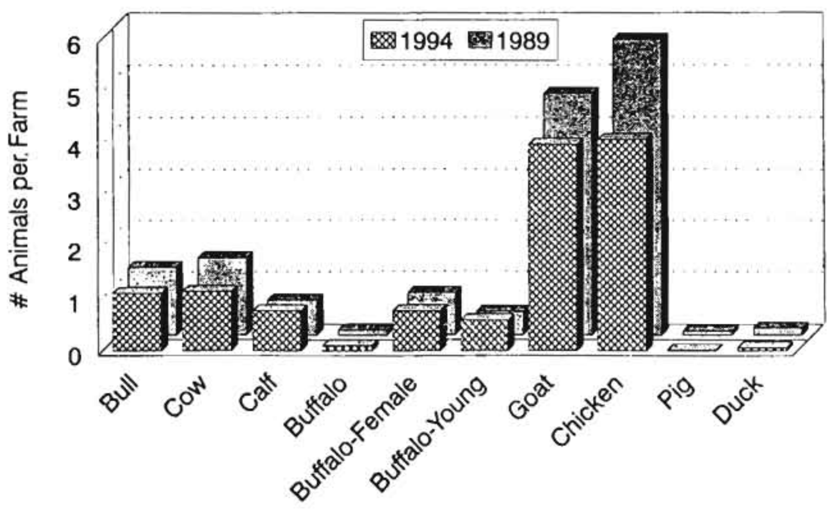


Figure 5. Livestock holdings (Bela).

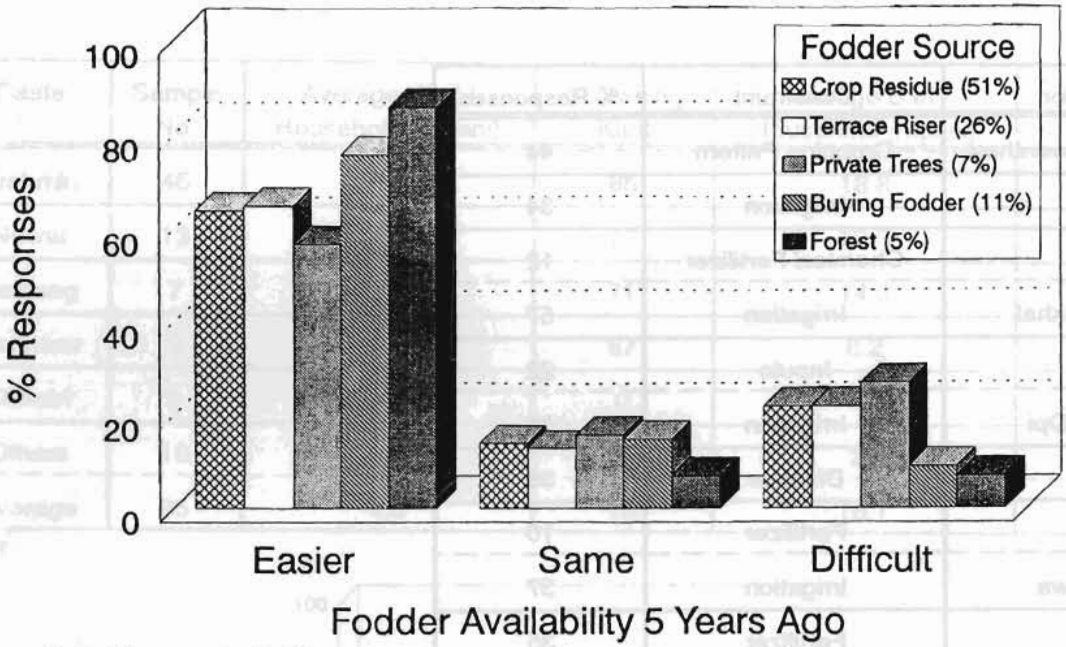


Figure 6. Fodder supply (Bela).

Over the last five years, there has been a substantial decrease in chickens, goats and cows but the average number of male and female buffalo per farm has remained constant, and the number of young buffalo has increased slightly (Figure 5). This is indicative of increased dairy activities and new dairy collection centres in the region. Sixty percent of households were producing milk in 1994. Of the milk produced, 100% of cow milk was consumed, while 55% of buffalo milk was sold. Note that buffalo produce a higher quality and quantity of milk than local cows. Milk production over the last five years from cows and buffalo (Figure 7) has increased by 15 and 23 percent respectively. This increase is largely due to new operations (farms producing milk for less than 5 years) rather than increased production.

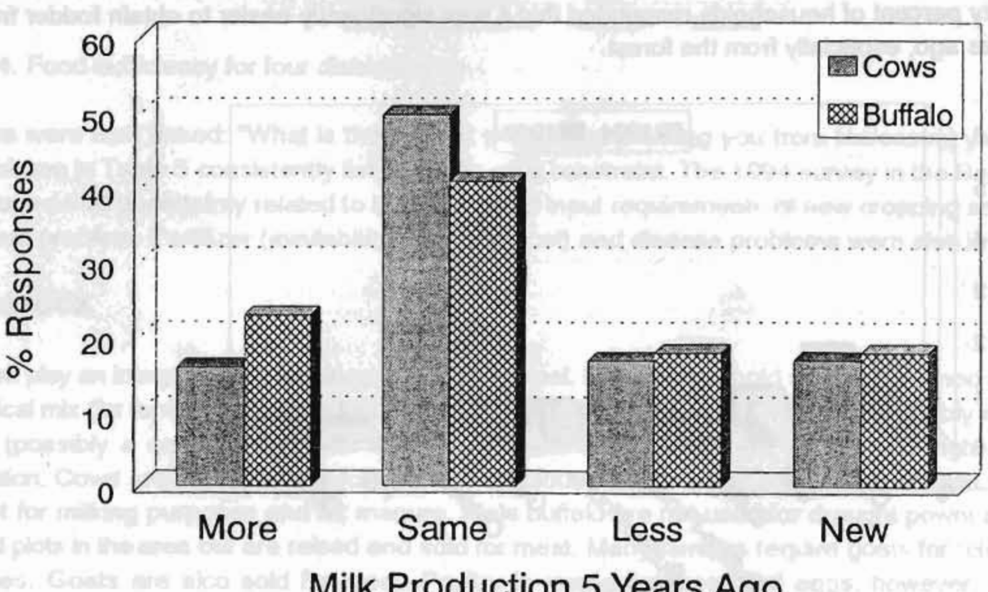


Figure 7. Milk production (Bela).

6. FORESTRY

The forest provides fuelwood, fodder and animal litter, and is an integral part of the farming system. Forest product collection for the Bela-Bhimsenthan region is summarized in Tables 6 and 7. The majority of the collection of forest products is conducted by women in the household. On average, wives, daughters and daughter-in-laws collect 86% of forest products for the household (Table 6). An average household makes 2.1 trips per week to collect fuelwood, 7.6 trips per week to collect fodder, and 4.1 trips per week to collect litter. The average return trip takes 2.9 hours, and up to 38 hours per week may be spent by a household in the collection of forest products.

This is confirmed by identifying all houses and forest sites used by each household on the enlarged aerial photos (scale 1:5000), transferring the information into GIS, determining the aerial distance between the household and forest sites, and walking the trails to determine average times to cover the daily trip to the forest. In the case of the Dhulikhel village the average fodder collection distance was determined to be 341 m, for fuelwood 480 m, and for forest litter 633 m. This translated into average time commitment of 50 minutes for fodder collection, 70 minutes for fuelwood collection and 95 minutes for litter collection. Since women do most of this work such time commitment places additional burden on the already overworked female labour force.

Table 6. Forest product collection by household position in the Bela-Bhimsenthan region, 1994.

Product	% Responses			
	Wives	Daughters	Daughter-In-Law	Sum
Fuelwood	49	21	18	88
Fodder	43	21	19	83.
Litter	50	19	19	88

Table 7. Forest product collection frequency in the Bela-Bhimsenthan region, 1994.

Product	Frequency (trips / week)	Time / Trip (hours)	Time Spent (hours / week)
Fuelwood	2.1	3.2	6.7
Fodder	7.6	2.5	19
Litter	4.1	3	12.3
Total	13.8	8.7	up to 38

The number of privately owned trees (on-farm) are summarized in Figure 8. Over the last five years there has been a 32% increase in the average number of private trees per farm. The largest increase has been in fruit trees, reflective of increased horticultural activities, but timber and fuelwood trees are the greatest in number.

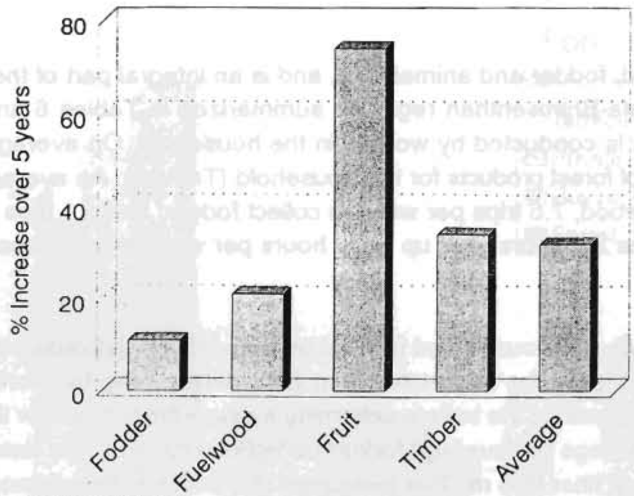


Figure 8. Number of on-farm trees (Bela).

7. IMPLICATIONS

From the compilation of population data, we have learned that the population pressure is far greater than previously indicated and this has a widespread impact on the resource conditions. The farmers are acutely aware of some but not all of the constraints.

The decline in available water resources and the stagnation of biomass production are the most serious and readily visible problems. The interconnections between forests, agriculture, livestock and water resources are obvious but the recycling of nutrients and reallocation of the nutrient pool from the forest and grazing land into agriculture is not as obvious over the short term. However, the long term implications are of great concern. Off-farm employment is not diversified and is dominated by brick making. This also has detrimental effects on the environmental conditions, because it uses up valuable soil and firewood resources and produces significant air-pollution problems. It does not improve the economic diversity since little value is added by brick making although shelter is provided for the growing population. Based on the collected socio-economic information it is clear that unless the economy can be diversified the resource conditions will likely deteriorate.

8. FARMERS' PERCEPTIONS AND GOALS

The village development needs as perceived by men and women farmers in the Bela-Bhimsenthan survey (1994) and the Panchkhal, Rabi Opi, Baluwa surveys (1988/89) are given in Table 8. The top four priorities of both men and women farmers are the same, however, the order of priorities differs between men and women and between 1988/89 and 1994. Drinking water (supply and quality) and electricity (supply) are the highest overall priorities. Irrigation and transportation are also important and reflect the increasing importance of market oriented production (transportation to market and irrigation required for cash crops).

Farmers were asked: 'If you had some extra money, what would you buy?' Their individual goals are listed in Table 9. The highest priorities were land, banking or finance, housing, livestock operations, agricultural inputs and small business. The priorities between men and women were similar but differed in order, and priorities in Bela-Bhimsenthan 1994 were similar to Panchkhal, Rabi-Opi and Baluwa 1988/89.

Table 8. Village development needs.

Priority	Women	Men
Bela 1994		
1	drinking water (39)	irrigation (46)
2	electricity (36)	drinking water (45)
3	irrigation (26)	road / transportation (38)
4	road / transportation (23)	electricity (22)
Panchkhal, Rabi Opi, Baluwa 1988/89		
Priority	Women	Men
1	electricity (43)	drinking water (54)
2	road / transportation (34)	electricity (40)
3	drinking water (13)	irrigation (40)
4	irrigation (10)	road / transportation (30)

N.b. numbers in ( ) are number of responses (also for Table 9).

Table 9. Farmer goals (ways to spend extra money).

Priority	Women	Men
Bela 1994		
1	bank / finance (62)	land (40)
2	land (45)	shop / business (28)
3	housing (18)	bank / finance (25)
4	livestock (18)	agricultural inputs (25)
5	shop / business (17)	livestock (25)
Panchkhal, Rabi Opi, Baluwa 1988/90		
Priority	Women	Men
1	land (54)	land (41)
2	bank / finance (45)	livestock (38)
3	cloth / clothes (20)	agricultural inputs (34)
4	livestock (10)	shop / business (14)
5	housing (9)	housing (14)

9. CONCLUSIONS

Both from the overall and the detailed surveys, it is evident that the population growth rate has been very rapid, reaching levels of 6 % per annum in the last 5 years. This is the result of both high reproduction rates and immigration into the watershed. This increase is placing enormous stress on the environmental conditions in both agriculture and forestry.

About one third of all activities are in non-farming occupations, with the adult male having the highest share. The demand for brick production both within and outside of the watershed is the greatest source of non-farm employment and is a direct result of population increases. Associated with this are high demands for selective firewood.

Average land holdings are very small but there is great variability between families and castes. A few families (15%) own more than half of all agricultural land and this will likely cause difficulties in the future.

Between 20 and 50% of the farmers indicated insufficient food production, insufficient irrigation water and nutrient inputs were identified as the major problem limiting increases in biomass production.

Livestock numbers have declined significantly over the past 5 years and the lack of feed is cited for the reduction. However, milk production has increased and is becoming a new source of income.

The use and management of the forest is primarily in the domain of women. The lack of forest productivity is placing a large burden on the women since they spend more than half of their working time collecting fodder, firewood and forest litter.

These findings clearly show that rapid population growth has placed demands on the resources that are difficult to meet even with transformation of land use and crop intensification. The farmers are finding that it is increasingly difficult to meet their basic demands, and the general perception of the inhabitants is that drinking water supplies and the introduction of electricity are of highest priority. The main desire is to improve the irrigation systems and transform the infrastructure to create more market access. The pressure to increase production is placing constraints on the environmental conditions, and water shortages and limited nutrient inputs are the major challenges facing the farmers in the watershed.

10. REFERENCES

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Land Use Dynamics and Intensification

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1. INTRODUCTION

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

2. METHODS

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

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

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

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

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

3.0 RESULTS AND DISCUSSION

3.1 Land Use Characteristics

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

3.2 Land Use Changes 1947 - 1981

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

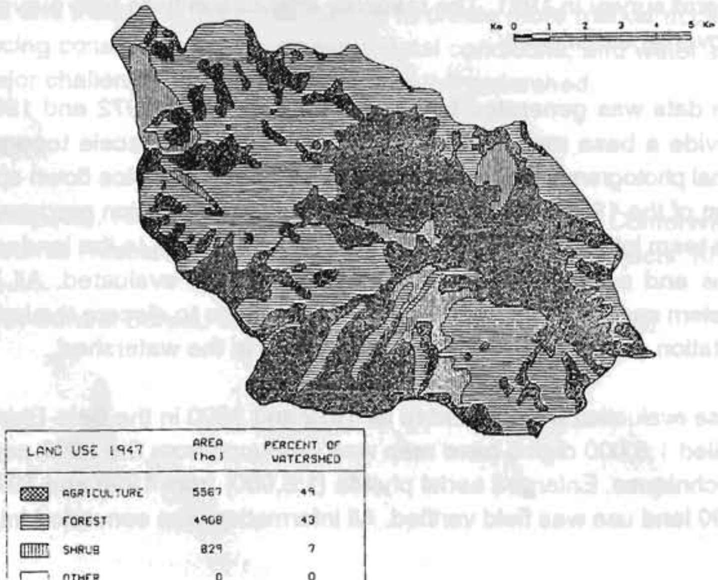
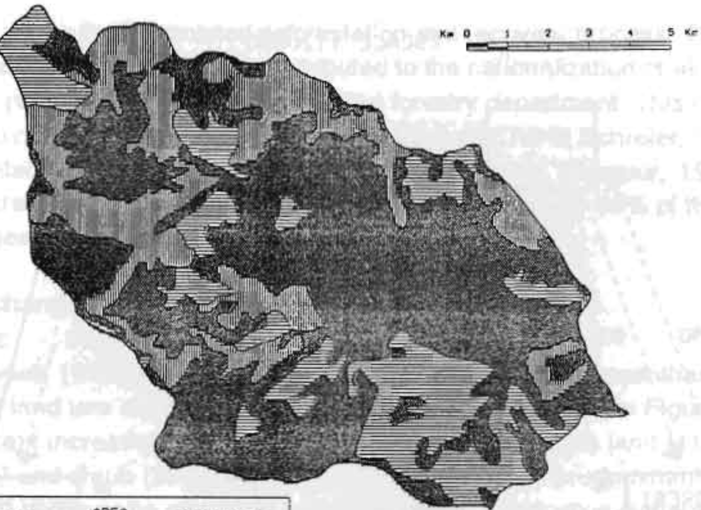


Figure 1. Land use in the Jhikhu Khola watershed in 1947.



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

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

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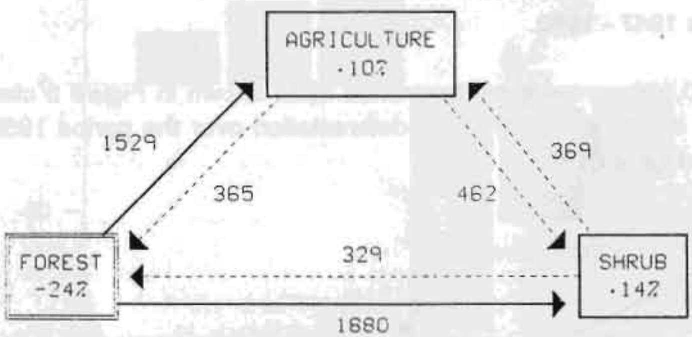

Figure 3. Land use dynamics from 1947 to 1981.

3.3 Land Use Changes 1972 - 1990

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

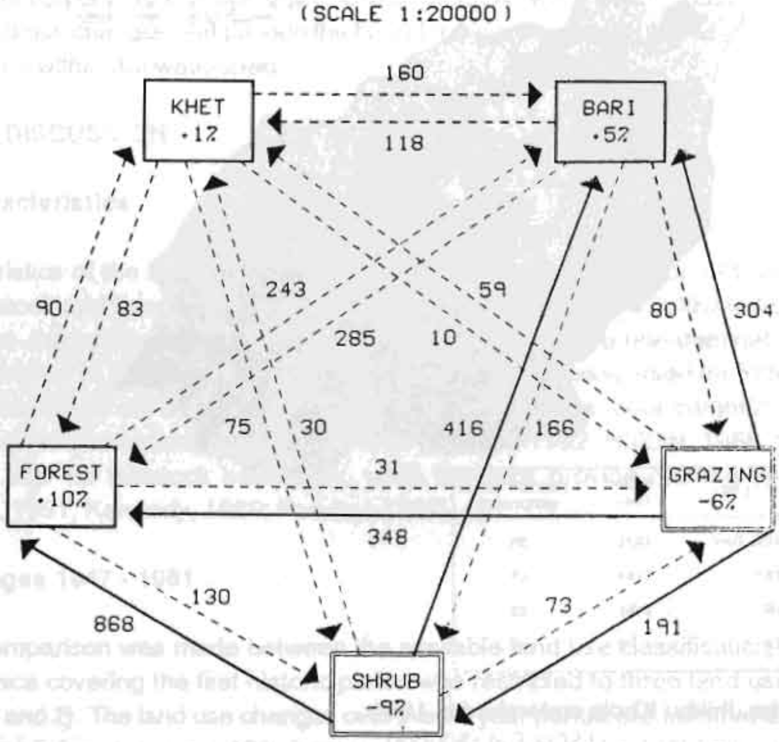

Figure 4. Land use dynamics from 1972 to 1990.

3.4 Overall Land Use Dynamics 1947 - 1990

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

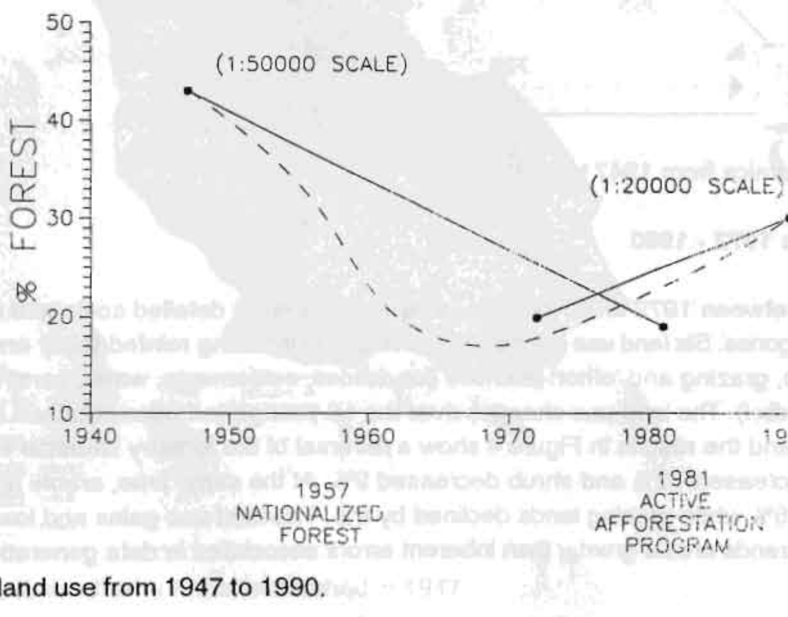

Figure 5. Overall land use from 1947 to 1990.

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

3.5 Detailed Land Use Changes 1972 - 1990

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

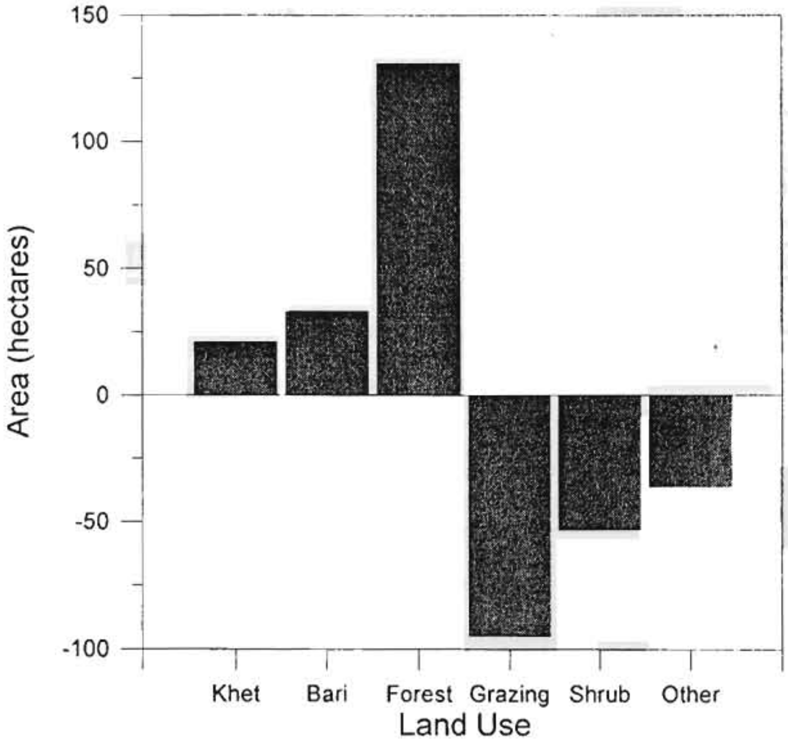

Figure 6. Net land use changes between 1972 and 1990.

3.6 Spatial Relationships between Land Use and Site Conditions

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

3.6.1 FOREST EXPANSION

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

Table 1. Forest classification used in the field survey.

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

[a]More than 75% of tree species

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

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

[a] Includes pine plantations

[b] Includes shrub

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

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

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

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

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

3.6.2 AGRICULTURAL EXPANSION

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

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

Table 4. Cropping intensity.

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

3.6.3 FOREST DYNAMICS 1989 - 1994

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

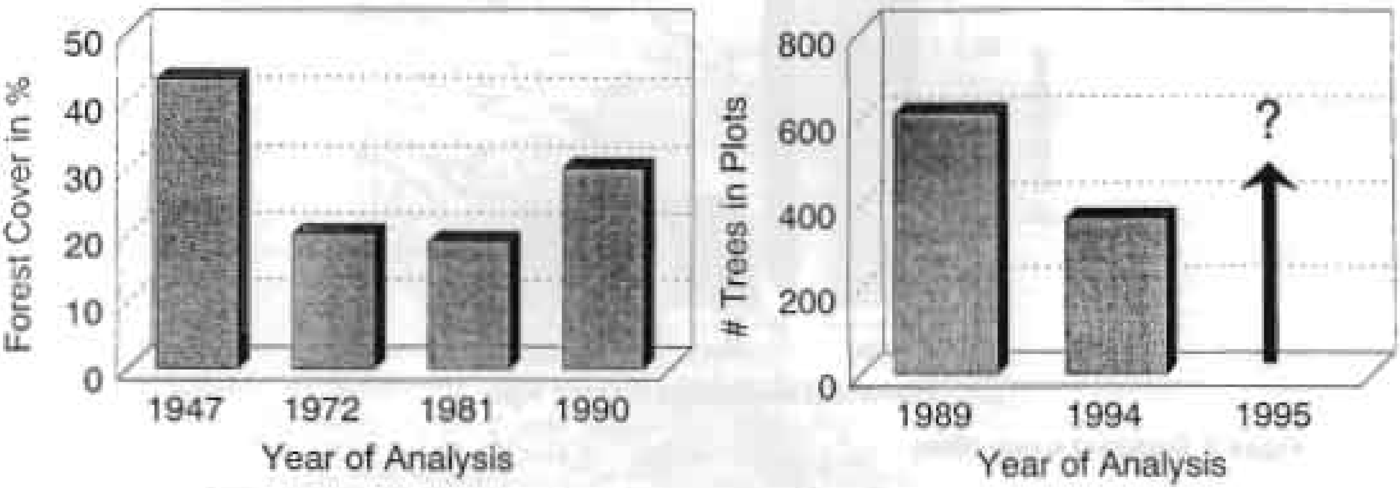

Figure 7. Forest cover and dynamics.

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

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

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

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

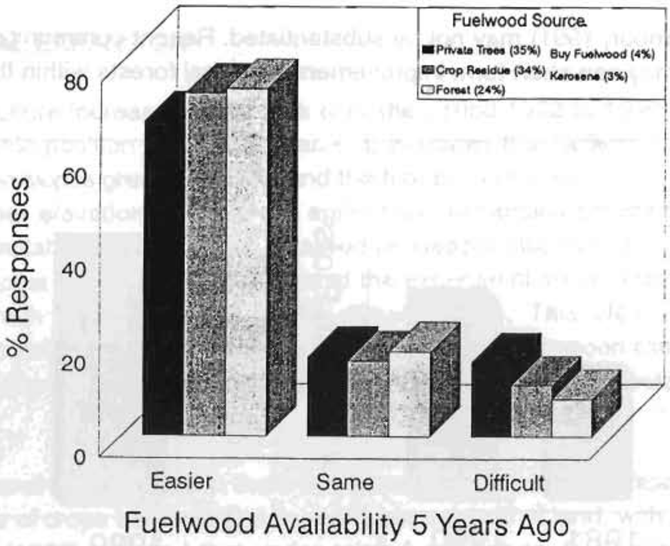

Figure 8. Fuelwood supply (Bela).

3.6.4 FOREST IMPROVEMENTS

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

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

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

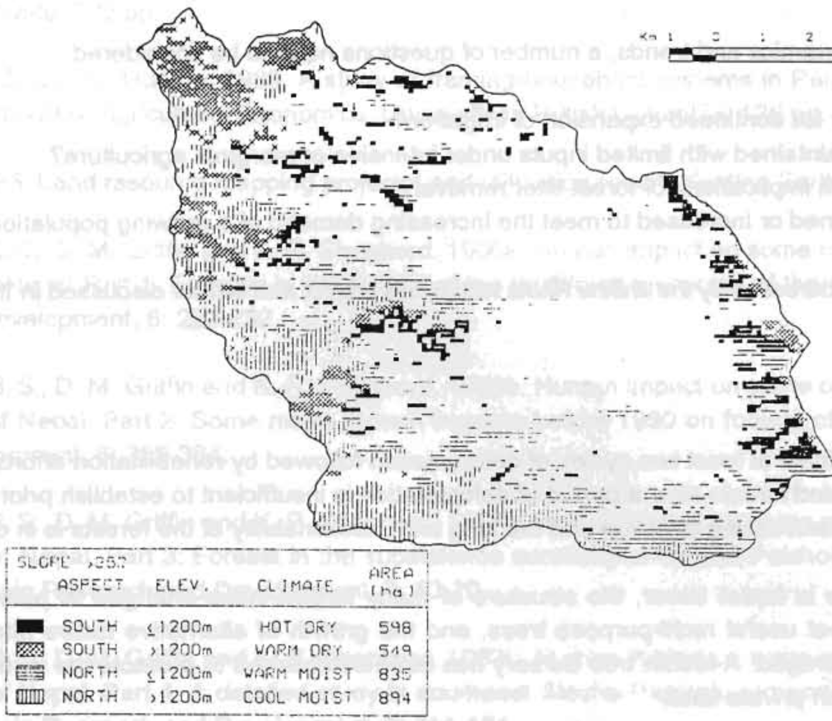

Figure 9. Microclimatic site conditions.

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

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

3.6.5 ISSUES

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

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

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

4. CONCLUSIONS

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

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

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

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The Effect of Surface Conditions on Soil Erosion and Stream Suspended Sediments

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1. INTRODUCTION

Much is said about the effects of upland erosion on those living downstream. For instance, in the Middle Mountains of Nepal, farming practices are often blamed for generating widespread flooding in the lowlands of Bangladesh (Eckholm, 1975). Many statements are made about the causes of basin sediment output from upland basins. In the Middle Mountains, the cutting of trees is often put forth as the reason for alleged elevated basin sediment output. However, little or no quantitative data exist which examine the actual sediment dynamics within these headwater basins, especially during the monsoon season. Hence, it is very difficult to evaluate the causes of upland erosion and basin sediment output.

In this paper, attention is focused on erosion and sediment dynamics within a highly-monitored headwater basin in the Middle Mountains. The goals of this paper are to describe patterns of sediment transport within this headwater basin in the Jhikhu Khola Watershed and to provide some explanations of observed sediment regimes.

2. MONITORING NETWORK

Hydrometric monitoring started in 1989 in the Jhikhu Khola Watershed with the establishment of five hydrometric stations (Shah et al., 1991). In 1992, detailed hydrometric monitoring was initiated. The complete network consisted of four automated hydrometric stations, four manual hydrometric stations, five erosion plots, five tipping-bucket rain gauges, and up to fifty 24-hour rain gauges. The majority of the hydrologic measurements are concentrated in the Andheri sub-watershed as shown in Figure 1. Intensive flow and sediment monitoring programs were carried out throughout the entire 1992, 1993, and 1994 monsoon seasons (June through September) with detailed monitoring of flow and suspended sediments occurring during most individual storm events. Over a typical monsoon season, up to 100 individual basin flood events were monitored. At the same time, runoff and soil-loss measurements were made at all five erosion plots. Samples were analyzed to determine total losses from the 70 - 100 m^2 plots for each event over the three-year monitoring period.

The basins discussed in this paper are the Andheri and Kukhuri basins, covering 540 ha and 72 ha respectively. The Kukhuri basin forms part of the headwaters of the Andheri sub-watershed. The streams of these basins are extremely steep with slopes of 5-15 degrees in the Kukhuri basin reducing to 2-5 degrees in the lower reaches of the Andheri basin.

3. STREAM SEDIMENT REGIME

The data for all measured stream flow and sediment samples were compiled into a comprehensive database. Figures 2 and 3 show the combined sediment rating curves for Andheri and Kukhuri basins over the three- year study period.

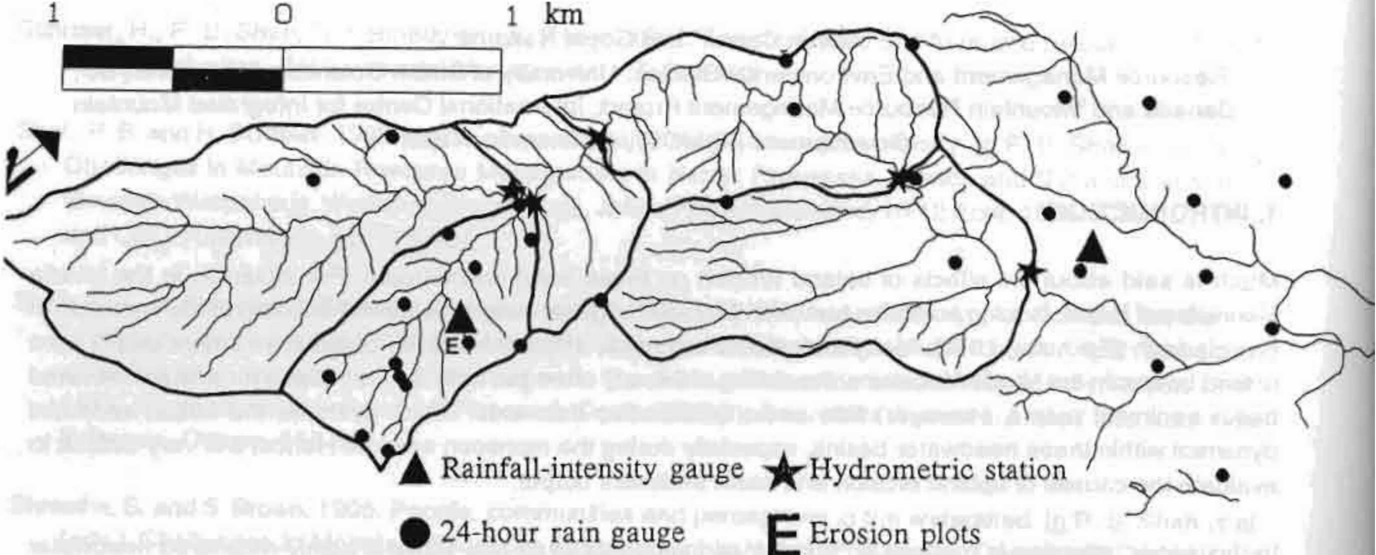

Figure 1. Hydrometric monitoring network in the Andheri Khola sub-watershed.

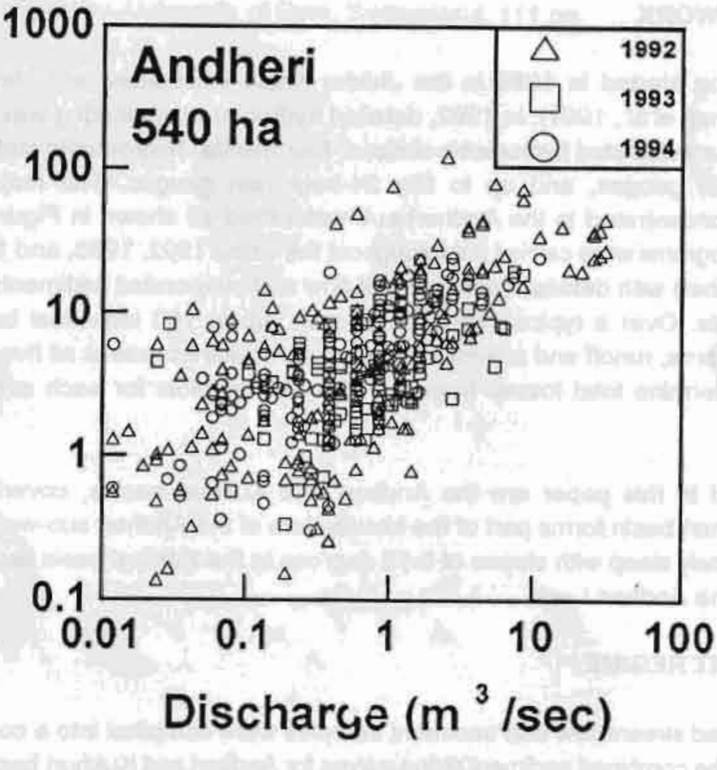

Figure 2. Sediment rating curve for the Andheri Khola basin.

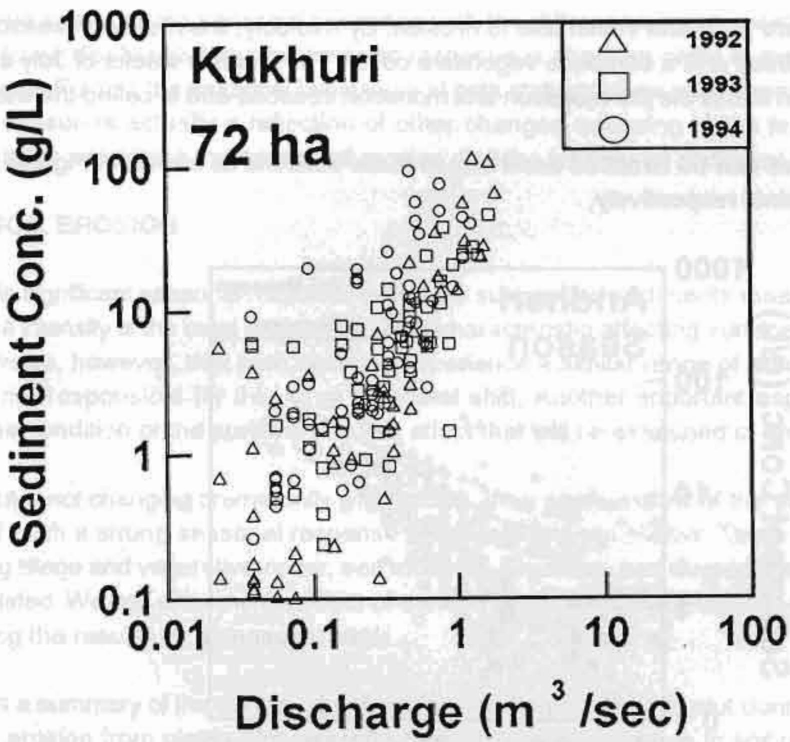

Figure 3. Sediment rating curve for the Kukhuri Khola basin.

A sediment rating curve relates the suspended-sediment concentrations at a stream hydrometric station to its corresponding flow rate or discharge. In both cases, stream sediment concentrations show a strong dependence on discharge. For most discharges, 1 to 2 orders of magnitude of scatter is evident.

To account for the wide scatter of points, it is essential to consider the factors that can influence the sediment-discharge relationship. These include:

- rainfall characteristics
- surface conditions
- sediment storage
- antecedent flood history
- hysteretic effects
- season

Unfortunately, most of these factors interact, making interpretations a challenge.

The surface vegetative cover and the extent of degradation of the land are two surface-condition factors which are important in the Andheri sub-watershed. These factors are examined in this paper in relation to sediment transport. To assess the way in which these two variables shape the basins' sediment regimes, we first consider the importance of the effect of season on erosion and sediment transport.

Perhaps the most common approach to evaluating sediment rating curves is to separate the data according to season. In the study area, there are distinct seasons as the climate changes from the dry to the wet seasons. When the rains arrive in the late spring (the pre-monsoon season), the land surface is extremely dry and the upland cultivated fields are bare and vulnerable to erosion. By mid-July, the monsoon season is well under way, bringing regular rainfall and a complete vegetative cover. The first few weeks of July show behaviour which intergrades between that of the pre-monsoon and monsoon seasons and is called the transition season.

The sediment rating curves can be stratified according to these seasons as shown in Figures 4 and 5 for the Andheri and Kukhuri basins, respectively.

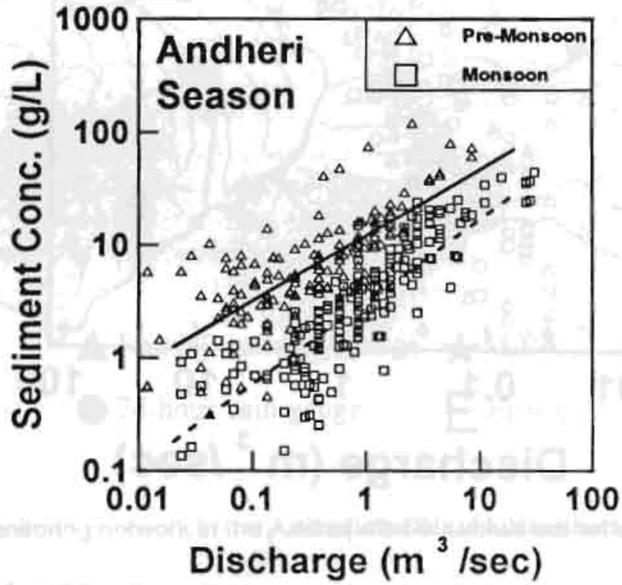

Figure 4. Seasonally-stratified sediment rating curve for the Andheri Khola basin.

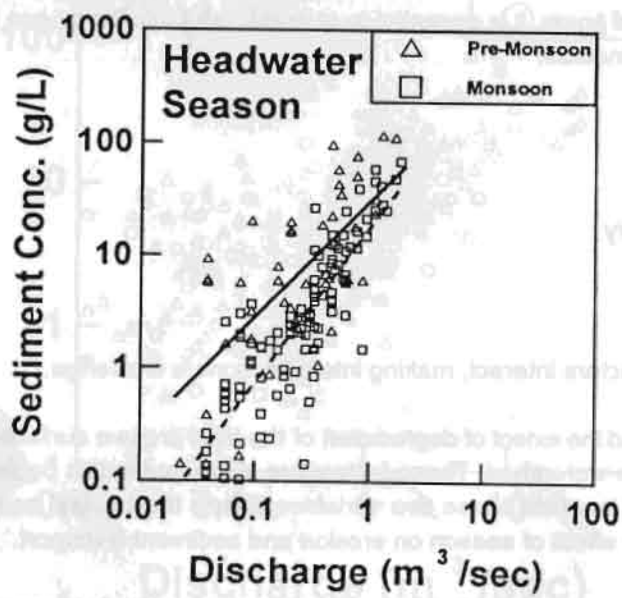

Figure 5. Seasonally-stratified sediment rating curve for the Kukhuri Khola basin.

In each case, we see a strong seasonal response with the difference being greater for the Andheri basin. Generally, for a given discharge, the pre-monsoon response is about an order of magnitude greater than the monsoon response. Further, the seasonal behaviours at both stations show a tendency to merge at the highest flows. Though season is actually a reflection of other changes occurring in the farming system, it forms a convenient basis for examining the causes of erosion and the sources of sediment to the streams.

4. SURFACE SOIL EROSION

What causes this significant seasonal response in stream suspended sediments measured at the hydrometric stations? Rainfall intensity is the most important rainfall characteristic affecting surface erosion. The three-year rainfall record shows, however, that both seasons experience a similar range of rainfall intensities, indicating that rainfall is not responsible for this large seasonal shift. Another important aspect which does change seasonally is the condition of the surface. It is this effect that will be examined in greater detail in this paper.

If the rainfall input is not changing dramatically with season, then some aspect of the surface must be changing in order to yield such a strong seasonal response at the hydrometric station. There are many aspects to the surface including tillage and vegetative cover, soil moisture, land use, and degradation. Further, these factors are often interrelated. We can examine the effect of surface cover on surface erosion by turning to the erosion plots, expressing the results on a seasonal basis.

Table 1 presents a summary of the annual rate of soil loss from each erosion plot during 1992-1994. The large variation in soil erosion from plot to plot is a reflection of the large variation in soil properties across the five plots. We can stratify these results by season to compare them to the stream sediment rating curves. This result is presented in Table 2 and shows that regardless of soil properties, most of the annual erosion occurs in the pre-monsoon season.

Table 1. Annual rate of soil loss (tonnes/ha) at all erosion plots, 1992-1994.

Plot No.	Annual Rate of Soil Loss (tonnes/ha)		
	1992	1993	1994
1	18	4.1	42
2	23	34	6.4
3	38	37	6.9
4	0.1	0.2	2.9
5	0.1	0.3	2.6

5. SURFACE VEGETATIVE COVER

The major seasonal change in surface condition which occurs at each plot is a change in surface cover as weed growth and the summer crop develop. The farmers also frequently intercrop providing a further protection of the soil from intense rainfall.

Changes in vegetative cover can also explain the large inter-annual variation in soil loss at a given plot. Surface cover does not develop immediately but requires rainfall to get started and then takes several weeks to be complete. If damaging rains occur when the surface cover is only partially complete - which is common - then significant losses are likely at the plot. And if this cover is inadequate when an intense rainfall occurs then the losses can be large. Table 3 shows the percentage of each plot's annual soil loss that occurred in the two most-damaging events. At all plots and in all years, about 50 - 90% of the annual total occurs in only two events. The timing of these events was particularly unfortunate in plots 2 and 3 in 1992 and 1993 as they occurred very early in the pre-monsoon period when vegetation cover was at a minimum. These events are reflected in the production of high annual soil erosion losses as shown in Table 1.

Table 2. Percentage of annual total soil loss occurring in the pre-monsoon and transition seasons for all erosion plots, 1992-1994.

Plot No.	Percentage of Annual Soil Loss Occurring in Pre-Monsoon Season (%)		
	1992	1993	1994
1	65	25	88
2	96	100	99
3	99	100	97
4	87	68	100
5	31	78	100

Table 3. Percentage of the total annual erosion at each plot which occurred in the two most-damaging events of each year, 1992-1994.

Plot No.	Total Annual Erosion (%)		
	1992	1993	1994
1	55	50	44
2	96	88	87
3	78	91	82
4	69	40	60
5	60	57	67

6. SURFACE -SOIL DEGRADATION

As vegetative cover is important in shaping erosion levels, so is the condition of the soil at the surface. The erosion plots discussed in the previous section are situated on land which is largely well managed. Farmers take great care to prevent soil loss in these upland cultivated fields. However, large tracts of land in the Middle Mountains are degraded as a result of over utilization and extreme surface erosion. These lands have deeply-exposed surface soil and subsoil, have extensive rills and gullies and often experience surface crusting. These surfaces are poorly vegetated and since they are not cultivated, do not experience the seasonal development of a strong surface cover. Not only do these lands have a poor surface cover year-round but they are also very susceptible to soil erosion.

To show the influence of degraded land, Carver (1995) compares the sediment regime of the degraded Dhap basin to that of the Andheri basin (presented above in Figure 4). The Dhap basin covers about the same area but is much flatter than the Andheri basin. On the basis of topography alone, one expects a higher response in sediment output from the Andheri basin than from the Dhap basin, yet exactly the opposite is measured. Though the surface-cover effect may be part of the explanation, probably a bigger part is related to the extent of degradation. Over 13.6% of the Dhap basin (by area) is gullied land in contrast to the Andheri basin which has only 5.4% of its area classified as degraded (based on 1990 1:20,000 mapping). These degraded lands have largely been abandoned to a non-productive condition due to an advanced state of surface erosion. Hence, though they are not particularly steep in comparison to many frequently-cultivated soils in the Middle Mountains, they contribute a proportionately larger amount of sediment to the overall basin output. In contrast, in the conventionally-managed land, the drop in erosion at the end of the pre-monsoon season is dramatic resulting in a more reasonable sediment regime during much of the monsoon season.

7. DISCUSSION

These results illustrate how land-use practices change soil surface conditions, thereby influencing the overall sediment regime of a sub-watershed. Under conventional hill-farming, sediment output due to surface erosion from cultivated fields can be high for short periods during the pre-monsoon season. These rates of surface erosion drop dramatically due to the development of an effective surface vegetative cover as the crop develops. The risk of large losses due to erosion resulting from pre-monsoon storms is high and though the timing of crop planting is critical, resulting soil loss is largely up to chance. In some years, the farmers are unlucky with the timing of the pre-monsoon rains and high levels of soil loss result. In other years, the vegetative cover is adequately advanced to protect the soil from heavy pre-monsoon rains and low levels of soil erosion result. It is worth stressing that these dynamics are associated with well-managed soils.

Where land has been lost from productivity altogether, a more serious problem results regarding the land's contribution to overall basin sediment output. On a year-round basis, these areas lose soils at an elevated rate, potentially in excess of the rate in the pre-monsoon season on conventionally-managed land. In such cases the seasonal effect is much reduced and the overall contribution during the monsoon season is much more substantial.

Individuals trying to mitigate erosion and improve basin sediment regimes should pay careful attention to the specific goals of their project. For instance, if one is concerned largely with downstream sedimentation perhaps for hydropower development, then it is probably more effective to concentrate one's effort on getting degraded soils back into production or under a vegetative cover. This approach is likely the most efficient way to reduce the amount of material leaving a basin. However, if one is more concerned with improving the productivity of the farming system, then supporting farmers in their conventional management is more effective. In particular, findings ways to reduce soil loss during the pre-monsoon season, by establishing a vegetated surface early in the season, will contribute greatly to improving the overall productivity of the farming system.

8. CONCLUSIONS

The principal conclusions of this paper are:

1. Stream sediment concentrations in the pre-monsoon season are almost an order of magnitude higher than during the monsoon season; the seasonal behaviours tend to merge at the highest flows.

2. Surface erosion is highly variable with potential annual rates of over 40 tonnes/ha; surface erosion is also strongly seasonal with 50-90% of annual surface soil loss typically occurring in only two pre-monsoon events.

3. There is little evidence of significant seasonal differences in rainfall intensities. The observed large changes in erosion and sediment transport cannot be attributed to this factor.

4. The development of a complete vegetative surface cover strongly inhibits surface erosion though unfortunate timing of rainfall in advance of adequate vegetation can yield high losses in the pre-monsoon season.

5. Land with a degraded soil surface contributes to basin sediment output at a potentially greater rate and through the entire rainy season than steeper, well-managed cultivated land.

This paper has tried to diagnose some causes of erosion in headwater basins. Though we now have a better understanding of the causes of sediment dynamics, we ultimately must know the relative influences of these and other factors. To do this we must construct sediment budgets over various spatial and temporal scales and this is the subject of the following paper (Carver and Schreier, 1995).

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Sediment and Nutrient Budgets over Four Spatial Scales in the Jhikhu Khola Watershed: Implications for Land Use Management

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1. INTRODUCTION

There are many factors which determine the type and amount of erosion in mountain watersheds in Nepal (Carver and Nakarmi, 1995). The diagnostic approach is an essential first step in evaluating the status of erosion in a watershed. To identify which factors contribute most to the overall basin sediment output, it is necessary to construct sediment budgets over different spatial and temporal scales. In this paper, we examine the effects of three major rainfall events on sediment and nutrient budgets: a heavy event in each of the pre-monsoon and monsoon seasons and an extreme event during the transition period between these seasons. The effects of these storms on erosion and sediment movement are evaluated by calculating the sediment and phosphorus budgets for each event for four different areas: an upland terrace (70 m^2), a mini-watershed (72 ha), a sub-watershed (540 ha), and the overall Jhikhu Khola watershed (11,141 ha).

Which process dominates depends on the spatial scale under consideration. We cannot look at one spatial scale, for example the agricultural field, deduce the cause and then assume that this cause is dominant over larger spatial scales. The same is true temporally. In this paper, we describe which processes dominate over different spatial and temporal scales because an understanding of highland-lowland interactions is essential in evaluating the future health of the farming system as a whole.

2. SOURCES AND PATHWAYS

A sediment budget is a quantitative expression of the movement and storage of sediment within a basin. The first step in constructing a sediment budget is to identify sediment sources and pathways, as illustrated in Figure 1. The causes of erosion and sediment transport should be understood to assure confidence in extrapolating the data. If nutrient dynamics are also understood, then nutrient budgets can also be constructed.

3. METHODS

Routine hydrometric monitoring was started in 1989 in the Jhikhu Khola Watershed at five hydrometric stations (Shah et al., 1991). In 1992, detailed hydrometric monitoring was initiated using a network of four automated hydrometric stations, four manual hydrometric stations, five erosion plots, five tipping-bucket rain gauges, and up to fifty 24-hour rain gauges. The majority of the hydrologic measurements has been concentrated in the Andheri sub-watershed. Intensive flow and sediment monitoring programs were carried out throughout the entire 1992, 1993 and 1994 monsoon seasons (June through September) with detailed monitoring of flow and suspended sediments occurring during most individual storm events. At the erosion plots, all run-off and soil loss have been determined for each event of the three-year monitoring period.

The three events described in this paper have been chosen to reflect a variety of important conditions within the annual farming cycle. The pre-monsoon and monsoon events typify sediment dynamics during these two major agricultural seasons. These two events are of similar magnitude with the pre-monsoon event being of higher rainfall intensity. The third event was the heaviest of the monitoring period and occurred in the period of transition between the pre-monsoon and monsoon seasons. It will be referred to as "the extreme event".

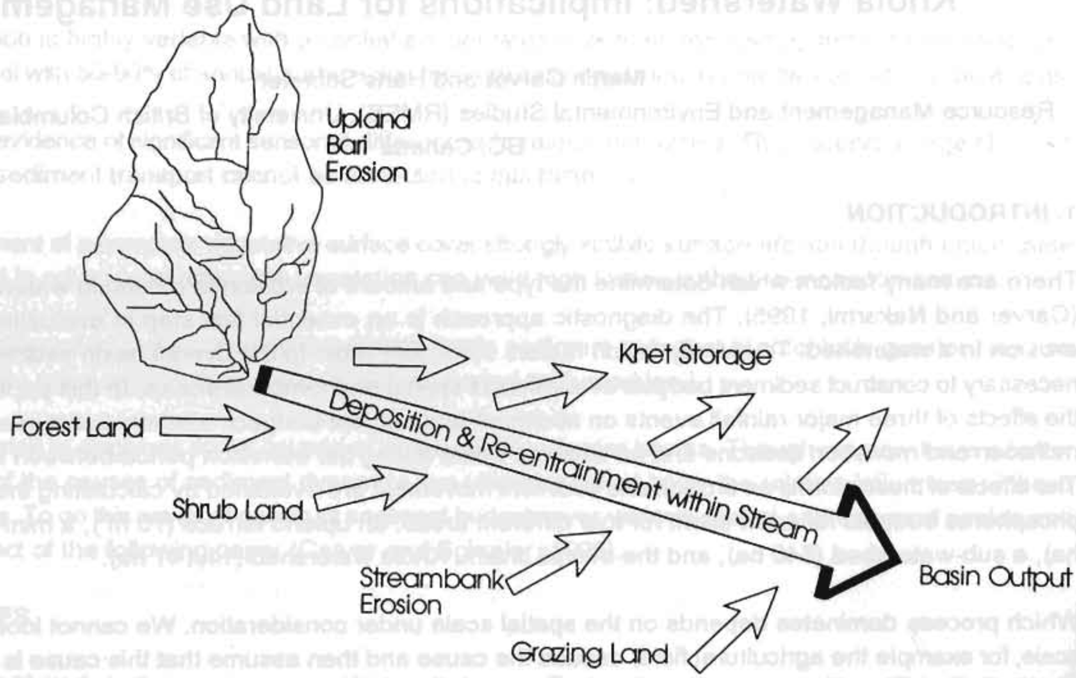

Figure 1. Sediment sources and pathways in the Andheri Khola basin.

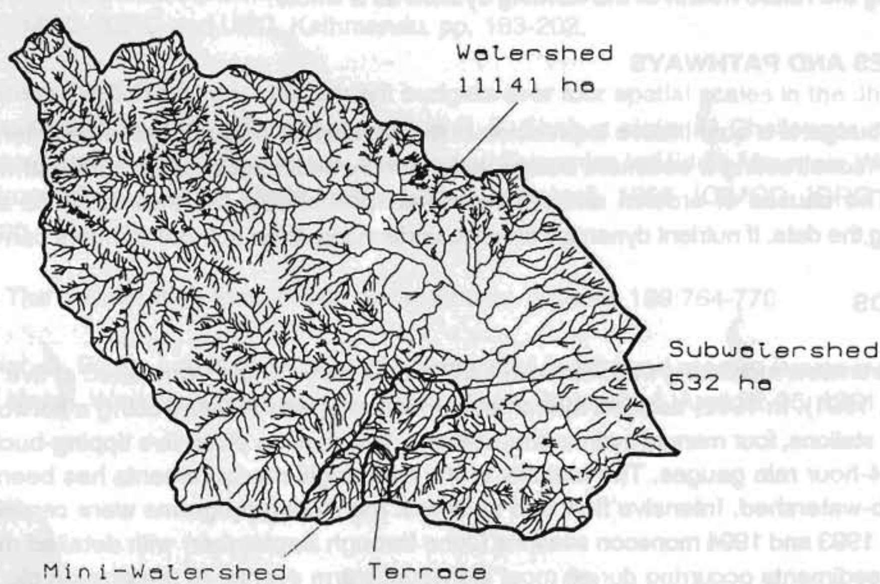

Figure 2. Spatial scales of the sediment and nutrient budgets within the Jhikhu Khola watershed.

The budgets were calculated by first defining the temporal and spatial scales of interest and then quantitative measurements from the long-term monitoring study were used to fill in the gaps between sample points. The temporal scale of interest here is fixed at the single event; budget calculations over entire seasons and years are still in preparation. Using data from the erosion plots and from three different stream hydrometric stations, budgets over catchments of 70 m^2, 72 ha, 540 ha, and 11,141 ha are calculated. The spatial scales are illustrated in Figure 2. In each case, the numerical results are integrated values representing the net result of all sediment and nutrient transfers and movements upstream of the monitoring location for the three specific events. Dissolved nutrients are not included.

The calculation of the budgets at the erosion plot was possible because monitoring was carried out on an event basis and because all eroded material was captured and measured after each storm event. For the budgets over the three larger spatial scales, sediment rating curves (Carver and Nakarmi, 1995) from stream hydrometric stations were used to develop seasonal relationships between stream discharge and sediment transport. These general seasonal curves were calibrated for individual events using actual flow and sediment measurements taken during the events themselves. Laboratory analyses were carried out to determine the phosphorus content in sediment collected from the erosion plot and at the stream monitoring stations. The sediment budgets were converted into phosphorus budgets by using representative phosphorus values derived from these laboratory analyses.

The results are rounded to one significant figure to reflect the level of uncertainty associated with these calculations. It is not the actual numbers but the relative magnitude between scales and events that is of greatest interest. As more data become available, the empirical relationships used in these calculations will no doubt change.

4. EVENT DESCRIPTIONS

From earlier analysis (Carver and Nakarmi, 1995), it is evident that soil erosion and sediment transport are strongly influenced by the seasonal effects associated with the pre-monsoon and monsoon seasons. Pre-monsoon sediment regimes are almost an order of magnitude greater than those of the monsoon season.

The rainfall characteristics for the three individual events evaluated in this paper are summarized in Table 1.

Table 1. Rainfall characteristics of three storm events measured at the upland recording gauge.

Rainfall Type	Season	Date	Peak Rainfall Intensity (mm/hr)	Rainfall Duration (hr)	Total Storm Rainfall (mm)
Upland	Pre-monsoon	June 9, 1992	109	6.4	49.5
Upland	Monsoon	July 17, 1993	63	2.5	35.8
Extreme	Transition	July 10, 1992	103	8.8	90.6

These event descriptions include rainfall intensity and total rainfall as derived from the recording rain gauge in the upland part of the Andheri basin. Using results from the dense network of 24-hour rain gauges within this basin, the spatial characteristics of each event have been determined and are displayed in Figure 3. These 3-dimensional images are not topographic maps but rather are representations of the spatial variation of rainfall amounts over the Andheri basin for each storm event. The event on June 9, 1992 was a heavy pre-monsoon storm centred over the upland portion of the basin. The event on July 17, 1993 was of similar magnitude but occurred in the beginning of the monsoon season. And the event on July 10, 1992 occurred in the middle of the transition season. This event was the heaviest storm rainfall recorded during the 3-year study period.

5. TERRACE SCALE (70 m^2)

The rates of soil loss from the erosion plots for each of the three example events are given in Table 2 for both sediments and nutrients. Pre-monsoon losses are orders of magnitude above those of the monsoon season. In the pre-monsoon, the cultivated land is bare and susceptible to surface erosion as shown in Carver and Nakarmi (1995). As the monsoon season develops, so does a comprehensive vegetative surface cover, essentially halting surface erosion as illustrated by the 0.02 tonnes/ha result for the upland monsoon event. The losses in nutrients are proportionately higher in the pre-monsoon season because of the high nutrient status of the soils during that time.

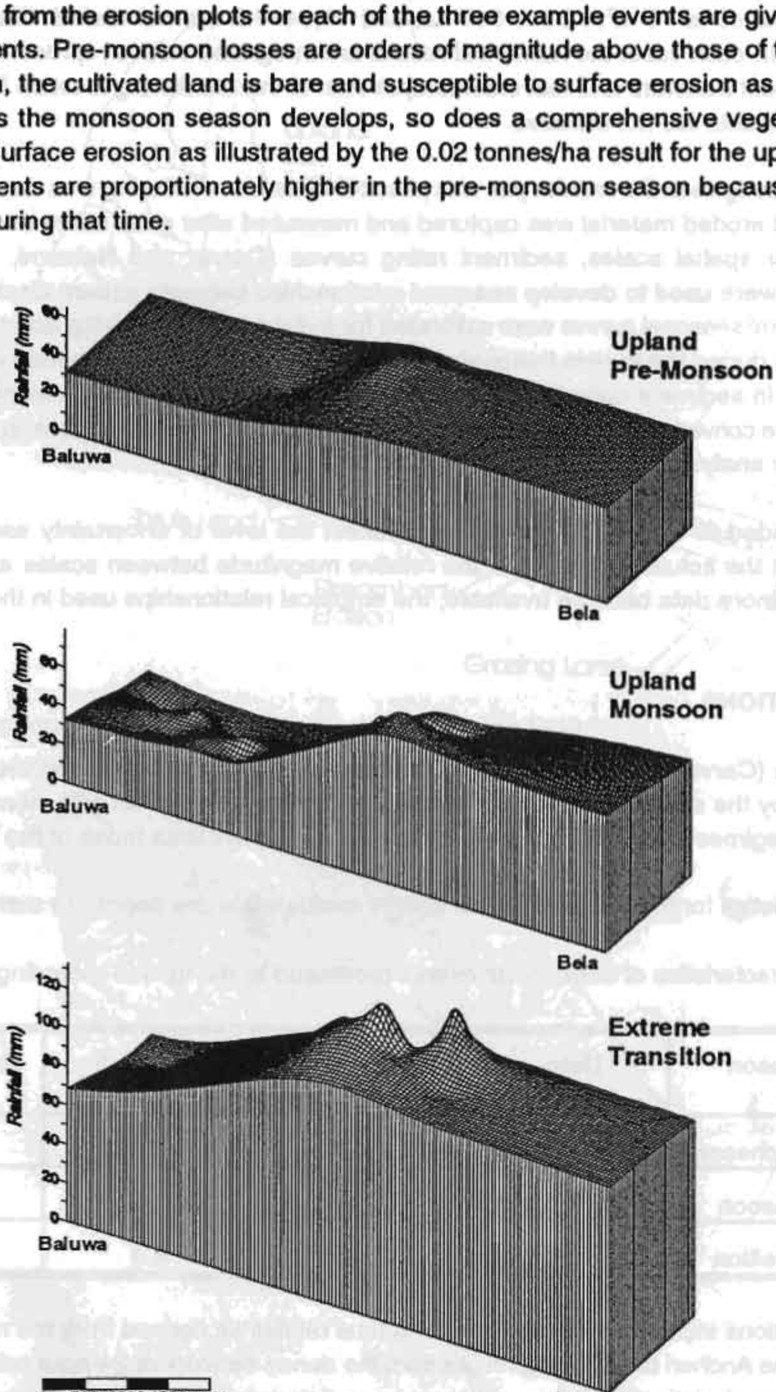

Figure 3. Three-dimensional representations of the rainfall spatial distribution for the three events over the Andheri sub-watershed.

Table 2. Sediment and nutrient budgets at the terrace scale (70 m^2) for the three events.

Rainfall Type	Season	Sediment (tonnes/ha)	Phosphorus (g/ha)
Upland	Pre-monsoon	20	300
Upland	Monsoon	0.02	0.1
Extreme	Transition	10	10

The extreme event, which was a particularly heavy rainfall event, was only half as damaging at the erosion plot as the pre-monsoon event of lower magnitude. This apparent anomaly is easily explained by considering the development of a surface cover. The extreme event occurred in the transition season between the pre-monsoon and monsoon seasons when the vegetative cover is developing but not yet entirely adequate to restrict the rain's ability to erode the soil surface. During this event, a partial vegetative cover existed enabling the loss to be half that of a lighter pre-monsoon event.

6. MINI-WATERSHED SCALE (72 ha)

Table 3 shows the sediment and phosphorus budgets calculated for the three events at the Kukhuri Khola hydrometric station, the 72-ha mini-watershed. The gap between the pre-monsoon and the monsoon events has narrowed. At this scale, other material such as that from terrace slumping serves to increase the loss during the monsoon season. In the pre-monsoon season, losses due to surface erosion are generally far higher than due to slumping and thus the rate decreases at this scale.

Table 3. Sediment and nutrient budgets at the mini-watershed scale (72 ha) for the three events.

Rainfall Type	Season	Sediment (tonnes/ha)	Phosphorus (g/ha)
Upland	Pre-monsoon	5	200
Upland	Monsoon	0.8	20
Extreme	Transition	7	200

At this scale, the extreme event contributes as much to the net basin output as the pre-monsoon event. This is reasonable because of the high degree of terrace slumping from the heavy rainfall. At the terrace scale, the pre-monsoon event produced twice as much sediment as during the extreme event but both were 2 to 3 orders of magnitude higher than the monsoon event. This pattern changes at the mini-watershed scale: the difference between the pre-monsoon and extreme events is gone but the budgets for these events both remain an order of magnitude greater than those of the monsoon event.

7. SUB-WATERSHED SCALE (540 ha)

Table 4 shows the sediment and phosphorus budgets calculated for the three events at the Andheri Khola hydrometric station, the 540-ha sub-watershed. At this scale, the relative difference between the pre-monsoon and monsoon events is similar to that at the mini-watershed scale. The values for both are declining, suggesting either a downstream reduction in sediment production and delivery to the stream or a recapture of material entrained upstream, perhaps through the irrigation system.

Table 4. Sediment and nutrient budgets at the sub-watershed scale (540 ha) for the three events.

Rainfall Type	Season	Sediment (tonnes/ha)	Phosphorus (g/ha)
Upland	Pre-monsoon	2	40
Upland	Monsoon	0.4	4
Extreme	Transition	40	1000

At this scale, the major change is in the large difference between the pre-monsoon and extreme events. The extreme event is now dwarfing the other two in magnitude. It is dominated by erosion associated with the stream which is now enormous. A stream survey following this event showed that the bed in particular was ripped apart by the swollen stream.

Each year, many rainfall events are spatially confined and, even if large areas of the basin experience no rain, a significant flood still occurs at the outlet. It is at the sub-watershed scale that nearly all events are noticed. However as we have seen above, the areal averages may not well represent the actual erosion condition because of the bias toward a small part of the catchment.

8. WATERSHED SCALE (11,141 ha)

Table 5 gives the average rates of soil and phosphorus loss measured at the 11,141-ha Jhikhu Khola hydrometric station for the three sample events. The gap between the pre-monsoon and monsoon events has gone. Either the monsoon event was much more damaging or the pre-monsoon event was much less damaging in other parts of the Jhikhu Khola Watershed than it was in the Andheri Khola sub-watershed. And, though the third event was extreme at the sub-watershed scale, it rates only as an annual event at the watershed. Its high rainfall was evidently not widespread beyond the sub-watershed and so the bigger Jhikhu Khola channel could easily carry the higher volume of run-off without suffering extensive damage to its bed and banks. In general, the signature of sub-watershed variability cannot be discerned: differences in the rainfall input or land-surface response over spatial scales within the sub-watershed are virtually invisible at this watershed scale.

Table 5. Sediment and nutrient budgets at the watershed scale (11,141 ha) for the three events.

Event Type	Season	Sediment (tonnes/ha)	Phosphorus (g/ha)
Upland	Pre-monsoon	0.1	1
Upland	Monsoon	0.1	0.8
Extreme	Transition	2	60

9. DISCUSSION

Table 6 summarises the sediment and phosphorus budgets across all spatial scales and suggests that scale and season are essential considerations when interpreting erosion data. The location of the sediment sources for each event is reflected in these results. In the pre-monsoon event, the source is dominantly the upland terraces: the erosion there is high and it declines steadily downstream due to deposition and recapture through water diversion. This contrasts with the monsoon event in which sediment and phosphorus losses increase up to the mini-watershed scale and then begin to decline, suggesting that sediment sources were due to slumping and streambank erosion resulting from the channelized run-off. The extreme event shows a pronounced increase at the sub-watershed scale: this event was heavy over the entire sub-watershed and the stream grew enormously causing extensive bed scouring and streambank erosion in the lowest reaches of the Andheri basin. At the watershed scale, this swollen stream easily left the basin with little new erosion because there was little addition from other parts of the watershed.

These trends in the sediment budgets across spatial scales are also applicable for the phosphorus budgets. However, the seasonal differences for phosphorus (and other nutrients) are accentuated due to the enriched nutrient content of the soils in the pre-monsoon season.

Table 6. Sediment and nutrient budgets across all scales for the three events.

Budget scale	Sediment (tonnes/ha)			Phosphorus (g/ha)		
	U/P	U/M	Ext/T	U/P	U/M	Ext/T
Terrace	20	0.02	10	300	0.1	10
Mini-Watershed	5	0.8	7	200	20	200
Sub-Watershed	2	0.4	40	40	4	1000
Watershed	0.1	0.1	2	1	0.8	60

10. CONCLUSIONS AND IMPLICATIONS

This paper has examined sediment and nutrient dynamics resulting from three characteristic storm events over four spatial scales in the Jhikhu Khola watershed. Specifically, the results are presented as sediment and phosphorus budgets for each event over 70 m^2, 72 ha, 540 ha, and 11000 ha. Comparing these budgets leads to the following conclusions regarding erosion, sediment sources, and the effects of season and scale in this Middle Mountain farming system:

1) The type of sediment source which dominates in the sediment budget changes seasonally from surface erosion in the pre-monsoon season to terrace slumping and streambank erosion during the monsoon season.

2) Erosion during the pre-monsoon season is most significant at the terrace (70 m^2) and mini-watershed scales (72 ha).

3) Erosion during the monsoon season is often minor except for heavy rainfalls which can be damaging at the mini-watershed and sub-watershed scale (540 ha).

4) Unusually-heavy rainfall creates an additional sediment source from downstream streambank erosion and streambed scouring.

5) Phosphorus budgets correspond closely to sediment budgets and the enriched soil fertility of the pre-monsoon season accentuates the seasonal difference.

6) At the watershed scale (11,141 ha), the signature of variability at all spatial scales within the sub-watershed is lost.

These conclusions suggest the following management implications:

1) Present management techniques are effective at avoiding sediment loss during the monsoon season.

2) The pre-monsoon season is a period of vulnerability when high soil and, particularly, nutrient losses are possible due to the lack of a vegetative cover (see Carver and Nakarmi 1995). This is of great concern for on-farm productivity and does not appear to have a major effect downstream.

3) High basin sediment output is caused by extremely-heavy (and widespread) rainfall. This is of greatest concern for downstream development such as hydropower.

4) A sediment monitoring program should clearly identify whether it is directed at those within or those downstream of these headwater areas: the location, timing, and frequency of sampling will be different for each program.

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Maintaining Soil Fertility in Agriculture and Forestry

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1. INTRODUCTION

The theme for the 1991 Jhikhu Khola watershed workshop (Shah et al., 1991) was "Soil Erosion and Fertility Issues in the Middle Mountains of Nepal." It was during this meeting that we became convinced that soil fertility is one of the key issues regulating future biomass production in Nepal for both agriculture and forestry. This was reinforced by Carson (1992) in his publication "The Land, the Farmer, and the Future." Despite the efforts at the agricultural research stations at Lumle and Pakribas, soil fertility has not been a priority issue in the national Agriculture and Forestry Departments. It was not until the 1995 status paper by the National Agricultural Research Council (NARC, 1995) presented to the Donors' Consortium Meeting that soil fertility became a major priority at the national level.

We identified three processes that lead to widespread soil fertility problems in the Middle Mountains of Nepal and these include: agricultural intensification, conversion of marginal lands into agriculture, and intensive use of the forests for feed, fuelwood and litter collection. The latter practice is becoming a major source of nutrient input into agriculture.

Agricultural intensification is particularly evident in the cultivated areas at the bottom of the watershed, where the introduction of short growing-season crop varieties and irrigation enabled the farmers to move from a single annual crop rotation system to triple crop rotations. In 1980, Hagen (1980) estimated 1.3 crops/year, Panth and Gautam (1987) indicated 1.6 crops/year and Riley (1991) reported averages of 2.0-2.5 crops/year. From the socio-economic surveys conducted in the Jhikhu Khola watershed (Kennedy and Dunlop, 1989; Wymann, 1991) an average figure of 2.7 crops/year was obtained in irrigated fields and 2.5 crops/year in dryland agriculture. These increases are a direct result of increasing demands for food and feed, resulting from a population growth rate which ranges between 2.7 and 3.0% per year. In spite of this intensification, there is mounting evidence that crop yields are declining (Chitrakar, 1990; Shakya et al., 1991; Sherchan and Gurung 1995; Panday et al., 1995) and soil fertility decline has been suggested as one of the main causes of reduced biomass performance by Riley (1991) and Carson (1992). Given the poor infrastructure, the unreliability of external nutrients supplies and accessability problems, we must question the sustainability of the intensive cultivation systems practiced in the watershed. With limited inputs it is not only difficult to maintain the nutrient status in the soils but soil structure, carbon content and the physical behaviour of the soils are also adversely affected.

The second issue of concern is the increasing use of marginal lands for agriculture. As shown by Schreier et al. (1994) and Shrestha and Brown (1995), up to 39% of the agricultural expansion has occurred on slopes greater than 35%. Due to land shortages and insufficient water supplies for irrigation, the poor farmers convert forest and shrub land into agricultural lands. These land conversions occur on steep slopes, where the soils are more susceptible to erosion and where the maintenance of soil fertility is even more difficult because access is more limited and the poor farmers that tend to initiate such conversions have insufficient purchasing capacity for fertilizers and other chemicals.

Forest soil fertility is also declining due to intensive fodder and fuelwood consumption and the increasing practice of collecting litter material and fodder from the forest floor. This practice is most evident during the dry season when fodder is in short supply. Forest litter is used as animal bedding and fodder, and once mixed with manure and incorporated into the agricultural system, provides a substantial nutrient input into agriculture. Given the intensity of fodder collection and litter removal, it is apparent that large amount of nutrients are removed from the forest. Since nothing is returned or recycled the only new supply of nutrients in the forest is from weathering of the bedrock. Given that many soils are deeply weathered and the dominant bedrock is inherently poor in nutrients (sandstones, siltstone, quartzite, phyllite, schist), soil nutrients in the forests are expected to decline under current forest management practices. The problem is more acute in the forest because soil erosion generally increases with slope, changes in vegetation cover, reduction in litter cover, and changes in soil structure.

The aims of this paper are to:

1. provide a status report of soil nutrients under different land uses (dryland and irrigated agriculture, grazing land and forests);
2. identify those factors that have the greatest influence on soil fertility;
3. indicate the rates of soil fertility decline; and
4. show how the cycling of nutrients can be improved.

2. STUDY SITES AND METHODS

Five different soil fertility surveys were carried out over a span of five years and they include:

a) A survey of forestry and agricultural land in the Dhulikhel watershed, in the headwater region of the Jhikhu Khola. This study included 136 forestry and shrub sites and 120 agricultural sites.
b) A general soil survey was carried out in 1990 (Maharjan, 1991) and covered the entire watershed. Samples from 350 soil pits were analyzed for basic nutrients during this survey.
c) A detailed survey of agricultural and grazing land was carried out in 1993/94 in the Bela-Bhimsenthan test area. A stratified sampling design was used to isolate slope, aspect, elevation, soil type and land use effects. Two hundred sites in irrigated and dryland agricultural fields and grazing lands were selected for this purpose.
d) A detailed comparison was made to determine the influence of land use practices on soil fertility at a site where soil type, climate and topography were held constant. Ten samples were collected in the forests, and adjacent irrigated and dryland agriculture fields.
e) A detailed forest soil fertility survey was carried out in 12 forest plots in 1989. These were selected for long term monitoring and included a detailed biomass survey of 20x20 m plots, as well as soil and foliar nutrient determinations.

Samples collected during the general soil survey (b) consisted of genetic horizons and only the first two were analyzed for nutrient content. For all other surveys, the surface layer (0-15 cm depth) was used for the analysis. Nutrients examined included % carbon (Leco), pH (in $CaCl_2$), cation exchange capacity and exchangeable cations (CEC, Ca, Mg, K, Na, in cmol/kg with ammonium acetate extraction method), % base saturation, and available phosphorus (mg/kg^{-1}, with the Bray method). All chemical analysis was carried out in the Soil Science laboratory at the University of British Columbia.

3. RESULTS

3.1. Overall Soil Fertility Status

The samples from the survey in the Dhulikhel sub-watershed (a, 1270 ha) were compared with those from the Bela-Bhimsenthan sub-watershed test area (c, 1927 ha) and the overall Soil Survey for the entire watershed (b, 11,141 ha). The Dhulikhel sub-watershed is located in the headwaters of the Jhikhu Khola watershed and was described in detail by Schmidt (1993), Schmidt et al., (1994) and Wymann (1993). The results of the three surveys are provided in Table 1 and show that the overall soil conditions are generally very poor for both agriculture and forestry. The soil acidity is at least one pH unit below optimum and the carbon, phosphorus, cation content and base saturation are very low. Only exchangeable K appears to be in adequate supply. The Bela-Bhimsenthan survey has slightly higher values because the focus was on agricultural soils while the Dhulikhel survey focused on a comparison between forests and agriculture. The soil survey included all types of land uses and thus gives a better overall representation of the conditions.

Soil acidity and available phosphorus are of major concern and will be addressed in two papers of this proceedings. The low cation exchange capacity is the result of inherited bedrock conditions (sandstone, siltstone, quartzite), and extensive weathering leaving kaolinite as the dominant clay minerals in these soils. Historic losses of organic matter due to soil erosion, crop removal and litter collection are another cause for the low exchange capacity of the soils.

Table 1. Comparison of three soil fertility surveys in the Jhikhu Khola watershed.

Variables (mean values)	Dhulikhel Survey (1,270 ha, n = 256)	Bela-Bhimsenthan (1,927 ha, n = 200)	Overall Soil Survey (11,141 ha, n =225)
pH ($CaCl_2$)	4.4	4.8	4.6
CEC (cmol/kg)	10.5	10.8	10.4
exch. Ca (cmol/kg)	2.18	3.75	2.58
exch. Mg (cmol/kg)	0.61	1.39	0.99
exch. K (cmol/kg)	0.27	0.28	0.29
Base Satur. (%)	30.9	51.7	39
avail. P (mg/kg)	11.6	16.5	2.1
Carbon (%)	0.68	1.01	1.01

3.2. Factors Influencing Soil Fertility

From the analysis of these surveys it became evident that a number of factors have contributed to the poor state of soil fertility in the Middle Mountains. They include factors of soil formation such as topography, parent material, climate, time, land use, and management. Since there is little historic information on soil conditions, it is difficult to isolate which factors are most important but the human influence must be considered to be a primary factor. The Bela-Bhimsenthan survey was carried out in 1993/94 to isolate some of the key factors that affect soil fertility. The survey included 200 sites with 10 sites each in three land use classes, two soil type, two aspect and two elevation categories. As shown in Table 2, only 20 of the 24 possible combinations could be sampled because the red soils, which are the oldest soils in Nepal, have only a limited distribution at elevations above 1200 m in the Jhikhu Khola watershed.

Table 2. Sampling design for detailed nutrient analysis.

# of Sites	Land Use	Soil Type	Aspect	Elevation
10 each	Bari, Khet, Grazing Land	Red Soils	South	< 1200 m
10 each	Bari, Khet, Grazing Land	Red Soils	North	< 1200 m
10 each	Bari	Red Soils	North	> 1200 m
10 each	Bari, Grazing Land	Red Soils	South	> 1200 m
10 each	Bari, Khet, Grazing Land	Non-Red Soils	North	< 1200 m
10 each	Bari, Khet, Grazing Land	Non-Red Soils	South	< 1200 m
10 each	Bari, Grazing Land	Non-Red Soils	South	> 1200 m
10 each	Bari, Khet, Grazing Land	Non-Red Soils	North	> 1200 m

* Bari = Dryland Agriculture, Khet = Irrigated Agriculture

The data set was analyzed using analysis of variance, T-test, and Mann-Whitney U-test. The results, provided in Table 3, indicate that overall, the soil type (red vs. non red) was most important followed by land use, and aspect. Different soil variables are influenced in different ways. For example phosphorus appears to be influence by all factors, while carbon can only be differentiated by aspect and CEC by soil type. Fortunately, factor interactions were minimal and only in the case of elevation/aspect is the validity of the analysis of variance questionable.

Table 3. Significant factors that influence soil development and soil fertility (based on analysis of variance).

Variables	Aspect	Elevation	Soil Type	Land Use
pH		2	3	1
P (mg/kg)	3	4	1	2
C (%)	1			
CEC (cmol/kg)			1	
Exch. K (cmol/kg	2		1	3
Exch. Mg (cmol/kg)	2		1	
Exch. Ca (cmol/kg)	3	2		1
Base Saturation (%)			1	2

* 1-4 = F-Values (in decreasing order of significance, cells with no number are not significant at P = 0.01)

3.2.1. ASPECT AND ELEVATION

Only pH and Ca show a consistent pattern between elevation/aspect and soil chemistry. As shown in Figure 1, the pH is about 0.3 units lower in the upper elevations on the south facing slopes and 0.15 pH units lower in the upper elevation north facing slopes.

About 95% of all upper elevation sites ranged between pH ($CaCl_2$) 4.6-4.8, while 95% of all sites below 1200 m elevation ranged between 4.7-5.2. Similarly exchangeable Ca is 1.5 cmol/kg higher at the lower elevations on south facing slopes and 0.5 cmol/kg higher at low elevations on north facing slopes. More leaching and erosion losses in the upper elevations leads to the removal of bases and hence increases soil acidity and exchangeable Ca at lower elevations. The differences on the south facing slopes are significantly higher and are attributed to the greater diurnal temperature fluctuations that occur on the south facing slopes.

Although the cation exchange capacity (CEC) is significantly lower on the south-facing, higher elevations than at lower elevations, this pattern was not observed on the north facing slopes and it is concluded that these differences are not due to the elevation/aspect component but rather due to differences in parent materials. Sandstone and siltstone are the dominant bedrock at the south facing sites above 1200 m elevation. The coarse textured soils have much higher infiltration rates and, as shown by Carver et al. (1995), the differences have resulted in significantly lower soil surface erosion on dryland agricultural lands. The presence of sandstones is significantly less at all other sites, with phyllites and quartzites being more dominant. The available phosphorus values were significantly higher in the upper elevations on the north slopes, and this is in part due to differences in parent material and land use and not considered the result of aspect or elevation.

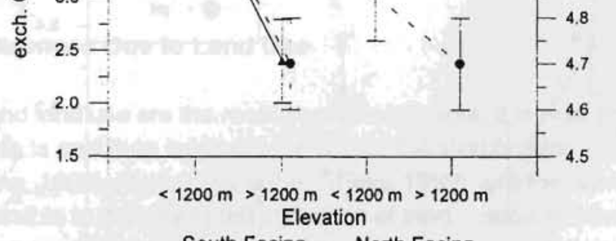

Figure 1. The impact of elevation and aspect on soil pH and exchangeable Ca.

3.2.2. LAND USE AND PARENT MATERIALS

Using the same data set, the influence of land use and soil type on soil chemistry was also examined. Differences between irrigated and non-irrigated sites and grazing lands were determine separately in red and non-red soils. As can be seen in Figure 2, CEC and exchangeable Mg values are clearly dominated by parent material. In both cases there is no difference between land use but consistent differences between soil type or parent materials.

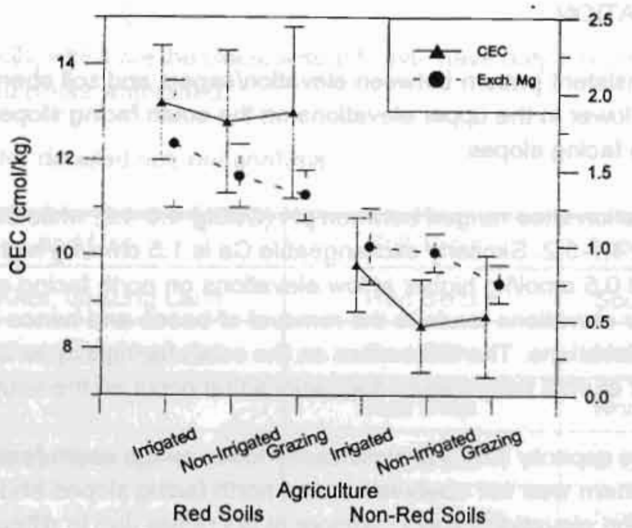

Figure 2. Differences in CEC and exchangeable Mg due to parent materials.

In contrast, land use is clearly the most dominant factor in influencing pH and exchangeable Ca (Figure 3). There are significant differences between irrigated agriculture land (khet), non irrigated agriculture land (bari) and grazing land in both red and non-red soils. The khet lands had the highest pH, Ca, and base saturation values followed by dryland agriculture and grazing land.

Available P, exchangeable K, and base saturation are influenced by both land use and parent material as can be seen in Figure 4. Since the red soils are dominated by deeply weathered phyllites, base saturation is expected to be lower and K content higher. Similarly the Fe and Al content in the red soils is significantly higher than in the non-red soils (Schreier et al 1994) and is likely tying up available phosphorus, hence the lower P content in these soils. The difference in input and management is clearly responsible for the variations between land uses.

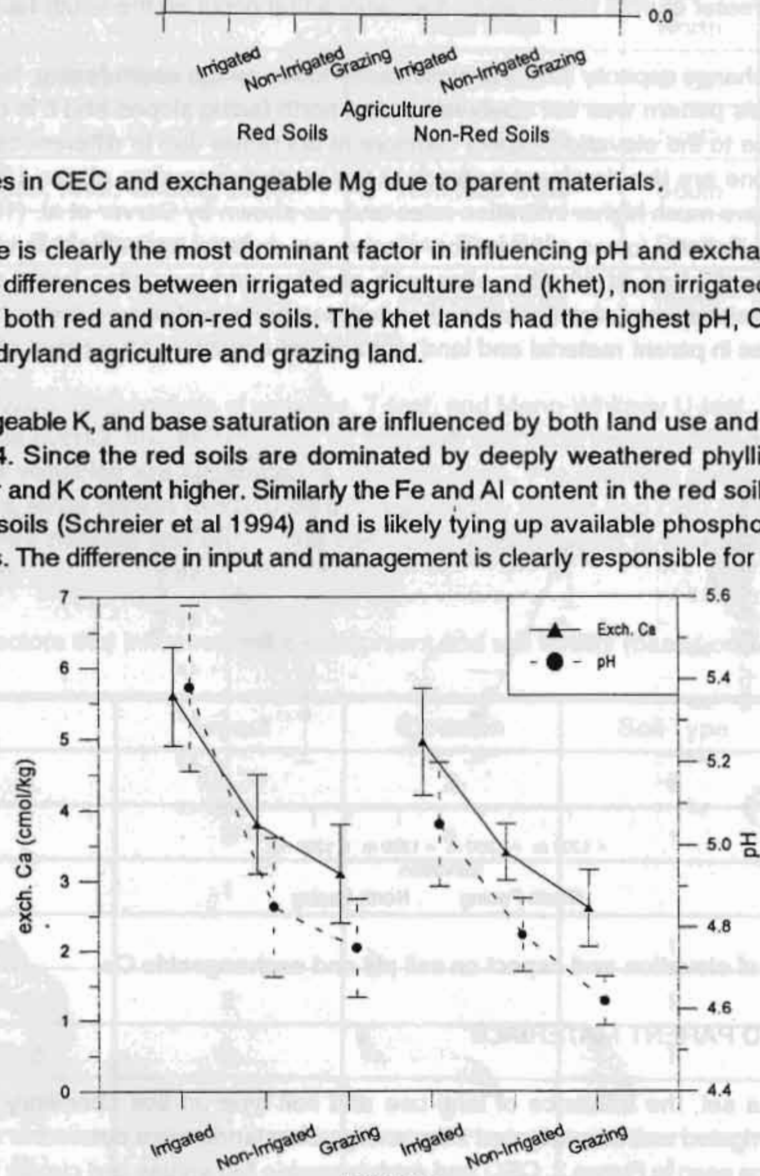

Figure 3. Land use effect on pH and exchangeable Ca.

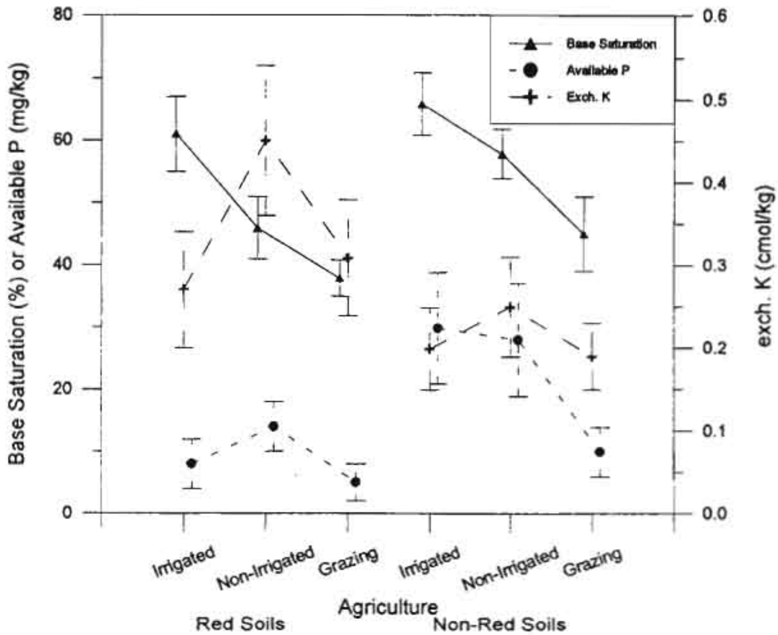

Figure 4. Land use and parent material impact on base saturation, available P and exchangeable K.

In summary, it appears that elevation and aspect influence pH, parent material differences can best be expressed using the cation exchange capacity and exchangeable Mg content, and land use is best expressed using pH and exchangeable Ca values. Available P, exchangeable K and base saturation are all influenced by both parent material and land use.

We have mapped the soils and land uses in the watershed and produced a digital topographic database to which the previous maps were georeferenced. Therefore, it is readily possible to produce selective soil fertility maps using the Geographic Information System (GIS) by linking the soil samples with the land use, soil type and elevation/aspect. An example of some of the GIS base maps are provided in Plates 1-6 (Appendix I).

3.3. Soil Fertility Differences Due to Land Use

Since parent material and land use are the most important factors, it is now possible to stratify all soil samples first by red vs. non red soils and then by land use. Using this stratification and including the Dhulikhel survey, (Schmidt, 1993; Wymann, 1993), the forestry survey (Feigl, 1989) and the controlled land use survey (Schreier et al.1994), it is then possible to document the influence of land use on soil fertility. From Figure 5, it is evident that, regardless of soil type, the forest soil fertility is the poorest, followed by grazing land and dryland agriculture.

The highest pH, exchangeable Ca and base saturation values were found in the khet lands. This is attributed to the input of cations through sediments and irrigation water. Bari land appears to have slightly higher P values and this is likely the results of more fertilizer and manure applications in dryland agriculture than in irrigated fields (Carson 1994). Grazing land, which receives minimal nutrient inputs, and the forest land, which receives no nutrient inputs, are significantly lower regardless of parent materials. These mean values are based on very large sample sizes, covering both the upper and lower portion of the watershed, and since the trends are consistent in all cases it can clearly be stated that land use management has significantly influenced soil fertility to the point were nutrient deficiencies are widespread.

3.4. Rates of Change In Soil Fertility

So far we have shown that land use and management have influenced the soil fertility status but to address the rate of changes due to management is a more challenging task as no historic data is available in the watershed. There are indirect ways to obtain data on rates of soil fertility changes over time, and two examples were used to develop more quantitative data. A 50 ha test site on red soils was selected to compare the differences in soil fertility due to irrigation, rainfed farming and forest use. Based on the 1972 aerial photos, tree coring and discussions with the farmers, it was discerned that the forest was established 17 years ago and all agricultural fields were under the current use for the past 30 years. Ten sites within each of the three land use categories were analyzed and compared. There is clear evidence that the soils originated from the same material and the climatic conditions between the sites are the same. Assuming that the soils had similar conditions before the forest was established, the differences between the forest and the agricultural conditions should be the result of management. The parent material was examined and showed no difference in nutrient conditions between the three land use activities. The soils, however, showed significant differences ($p = 0.05$) in Ca, Mg, P, C, and base saturation between the three land uses. The red soil set (number 2 in Figure 5) shows the differences between the land uses originating from the same soil unit.

It is evident that these differences were induced by management leading to poorer conditions in the forest. If we assume that the P values in dryland agriculture represent a steady state, then the forest soils would have been depleted by 0.76 g N/kg and by 3.6 mg P/kg over 17 years. This would translate into an annual loss of about 93 kg/ha of N loss and 0.5 kg P/ha. The N losses are of the same order of magnitude as the crop uptake by double crop rotation which is in the order of 60-120 kg of N /ha/year. The annual additions in the forest from pine litter fall measured 6 kg of N/ha and 0.44 kg of P/ha. The former account for about 7% of the N losses in the forest and the remainder is likely incorporated in the trees, or leached from the soil be solution, erosion and volatilization. In contrast the amount of P in the pine litter represents 73% of the annual decline and the remaining amount of loss was attributed to erosion and tree uptake. The rate of change in these nutrients between agriculture and forest land is substantial and of concern to the long term sustainability of the land use system.

The second evaluation of nutrient changes between different land uses was carried out in 24 irrigated fields. At the end of the monsoon season the soils which formed the growing media for the rice were sampled. At the same time the surface layer which represents the accumulated nutrients that were introduced as sediments in the irrigation water were also analyzed. Although, as shown by Carver (1995), the accumulation rates are highly variable, there was a significant difference in nutrient content between the residual soils and the newly accumulated soil material. As shown in Figures 6 and 7, with the exception of two samples, all newly accumulated material was higher in Ca and P than the residual that formed the nutrient pool for the rice crop. All points below the 45 degree line represent enriched conditions between residual and accumulated soils. This enrichment has a high spatial dependence and in areas with poor soil fertility the sediments show small enrichments and in more nutrient rich environments the sediments are correspondingly higher. A linear regression equation ($Ca = x+bY$) could be used to predict the rate of nutrient enrichments for all rice fields. The enrichment factor is about 1.5 at low fertility sites but can reach levels of up to 2.5 on the richer soils for soil P values. The implications of these results are two-fold. First, it is evident that irrigated agriculture is benefitting from soil erosion in the upper areas of the watershed. Since the khet lands are the most desirable fields and generally belong to the richer farmers, it can be stated that the rich farmers are getting richer by accumulating sediments and the poor farmers which predominantly own upland bari fields are getting poorer by nutrient losses from erosion. This redistribution is therefore creating a new form of poverty.

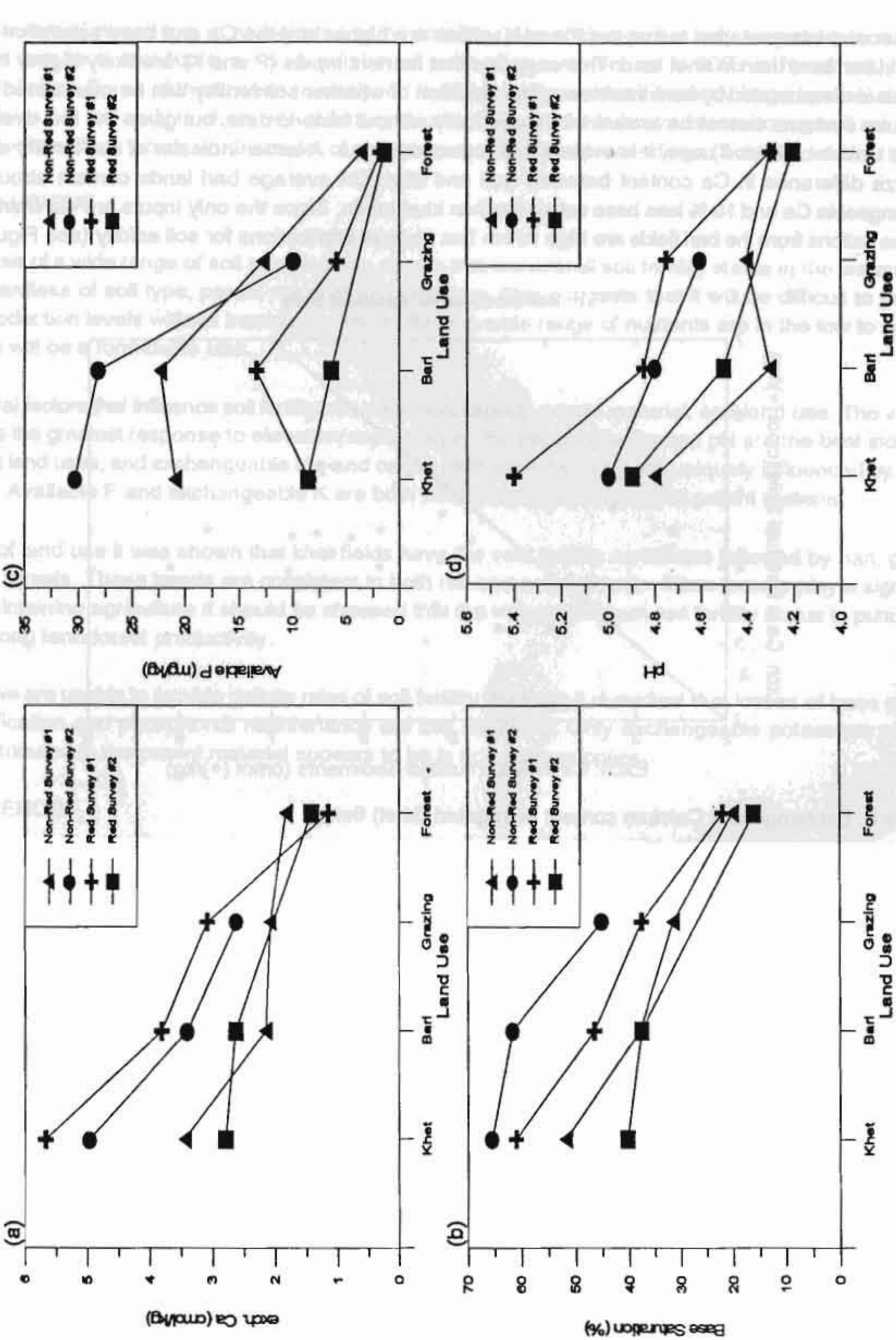

Figure 5. Land use effects on soil fertility from four comparable soil surveys.

The second interpretation is that the P and K values are higher and the Ca and base saturation values are lower in bari land than in khet land. This suggests that nutrient inputs (P and K) are likely higher in bari lands and this is corroborated by farm interviews. The question of whether soil fertility can be maintained under both land use systems cannot be answered categorically without historic data, but given the low overall nutrient status under both land uses, it is evident that losses do occur. A better indicator of soil fertility decline is to analyze difference in Ca content between bari and khet. On average bari lands contain about 33% less exchangeable Ca and 10 % less base saturation than khet lands. Since the only inputs are via manure, losses of base cations from the bari fields are high which has serious implications for soil acidity (see Figures 5a and 5b).

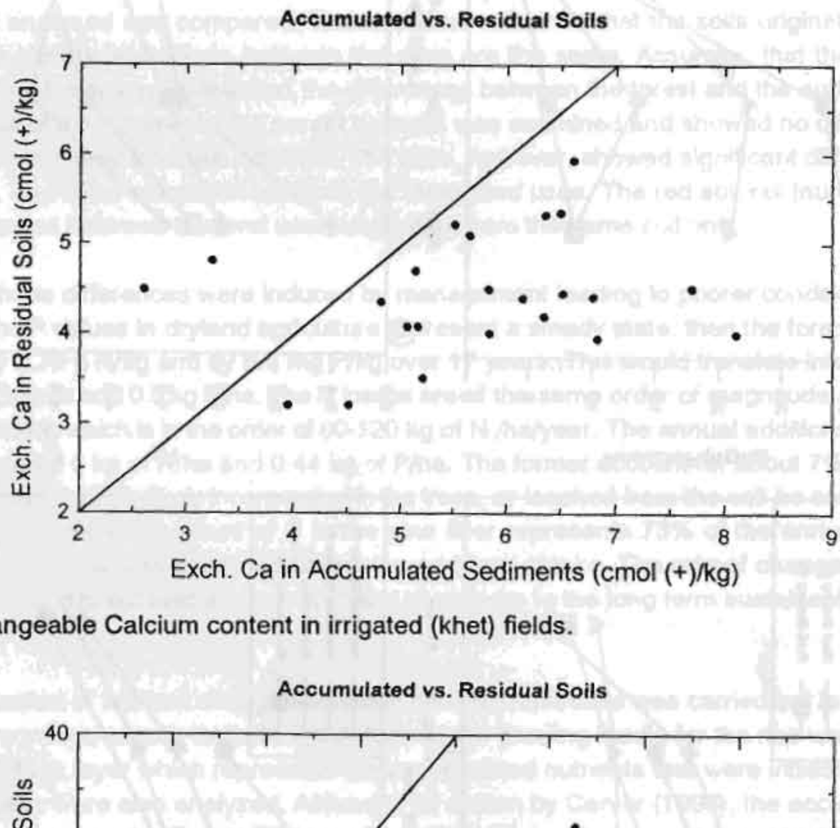

Figure 6. Exchangeable Calcium content in irrigated (khet) fields.

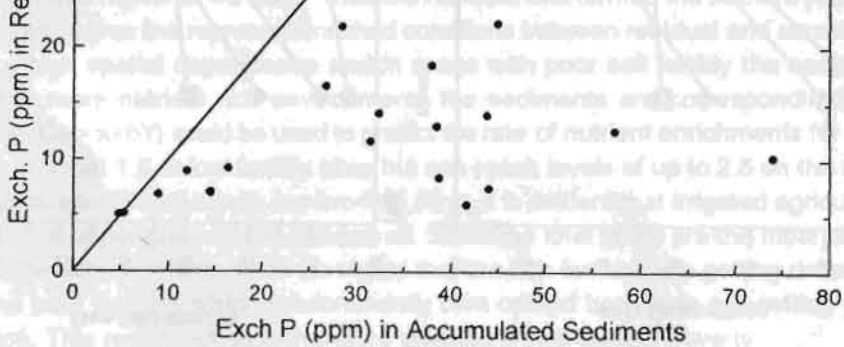

Figure 7. Exchangeable Phosphorous content in irrigated (khet) soils.

These indirect evaluations give us an indication of the possible rates of change but they cannot replace historic data from long term monitoring plots. A number of such sites were set up in 1989 in forest and dryland agricultural sites. Some of these were re-analyzed in 1994, but given the inherently large spatial variations between fields it is too early to show rate of fertility decline. One useful indicator is monitoring soil acidity and exchangeable cations which is the subject of another paper in these proceedings (Schreier, et al., 1995).

4. CONCLUSIONS

The analysis of a wide range of soil samples has shown that the overall soil fertility status in the watershed is poor, regardless of soil type, parent material and land use. This suggests that it will be difficult to maintain current production levels without increasing inputs. Since a wide range of nutrients are in the low to deficient range this will be a formidable task.

The general factors that influence soil fertility are elevation/aspect, parent material, and land use. The variable that shows the greatest response to elevation/aspect is pH. Exchangeable Ca and pH are the best indicators of different land uses, and exchangeable Mg and cation exchange capacity are uniquely influenced by parent materials. Available P and exchangeable K are both influenced by land use and parent material.

In terms of land use it was shown that khet fields have the best fertility conditions followed by bari, grazing lands and forests. These trends are consistent in both red and non-red soils. Since forests play a significant role in maintaining agriculture it should be stressed that the very poor forest soil fertility status is putting into question long term forest productivity.

Although we are unable to provide definite rates of soil fertility declines it is evident that losses of base cations, soil acidification and phosphorus maintenance are key concerns. Only exchangeable potassium which is widely distributed in the parent material appears to be in adequate supplies.

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Soil Acidification and Its Impact on Nutrient Deficiency with Emphasis on Red Soils and Pine Litter Additions

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1. INTRODUCTION

The optimum soil pH for the majority of agricultural crops is between 5.5 and 6.5. When we examine the soil acidity data from all the recent surveys and experiments in the Middle Mountains (Sherchan and Gurung, 1995), it is clearly evident that only a few soils in the region meet these requirements. There are a number of reasons why soils are acidic in the Middle Mountains. First, the dominant bedrock is sandstone, siltstone and quartzite, all of which produce acidic soil material. A second and very important reason is that with the introduction of double and triple annual crop production, chemical fertilizers are widely used.Nepal has no fertilizer plants and the farmers are entirely dependant on external supplies, so the most appropriate fertilizer if often unavailable at the time and location where it is most needed. As noted by Chitrakar (1990), Sherchan and Baniya (1991) and Suwal et al. (1991), ammonium sulphate and urea are the most commonly used fertilizers in Nepal and both of these fertilizers acidify the soils. As manure is in short supply and no lime is currently being applied in the farming system, the concern has been raised that soil acidification is reaching considerable proportions. This has serious implications because base cations, which are needed in large quantities for crop production, will be in short supply and available phosphorus, which has an optimum solubility in the 6.2-7.0 pH range, will not be available at low pH because it will be tied up with Al and Fe.

A more recent threat from acidity has come from the practice of forest litter collection during the dry season, to provide animal bedding and subsequent nutrient input into agriculture. Most of the litter from broadleaf trees is relatively neutral but as shown by Schreier et al. (1994) and Shrestha and Brown (1995), the afforestation efforts carried out over the past 15 years have been dominated by creating Chir pine plantations. Chir pines (*Pinus roxburghii*) are native to the Middle Mountains, they germinate easily in nurseries, need little maintenance and have a high survival rate once transplanted into degraded sites and soils with poor nutrient conditions. Pine can be considered a pioneer species that can stabilize the soil in very degraded areas. One of the reasons for its high rate of survival is that pine litter cannot be used as animal feed. As well, its use as a firewood is limited because of its undesirable burning properties. The planting of pine plantations has become a national tradition in Nepal, and as the forests become more pine-dominated, the forest litter collected by farmers during the dry season is becoming dominated by pine. Pine and pine litter have a tendency to acidify the soils and, in 1991, we expressed concern regarding the long term consequences of this forest transformation on soil acidity and agricultural productivity. Little research has been done to determine the effect of these management practices on the overall soil fertility and it is the aim of this paper to determine the extent of the acid problem, address the processes that lead to acidification, and present possible alternatives to resolve the problem

2. EXTENT OF SOIL ACIDITY IN THE JHIKHU KHOLA WATERSHED

Soil pH values were measured in 0.01 M $CaCl_2$ solutions and from all the surveys carried out in the project the average values are in the 4.8-5.4 range. The factors that have the greatest influence on soil fertility are land use and soil type, and when all samples were stratified by these two factors it became evident that the irrigated agricultural fields had the higher pH values while almost all dryland agricultural soils, grazing lands and forest soils were acidic to very acidic (average values between 4.2-4.8 pH).

A soil acidity map was produced for the entire watershed by grouping all measured soil samples into three acidity categories: pH > 4.8, pH between 4.3 and 4.8, and a very acidic class with pH < 4.3. Then all soil samples collected during the soil survey and the Dhulikhel survey were displayed by their proper spatial location and assigned to each of the representative soil acidity classes. The results provided in Plate 4 (Appendix I) revealed that 18% of all samples were in the very acidic range, 52% in the acidic range and only 30% were in the category considered adequate for agriculture. This clearly suggests that the soil acidity problem is widespread, encompassing almost the entire watershed.

The detailed information on soil fertility in the Bela-Bhimsenthan sub-watershed, described in the previous paper, showed that there are significant differences in soil pH and selective nutrients in different soil types,land use practices, and elevation/aspects. Using the geo-referenced information in the Geographic Information System (GIS), a digital overlay technique was used to display the combination of land use (khet, bari, grazing, forests), soil type (red vs. non-red) and topography (high and low elevation, above or below 1200 m, and north vs. south facing slopes). Of the 32 types of possible combinations only 24 existed in the study area. A minimum of 10 soil samples were available for each of the 24 identified types of polygons and the average value for each known polygon was used as a basis to produce a pH map for the sub-watershed. The resulting pH map (Plate 7, Appendix I) is unique as it is based on more than 200 soil samples and takes into consideration differences in land use, soil type and topographic position.

Based on this analysis, 48% of all land has pH values in the acid range (< 4.8), 33% were in the intermediate range, and only 19% of the land in the sub-watershed is considered to have acceptable pH values for agricultural production. It is obvious that forests can tolerate acidic conditions better than agricultural crops, hence the concern is more for the agricultural area. However, soil acidity affects essential nutrients such as Ca, Mg, P, K, and base saturation.

3. CAUSES OF ACIDITY AND THE EFFECTS OF ACIDITY ON OTHER NUTRIENTS

Given the variability, it is not easy to partition the causes of soil acidity. It is evident that soil type hassome influence, as the red soils are 0.15 pH units higher than the non-red soils. These differences likely influence other nutrients as can be seen in Table 1. From this data it is clear that red soils have slightly higher pH and significantly higher exchangeable cations (K, Mg, and Ca). In contrast, red soil base saturation is lower because the differences in cation exchange capacity is due to textural differences between these soils.

The data in Table 1 shows that red soils have on average a 0.15 pH value higher than non-red soils. This has indirect effects on the nutrient supplying capabilities of the soils. From Table 1, it can be noted that available phosphorus and percent base saturation are higher for the non-red soils than for the red soils. The salient point to consider, however, is not the absolute values of these parameters, but their contribution to crop productivity. Although the non-red soils may have higher available P, the lower pH makes the P very slowly available to crops, and thus the rate by which the soil supplies P to the plant may be insufficient to meet the seasonal requirements, or even the daily requirements, of crops. Cation exchange capacity measurements are more dynamic and exchange reactions are believed to occur instantaneously. It can be seen that although the two soil types have almost the same organic carbon (organic matter) contents, the red soils have the higher capacity by over 45 %. The exchangeable cations are higher in the red soils, but a better relationship may be seen when the ratio of the exchangeable ions is compared to percent base saturation. These values show that more of the basic exchangeable ions that are on the exchange complex are available to crops growing on the red soils, even though their percent base saturation is lower (46.8 vs. 55.7).

Table 1. Differences in soil fertility between red and non-red soils.

Variables	Red Soils (mean values, n = 90)	Non-red Soils (mean values, n = 110)
pH	4.94	4.78
Avail. P (mg/kg)	9.8	22.1
Carbon (%)	0.99	1
Cation Exchange Capacity (cmol(+)/kg)	13.1	8.9
Exch. K (cmol(+)/kg)	0.37	0.21
Exch. Mg (cmol(+)/kg)	1.77	1.09
Exch. Ca (cmol(+)/kg)	3.97	3.54
Base Saturation (%)	46.8	55.7
K: Base Saturation	0.8	0.4
Mg: Base Saturation	3.8	1.9
Ca: Base Saturation	8.5	6.3

From this data, it is clear that the red soils with their slightly higher pH have significantly higher available base cations (K, Mg and Ca) than the non-red soils. Thus, even though the red soils have a lower base saturation value as a percentage, the amount of total base cations available is higher than in the non-red soils.

The higher exchange capacity in the red soils is due to their higher clay contentwhich allows them to hold more cations within their structure. They are therefore slightly less vulnerable to cation losses and acidification than are the non-red soils, which are dominated by quartzite and sandstone. The latter are lower in exchange sites and tend to be more sensitive to acidification and leaching. These trends were fairly consistent even after all samples were stratified by land use (irrigated agriculture, rain fed agriculture and grazing).

However, acidification of the red soils is of particular concern in relation to phosphorus availability, as phosphorusis one of the key nutrients that are deficient in all parts of the watershed. Red soils have significantly lower available phosphorus content and this is in part related to soil acidity. The red soils have relatively high Fe and Al contents and the solubility of Al is particularly sensitive to soil acidity. As is shown in Figure 1, aluminum is insoluble between pH 4.3 and 6.5, but its solubility changes drastically below pH 4.3. Aluminum can readily interact with phosphorus creating occluded phosphate which will precipitate and no longer be available to plants. Since phosphorus is already one of the most limiting nutrients in the soils of the Middle Mountains, this acidity effect is considered to have serious consequences. The exchangeable Al content of a selected number of red soils was displayed in relation to pH and the results clearly indicate that exchangeable Al increases dramatically in the red soils at pH < 4.3.

The implications of these results are two-fold. First, the non-red soils have low buffer capacities and are generally of low pH. They are therefore vulnerable to leaching and acidification. In contrast, the red soils have more buffer capacity and higher cation content but their Al and Fe content also is high. This means that at low pH phosphorus deficiencies will occur.

To document these deficiencies, we first produced a soil phosphorus map for the Bela-Bhimsenthan sub-watershed. The same overlay and sampling stratification methods were used as before. The resulting phosphorus map is provided in Plate 8 (Appendix I) and as can be seen in Table 2, the results are not encouraging. Almost two thirds of all land in the sub-watershed has poor to very poor phosphorus conditions.

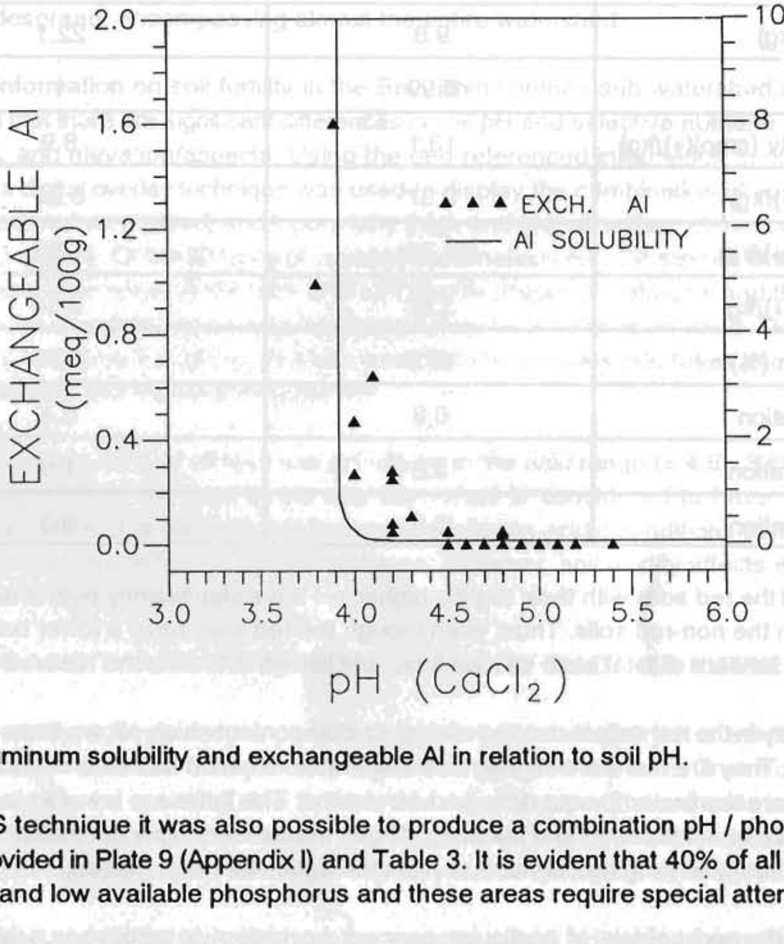

Figure 1. Aluminum solubility and exchangeable Al in relation to soil pH.

With the GIS technique it was also possible to produce a combination pH / phosphorus map, the results of which are provided in Plate 9 (Appendix I) and Table 3. It is evident that 40% of all soils in the watershed have both low pH and low available phosphorus and these areas require special attention.

Table 2. Extent of available Phosphorus in the Bela-Bhimsenthan sub-watershed.

Available Phosphorus (mg/kg)	Area in ha	Percent of Sub-Watershed
Very poor < 5	639	36
Poor 5 - 10	433	25
Fair 10-15	201	11
Moderate > 15	501	28

Table 3. Classification of combined soil acidity and available Phosphorus.

pH	Available P (mg/kg)	Area in ha	Percent of Sub-watershed
< 4.8	< 10	712	40
< 4.8	> 10	145	8
4.8 - 5.0	< 10	119	7
4.8 - 5.0	> 10	472	27
> 5.0	< 10	242	13
> 5.0	> 10	84	5
		Total : 1774 ha	1

We can now examine the 200 soil samples analyzed in the test area and document the number of samples under different land uses and soil types that fall into a high acidity and low phosphorus category. As is shown in Figure 2, 75 % of all grazing lands and 23 % of the dryland agricultural lands are very acidic (<4.8) and have P values below 10 mg/kg. In the red soils this percentage increases to 80% for grazing and 40% for dryland agriculture. This suggests that red soils have slightly more problems with acidity and phosphorus deficiencies than the non-red soils. In addition to the three land uses, we also analyzed 12 forest plots on red soils and all of them fall into this very acidic category.

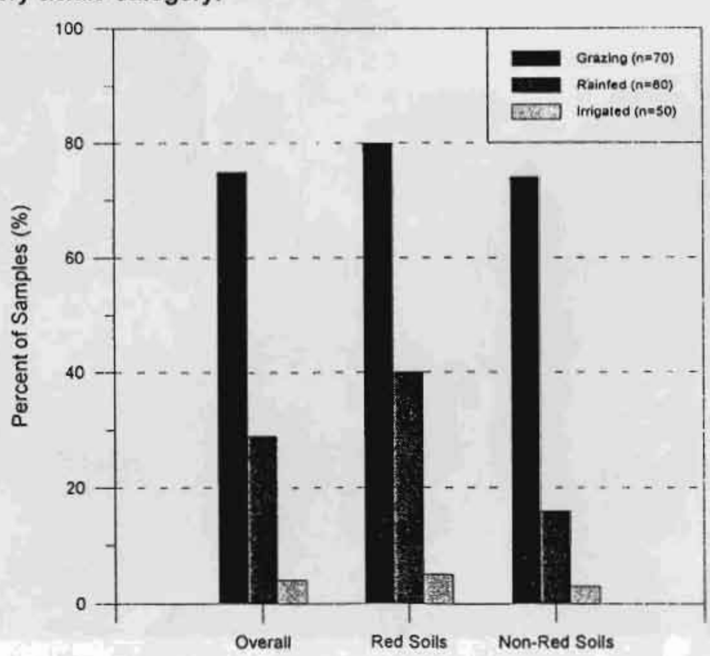

Figure 2. Distribution of acidic soils, with low phosphorus content in relation to land use and soil type.

As most of the grazing lands and forests are over-utilized and degraded, it is likely that leaching, soil losses by erosion and a lack of inputs (cations) have caused these difficult conditions. However, acidic bari land with low P content on red soils are almost three times as common as on non-red bari land. Since both of these soil types receive significant inputs from manure and fertilizers, other factors are likely to play a role. Shrestha and Brown (1995) have demonstrated that the forest cover has changed significantly from a mixed stand to one dominated by chir pine plantations. In contrast, khet land, which receives sediments and nutrient via irrigation water, is significantly enriched and, with the exception of a few samples, all soils under irrigation agriculture do not have an acidity problem. This enrichment effect was described in more detail in the previous paper (Shah and Schreier, 1995) and leads to significant increases in soil pH, Ca, Mg and base saturation.

4. PINE LITTER , TERMITES AND SOIL ACIDIFICATION

Traditionally, poor farmers collect forest litter during the dry season for use as animal bedding and subsequent input into agricultural soils in the form of compost. This practice has increased significantly over the past 10 years because of crop intensification (double and triple crop rotations), a lack of access to fertilizers at certain times of the year, and the farmers' belief that organic inputs are essential in maintaining the soil structure and nutrient pool under agriculture. Since the forests are becoming dominated by pine (70% of all trees planted in the watershed over the past 5 years have been pine) the proportion of pine litter collected during the dry season has gone up dramatically. Also, under temperate conditions, the decomposition of pine litter can take several years and can lead to soil acidification. As is shown in Figure 3, massive quantities of pine litter are transported and transferred from the forest into agriculture. The following questions must therefore be asked:

1. Is pine litter a good source of fertilizer?
2. Is the pine litter decomposition sufficiently rapid to benefit nutrient cycling in agriculture?
3. Is pine litter decomposition increasing soil acidity and what are the implications under agriculture? Since most of the fertilizers used in the watershed are acidifying soils and pine litter is inherently acidic, is the addition of pine litter adversely affecting the nutrient regime?

Figure 3. Forest litter collection during the dry season.

Two experiments were carried out to examine the effect of pine litter on soil acidity and nutrient conditions. In the first, two sets of 25 litter bags were used to document the pine needle decomposition process. The bags were constructed from fine mesh nylon, which allowed air and water to freely penetrate the bags. They were cut to 20x20 cm size, 10 grams of dry pine needles were added to each bag and nylon thread was used to sow the bags closed. Twenty-five bags were buried in red bari soils and 25 in non-red bari soils near the erosion plot site in a 10 metre strip at 15 cm depth. Five of the 25 bags were removed after every 4-6 month period to determine the amount and quality of the litter remaining. A similar experiment was carried out using metal mesh bags to provide information on the rate of decomposition of the litter.

The aim of the second experiment was to document whether pine litter is indeed acidifying the soils. Two five metre long trenches, 30 cm wide and 20 cm deep were dug in red and non-red bari soils at the same sites, and a layer of 15 cm of dry pine litter was added to the trench. The excavated soil was used to cover the litter. Ten soil samples were collected for pH and nutrient analysis from the excavated surface before the litter was applied. The remaining residue was examined after intervals of between 4-8 months over a time period of 2 years and the soil underlying the litter was analyzed each time to document the extent of acidification.

The results of these two experiments produced some unexpected findings. Termites play a very active role in the decomposition of the pine litter. Termites make holes into the nylon bags, break up the needles into small pieces and remove them from the site. The attack and removal rate is extremely variable and we suspect is dependant on soil type and moisture conditions. A much lower rate of removal was observed in the non-red soils, which were sandier in texture and drier than the red soils which contain significant portions of kaolinite. The rate of decomposition is shown in Figure 4, and indicates that almost all litter disintegrated and disappeared in the red soils within 7 months. In contrast, 30 months after the initiation of the experiment in the non-red soils, 2% residue still remained in the bag.

The experiment with a metal mesh bag indicated that 2/3 of the litter remained after 10 months. The termites apparently were unable to penetrate this structure. This suggests that in the absence of termites microbial decomposition of pine litter is slow, a fact that is well known from many studies in the northern latitudes.

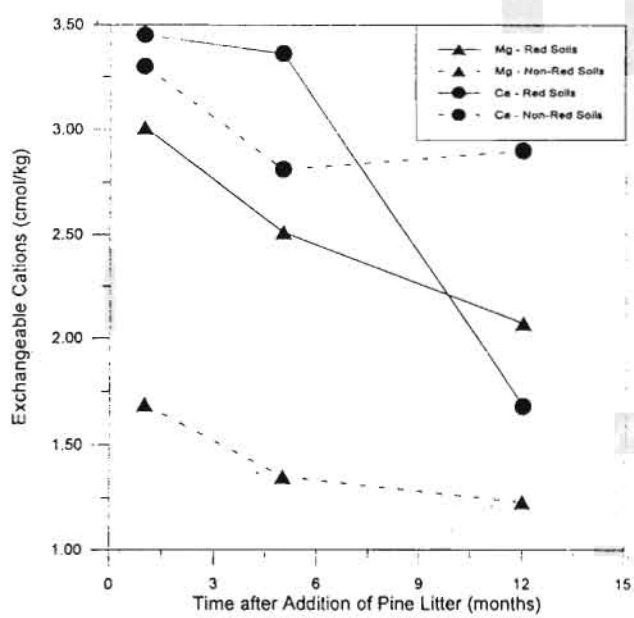

Figure 4. Rate of pine litter decomposition in different soils.

The results from the acid monitoring program are more complex. We were unable to show a pH change between the sample and the control after 12 months started in both the red and non-red soils. This was long after the pine litter had disappeared by termite and microbial action. However, the cations, particularly exchangeable Ca and Mg, decreased significantly over the 12 month monitoring period in both the red and non-red soils (Figure 5). This suggests that the soils might be buffered, but this buffer capacity may not be maintained if additions of pine litter were to continue.

Exchangeable Mg and Ca in the two soils decreased over time and the percent decrease in red soils was larger than for the non-red soils. This may indicate that the red soils had better soil structure which promoted infiltration of water, causing more leaching and potentially less surface erosion. However, it is more likely that, because termites were more active in the inherently more fertile red soils and incorporated much of the exchangeable Mg and Ca (exchangeable = more readily available) as they fed on the litter, they caused more rapid decomposition of the organic material. Since the termites are mobile, they exported much of the exchangeable cations, notably Ca, from the site and deposited these constituents elsewhere (e.g. termite mounds or termilaria, as it is known that Ca is a constituent of these structures).

The data also indicates that there is some buffering capacity in the two soils. This, however, may be of short duration. The presence of aluminum, which changes form at different pH levels, may be responsible in part for this buffering, hence temporarily limiting changes in pH. As the pH drops or the acidity increases, compounds in the soil begin to dissolve, freeing soluble silicic acid, which leaches and liberates Al and its various forms (e.g. H^+ + mineral-Al-OH ---> Al^{3+} + H_2O + residue). At pH equal to five, aluminum occurs in three different forms: Al^{3+}, $AlOH^{2+}$ and $Al(OH)_2^+$. The Al^{3+} increases in proportion as the pH drops below 5 and it is this form of aluminum which is most deleterious, or even toxic, to crops. Also, as the pH drops from 5 to 4, the amount of soluble aluminum increases about 1,000 times. Thus, in addition to the potential toxic effects of the aluminum on crops, this aluminum can polymerize with a gel and acts as a cement among sand, silt and clay particles when the soil dries (e.g. the dry season). These aluminum materials may form hardened layers (incipient pans) in the soils and affect both management and the rates of water infiltration. If acid inputs continue, this would remove basic cations and change the $Al(OH)_x$ forms, or the $Al(PO_4)_x$ forms, with largely unknown consequences in soil structure, fertility considerations and impacts on surface run-off and erosion.

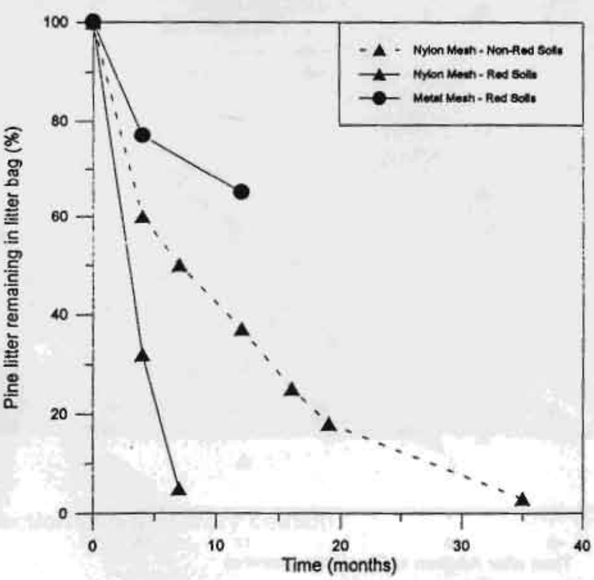

Figure 5. Leaching of cations under decomposing pine litter layer.

5. REMEDIATION OF SOIL ACIDITY

The application of lime and manure is one possible solution to avoiding further increases in soil acidity. To document this, a small experiment was carried out in a very degraded red soil site in the Bela sub-watershed. A 3x4 block treatment of lime and manure was applied to this site in 1992. Several nitrogen fixing tree species and native grasses were planted on bare soils in 10 by 1 metre strips, leaving a control site with no treatment. Lime, manure and a combination of lime and manure were applied at rates equivalent to 20 tonnes/ha at the beginning of the experiment and plant response is being monitored on a continuous basis. Two years were required to establish good plant growth (due to insect and disease attack) but in the third year we noted significant responses from the treated soils over the control. The combined lime/manure application did significantly better in term of biomass production than either the single lime or manure treatment. The plant response to the lime treatment was slightly better than to the manure treatment alone. The treatment was only applied once and consisted of 20 tonnes/ha of lime/ha and 20 tonnes/ha of manure/ha and after one year there were slight improvements in pH (0.2 pH units) in most plots that received treatment. Since local limestone sources are available in the watershed, additional tests are underway to document if such a treatment could be used to reverse the present soil acidification trend and to returnproductive capacity to the soils. A more extensive lime response test is needed using locally available sources before this management option is extended to the entire watershed. As part of this evaluation, emphasis should be directed toward documenting how the phosphorus availability changes as a result of the lime and manure treatment. The results obtained to date are encouraging.

6. CONCLUSIONS

A number of conclusions can be reached from this analysis.

1. The soils in the watershed are very acidic with approximately 70% of all surveyed samples below the 4.8 pH level (in $CaCl_2$). This was confirmed in a more detailed study in a sub-watershed where the soils were stratified into red and non red soils and four different land use classes. Significantly lower pH values were found in non-red soils. These soils are mostly developed over sandstone, siltstone and quartzite materials and hence have lower levels of base cations, lower CEC and higher base saturation than do their red soil counterparts which contain significant portions of clay minerals.

2. Soil acidity influences Al solubility and can cause Phosphorus deficiency. About 61% of all the soils analyzed were in the poor and deficient range and 40 % of all soils were found to have a combination of low pH (<4.8)and low phosphorus (< 10mg/kg) values.

3. Seventy-five percent of all grassland sites and 23% of dryland agricultural sites fell into the combined low pH and low P class. In contrast very few irrigated soils are low in pH or P because the annual input of irrigation water and sediments significantly enriches these soils.

4. Eighty percent of all red soil samples under grazing land and 40% of all red soils under dryland agriculture have high acidity and correspondingly low phosphorus. Aluminum solubility at low pH was shown to be at least in part responsible for making phosphorus unavailable to plants in these soils.

5. The addition of pine litter to agricultural soils is been viewed with concern because pine needles decompose very slowly and are known to acidify soils. In a litter bag experiment is was shown that termites play a significant part in the decomposition of pine litter. However, their activity is significantly

curtailed in the sandy non-red soils where decomposition took more than 32 months. In the red soils where termites are very active the same amount of litter was completely removed within 7 months.

6. Experiments with pine litter layers show no soil pH decrease under decomposing litter over a 12 month period, but the amount of exchangeable Ca and Mg was significantly reduced. It is postulated that Al hydrolysis is buffering soil acidity but that the leaching losses of cations will eventually lead to Al alteration and acidification.

7. Lime applications from local sources appear to be beneficial to plant growth on red soils but a combination of lime and manure showed the best biomass production results. The application of lime ameliorated the pH of the red soils and improved the cation content, hence red soil degradation might be reduced by such treatment.

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How do Indigenous Management Techniques Affect Soil and Water Movement?

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1. INTRODUCTION

Increasingly, there are concerns about the future viability of the farming system in the Middle Mountains of Nepal. Declining agricultural productivity and increased downstream sedimentation are frequently cited (Ives, 1989) as major concerns for the future. However, at the same time, there is a growing awareness of the effectiveness of indigenous farming practices throughout the world (Hudson, 1992; Wilken, 1987) and also of those specifically from this region (Gill, 1991; Tamang, 1993). Indigenous knowledge is becoming better recognised as both valuable and effective.

These two ideas are in conflict. How can indigenous knowledge be both adaptive, forward looking and innovative (Gill, 1991) while also be the cause of agricultural degradation (Eckholm, 1975)? How can these two views be reconciled? The missing link is a quantitative evaluation of the indigenous methods, especially in terms of soil erosion and soil fertility. Most evaluations to date have been qualitative (e.g. Muller-Boker, 1991); quantitative evaluations are very difficult to carry out especially in terms of soil erosion because there have been few or no data collected.

In terms of soil fertility, it is clear that soil fertility is on the decline. The farmers are "up against the wall" and are doing what they can with limited nutrients (Schreier et al., 1994). It is, however, far less obvious how effective they are in managing or "controlling" the soil's physical, chemical, and biological aspects relating to their farming environment. The focus of this paper is on the soil's physical aspects.

The goal of this paper is to evaluate the effectiveness of the local farmers at mitigating losses related to soil erosion by using the results from a three-year hydrometric study. First, the indigenous physical soil conservation techniques are described and classified. Second, selected techniques are evaluated using standard hydrological analyses. Conclusions and management recommendations are based on the results of these evaluations.

2. OVERVIEW OF INDIGENOUS SOIL-CONSERVATION TECHNIQUES

Western soil conservation has traditionally focused on preventing erosion from the field. Consequently, interest in indigenous methods has been oriented toward this aspect of soil erosion. However, Middle Mountain farmers use on-field methods as only a part of their overall strategy to keep soil losses at a manageable level. They use many methods to recapture eroded material once it has left the field. This differentiation between on-field and off-field methods forms the basis for the following classification of indigenous techniques.

On-field methods largely attempt to prevent upland erosion. Primary approaches include terracing, run-off ditches, intercropping, and fertility maintenance. Terracing is a successful and well-studied approach to cultivation on steep slopes (Carson, 1992). Farmers modify terrace characteristics to accommodate local slope and climate demands. Run-off ditches, like the one shown in Figure 1, are found throughout the terraced landscape. They serve to rapidly remove run-off from the steep fields, thus preventing terrace and hillside failure on the terraces. Intercropping both serves productivity needs and conveniently serves to enhance the vegetative cover of the field, decreasing the erosive action of intense rainfalls. Finally, farmers practise a wide range of fertility management activities such as composting and mulching which invariably serve to increase the organic matter content of the soil thereby increasing aggregate stability and decreasing soil erodibility.

Figure 1. Typical run-off ditch within the terraced landscape.

Off-field methods focus on the management of run-off, the sediment that is carried with it, and the frequent accumulation of this sediment during its passage out of the basin. These techniques include run-off canals, the entire irrigation system (dams and canals), streambank protection, and silt traps. Run-off canals are a necessary extension to the system of run-off ditches in the terraced slopes. These permanent, vegetated canals take swollen upland streams of run-off to the natural drainage network. The irrigation system captures stream flow, directing it into canals and ultimately into irrigated khet fields where previously-eroded soil is deposited and often held indefinitely. A typical irrigation dam is illustrated in Figure 2. Where land is threatened, farmers protect streambanks by using bamboo, stone walls, and occasionally gabions. Finally, silt traps are found in the wider valley bottoms and enhance the deposition of suspended sediments so that they can then be purposefully reincorporated into a productive field.

3. SELECTION OF TECHNIQUES FOR EVALUATION

Ideally, evaluation would involve first gaining a comprehensive, quantitative knowledge of sediment flows throughout the basin. With this understanding, management efforts would be judged on the basis of how effectively they are shaping these sediment flows. Unfortunately, it is essentially impossible to pursue this sort of an evaluation because it is extremely difficult to adequately describe the sediment budget in a way that can cope with its spatial and temporal variability.

Instead, specific aspects of the erosion and sediment transport system are examined and the efficacy of the chosen management efforts are evaluated in this context. Using basic understanding of how sediment and water moves through steep basins, we can reach conclusions about the effectiveness of specific indigenous management techniques. One on-field and one off-field management method have been chosen for evaluation. In addition, the erosion status of a sub-watershed managed using indigenous approaches is compared to that of another sub-watershed with extensive surface degradation and land no longer in farming use and, therefore, not maintained using the conventional Middle Mountain farming techniques.

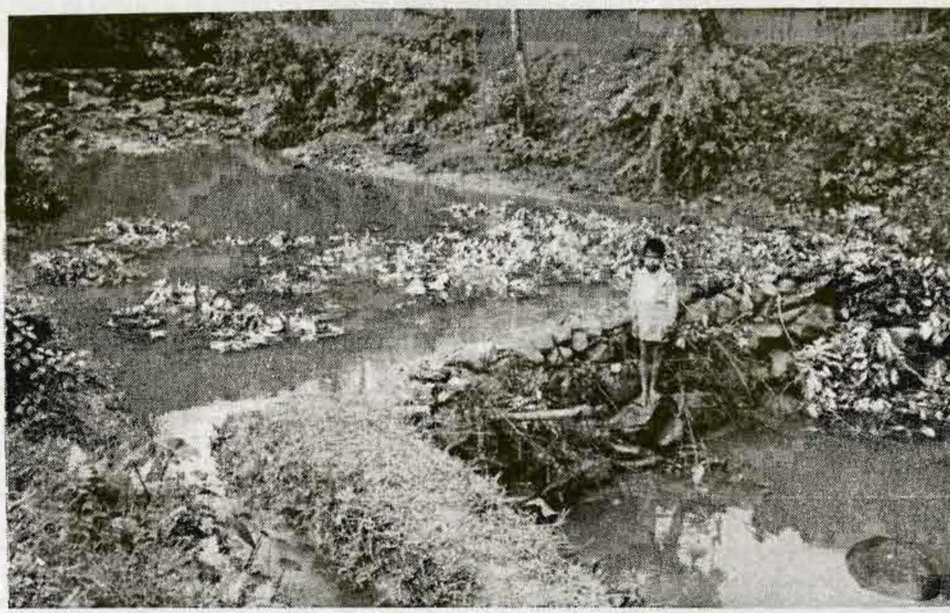

Figure 2. Diversion dam in the lower reaches of the Andheri Khola.

4. EVALUATION

4.1. On-Field: Vegetative Surface Cover

Elsewhere in this volume, Carver and Nakarmi (1995) present an analysis of the effect of crop development on the rate of surface erosion from cultivated fields. This analysis suggests that despite the presence of high-intensity rainfall events, the crop with its attendant root system, the intercrop and the weed cover form an extremely effective surface mat which restricts erosion during the monsoon season. Losses can be huge if the timing of heavy rainfall comes in advance of the development of an adequate surface vegetative cover.

This result is contrary to comments which say that "deforestation" of lands for cultivation results in high sedimentation rates downstream. A more reasonable assessment is that rates of surface erosion are, in fact, under control during most of the farming season and that elevated stream sediment concentrations from surface erosion occur during a period of vulnerability when indigenous techniques are inherently less effective at restricting soil loss at its source.

4.2. Off-Field: Irrigation System

The irrigation system serves as a sediment trap by diverting flow and halting the movement of eroded material out of watersheds. But how effective is this process? To what extent are the farmers able to recapture soil and nutrients lost from their upland agricultural fields and entrained in the drainage system? To answer these questions, two analyses are presented. The first focuses on the diversion of water while the second looks specifically at the extent of sediment accumulation in the irrigated fields.

As it progresses downstream, run-off is concentrated and thus streams generally increase in size. If rainfall is uniform over the basin and if there are no significant losses to the subsurface and no dramatic changes in the surface characteristics downstream, one would expect the stream to grow in volume in proportion to the ratio of the basin areas which contribute to their outflows. This principle is used here to evaluate the extent of diversion of floodwater by irrigation dams.

Figure 3 shows the Andheri and Kukhuri Rivers, the locations of the 62 diversion dams within this basin and the locations of two automated hydrometric stations. Table 1 summarizes pertinent information about each of these hydrometric stations. The ratio of the contributing areas of the two stations is 7.5:1. Assuming losses to the subsurface to be negligible and that surface run-off characteristics remain similar downstream, then we expect to see 7.5 times more flow at the Andheri station from rainfall events which provide even coverage over the entire basin. Further, if the lowland flow is half the "expected" value, then the flow ratio would be 3.75. If the total flow in the upland and lowland stations are equal, then the flow ratio is unity.

Figure 3. Location of all irrigation diversion dams on Kukhuri/Andheri drainage.

During the period of monitoring, 16 events were monitored simultaneously at both stations by the automated equipment and are available for comparison. For each of the flood events, the total flow through the two stations has been calculated and its season noted. The pre-monsoon season is the initial part of the rainy season when rainfall is infrequent but can be heavy. During the monsoon season, rainfall is frequent and surface soils are often saturated. (The transition season is a period in between the pre-monsoon and monsoon seasons which has sediment-regime characteristics in common with both seasons.)

Table 1. Contributing areas and number of irrigation dams for Kukhuri and Andheri hydrometric stations.

	Kukhuri Basin	Andheri Basin	Ratio
Total Contributing Area (ha)	72	540	1:7.5
Irrigated area (ha)	6	36	1:6.0
Number of dams	14	62	1:4.4

Table 2 presents the results seasonally in terms of the ratio of the flows of the lowland to upland stations. In all but two cases, the ratios are far less than would be expected under unmanipulated hydrological conditions. In fact, 31% experience **less** flow at the lowland station than at the upland station.

Table 2. Flow-ratio comparison for Kukhuri and Andheri hydrometric stations.

Outflow Ratio Class (Andheri/Kukhuri)	Number During Pre-Monsoon and Transition Seasons	Number During Monsoon Season	Total Number During All Seasons	Percentage of Total
0 - 1.0	2	3	5	31
1.0 - 3.75	3	5	8	50
3.75 - 7.5	1	0	1	6
> 7.5	1	1	2	13
Total	7	9	16	100

There is further support for the conclusion that irrigation dams divert a large proportion of floodwaters. Table 1 indicates that the number of irrigation dams and the amount of irrigated land are proportionally greater in the Kuhkuri basin than in the Andheri basin. This greater diversion should cause the flow ratio (lowland-flow/upland-flow) to be bigger, not smaller. Further, the water-holding characteristics of the surface soils in the lowland are lower in the upland. This should also cause the ratio to be greater than if this factor was equal. Presumably, if these other factors were equal, the flow ratios in Table 2 would be even **lower**.

The seasonal separation shown in Table 2 suggests that the tendency for a reduction in basin output is about equal during the pre-monsoon/transition and monsoon seasons. Due to greater need for irrigation water in the pre-monsoon season, it was hypothesized that the diversion in this season would be greater. Though these data do not support this hypothesis, because of the small number of events available, this seasonal consideration will have to be revisited when there are more events monitored in this comprehensive way.

The flow-ratio analysis supports the hypothesis that the diversion dams are very effective at directing floodwater out of the stream and into the irrigation system. In fact, it appears that a majority of the floodwaters is redirected into the irrigation system. And we know from the hydrometric data set that large amounts of suspended sediments are carried with the floodwater. If the hypothesis is correct, then there should also be evidence of soil accumulation within the irrigation system. We know that the farmers maintain the canals by annually removing considerable deposition but what of the fields themselves?

To examine the sediment accumulation in the fields, pins have been placed in a wide selection of khet fields before the onset of the flood season. The pins were collected after harvest and the soil level noted and compared to the level before the pre-monsoon season began. The results suggest that there is considerable deposition within the khet fields themselves (Table 3). Of the 25 fields involved, 76% showed accumulation and 40% showed more than 5 mm of accumulation. Further, these enriched deposits enhance the soil-nutrient condition: laboratory analyses show that base cation levels are higher in the deposition than in the underlying field.

Table 3. Accumulation in irrigated fields measured using pegs.

Accumulation Category (mm)	No. of Fields	Percentage of Total
-5 to 0	6	24
0 to 5	9	36
5 to 15	5	20
15 to 25	3	12
over 25	2	8
Total	25	100

4.3. Overall: Degradation

There are extensive areas of land in the Middle Mountains on which farming has ceased because of an exacerbated state of soil degradation due to surface erosion. Most farmers put enormous energy into their land to maintain it in a healthy productive state. If instead, they abandoned their land and allowed it to degrade, how might this affect downstream sediment concentrations? Such neglected land would also be subject to uncontrolled grazing, preventing natural regeneration.

The Dhap Khola basin is within the Jhikhu Khola watershed and is of the same size as the Andheri basin, but its condition is severely degraded. This provides an opportunity to examine the effect of degradation on sediment regime. The sediment rating curves for these two basins are given in Figure 4.

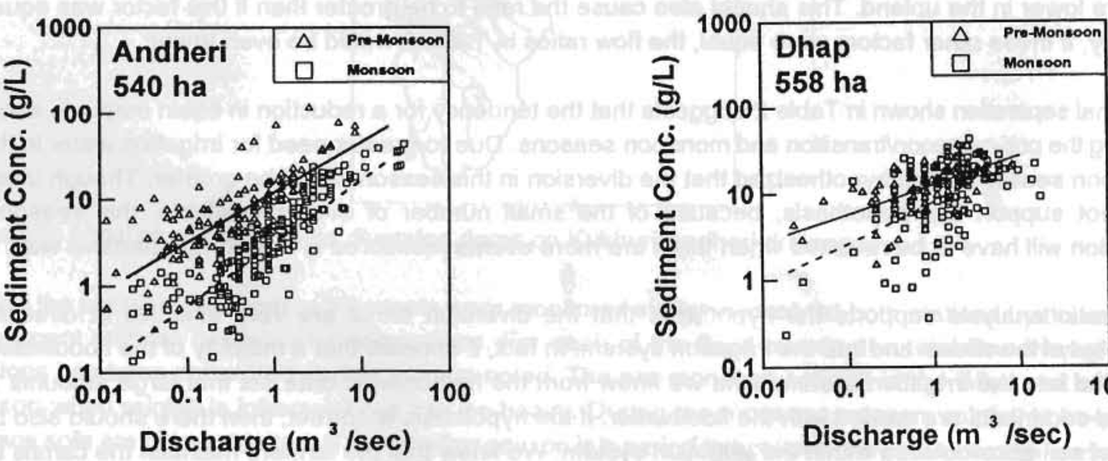

Figure 4. Seasonal sediment rating curves for Andheri and Dhap Khola basins.

The topography and land use of these two basins are given in Table 4, which shows that land use is largely the same in the two basins but that the topography in the Dhap basin is much gentler than that of the Andheri basin. Based on these factors alone, one would expect a greater sediment output from the Andheri basin.

Table 4. Topography and land-use comparison of Andheri and Dhap basins based on 1990 1:20,000 mapping.

	Andheri Khola	Dhap Khola
Total Area	540 ha	558 ha
Land Use		
Irrigated Agriculture	6.1	24.6
Rain-Fed Agriculture	39.3	36.7
Forest and Shrub	49.1	24.7
Degraded, Grazing and Other	5.5	14.0
Slope (degrees)		
0-19	26.1	78.9
20-34	35.9	18.1
35-49	33.2	3.0
≥50	4.8	0.0
Elevation (m)		
750-999	27.4	98.7
1000-1199	32.6	1.3
≥1200	40.0	0.0
Aspect		
Flat	2.6	20.4
N, NW, NW	73.3	9.1
E	12.4	9.7
S, SE, SW	8.7	47.0
W	3.0	13.8

Note: All numbers are % of total basin area.

Figure 5, however, reveals that the opposite is true: sediment output from the Dhap basin appears to be higher in both seasons than that from the Andheri basin. The reason for this lies in the level of degradation present in the two basins. The Dhap basin contains 14% degraded land (areas which are rilled and/or gullied and have less than 25% surface cover) while the Andheri basin has only 5.5% degraded land. At the highest flows, there is evidence that, regardless of the state of degradation and perhaps independently of season, the basin response merges. At these flow levels, the farmers have little ability to modify the basin sediment output. This is true in basins throughout the world, especially those where limited financing is available to build structures.

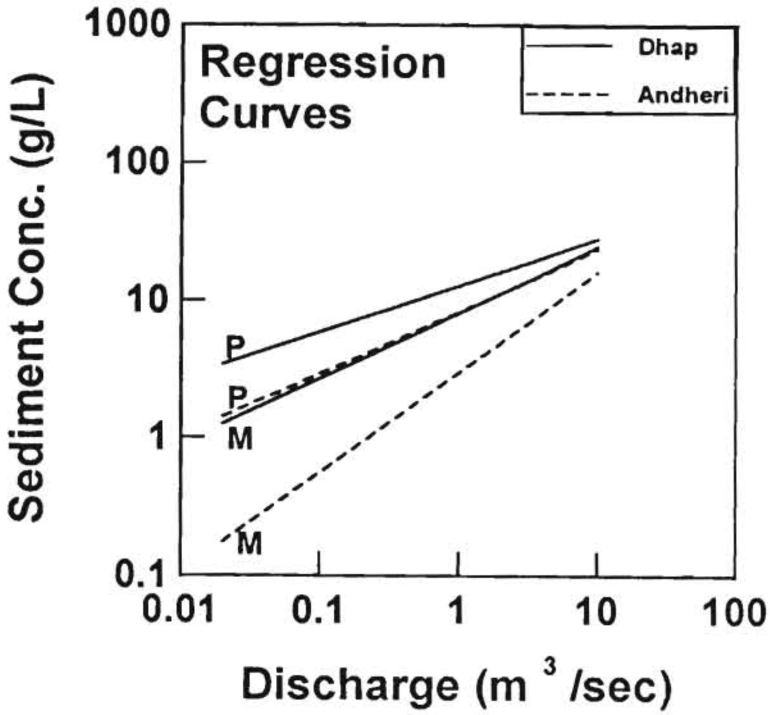

Figure 5. Seasonal sediment rating curves from Dhap and Andheri basins overlain for comparison.

It is important to also consider flood frequency to understand the overall significance of the seasonal suspended-sediment behaviour. The sediment loads during the pre-monsoon season, though generally quite high throughout the Middle Mountains, are short-lived because this season is brief and rainfall infrequent. The monsoon season, in contrast, lasts longer and experiences a greater number of flood events. The increased flood frequency in the monsoon season underlines the importance of the declining suspended sediment regime as the pre-monsoon season ends. In a basin with a degraded surface condition like the Dhap basin, the elevated pre-monsoon sediment levels are maintained during almost twice as many floods through the monsoon season. Local management which encourages the rapid return of a complete vegetative cover is therefore a key strategy to reducing net sediment output.

5. DISCUSSION

These three analyses all suggest that farming practices in the Middle Mountains are potentially quite effective in reducing downstream sediment concentrations. The farmers put enormous effort into maintaining the erosion-control and water-management structures of their agricultural system. It is, therefore, not surprising that in many cases they slow the movement of soil on its way downstream.

This is not to say, however, that everything that the farmer does is inherently positive for soil conservation. Farmers have limited time and money and must make choices. For instance, when they clean out the irrigation canals, soil is removed from the bottom of the canal, soil which has essentially been prevented from leaving with floodwaters. However, though some farmers use this material to raise or strengthen the canal sides or use it in adjacent irrigated fields, many others throw it directly into the stream, essentially facilitating its departure from the basin. The farmers would like to make use of this "free" soil (if it is not too sandy), but it is frequently not worth their time to do so.

6. CONCLUSIONS AND RECOMMENDATIONS

The principal conclusions of this paper are:

1. The development of a surface vegetative cover in the monsoon season serves as an effective approach for erosion control at the field level. A notable exception is in the pre-monsoon season when unfortunate timing of rainfall events can result in huge soil losses.

2. The indigenous irrigation system appears to capture a majority of storm run-off thereby capturing a large amount of entrained soil, preventing it from leaving the basin, and contributing to both soil fertility and accumulation in the irrigated fields.

3. Degraded land results in elevated stream sediment concentrations on a year-round basis.

4. Indigenous techniques appear to be effective at low and intermediate flows, but are far less discriminating at high flows, regardless of season and surface condition.

These conclusions suggest the following management recommendations:

1. In general, support rather than try to change current farming practices concerning erosion control and run-off management.

2. To reduce downstream sedimentation, rehabilitate degraded lands.

3. To enhance farm productivity, assist farmers in reducing soil loss during the pre-monsoon season and at high flow.

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Indigenous Agricultural Land and Soil Classifications

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1. OVERVIEW

The indigenous knowledge of rural farmers in the Himalayas regarding soil classification and management has been transferred verbally over many centuries. This knowledge can often be applied within socio-economic and spatial boundaries of a society or ethnic group. It has been preserved, communicated and used to overcome problems related to agricultural land management and production activities. A number of projects have been carried out to document indigenous management techniques (Gill, 1991; Tamang, 1991), but indigenous agricultural land and soil classification systems have not been documented in any depth, and few details are available for use in developing an integrated approach to soil management problems. Documentation of how farmers perceive and classify soil types can improve communication between technical personnel and farmers. Integration of knowledge developed by farmers over centuries, combined with modern science, can bring about positive changes in the implementation and design of development programs that could provide innovative and useful insights to modern research and extension activities. It is hoped that this documentation of indigenous knowledge on agricultural land and soil classification systems in the Jhikhu Khola Middle Mountain Watershed can serve as a prototype for regional and national centres interested in applying indigenous knowledge for improving management scenarios of small scale production systems by incorporating new scientific technology into the existing knowledge at the grass root level.

Given the intricate and sophisticated terraced agricultural systems which have been under agricultural use for centuries, the need to document the indigenous system has become more and more apparent. The socio-economic surveys provided a good forum for documentation of some of the indigenous classification systems. The information provided by the 200 farmers who participated in the soil fertility survey in the Bela-Bhimsenthan study area was used to document the local system. It also provided an opportunity to calibrate the system using laboratory analysis of the soils. The following is a first attempt at documenting the indigenous soil and land classification scheme in the Jhikhu Khola.

2. INDIGENOUS CLASSIFICATION OF SOIL AND AGRICULTURAL LAND

Farmers have a systematic criteria for distinguishing soils according to landform position, which are based on slope, elevation, and drainage. Top soil colour, texture and terrace type are the most dominant criteria for local land classification and soil fertility management. The farmers also use broad climatic regimes to differentiate climatic conditions. These are based on elevation and aspect, which relate to temperature, and which is in turn one of the most important factors influencing the choice of crops to be used in the rotation sequence, crop production and length of the growing season. The broad classes, with their native vegetation types, are illustrated in Table 1.

2.1. Khet and Bari Land Classification

Irrigated khet and rainfed bari terraces are classified according to landform position and slope. The classification system developed by the farmers forms the basis for land management and agronomic cultural practices. Tables 2 and 3 list the terminology used by the farmers for classifying the khet and bari lands in the

Jhikhu Khola watershed and provide information on terrace types and the management limitations of khet and bari lands. The farmers have adjusted the terrace system to the different sites by changing the size and height of the riser and the width of the terrace to obtain maximum stability, drainage and performance. These classes are well recognized by the local farmers and reflect their experience and adjustment to environmental conditions.

Table 1. Indigenous climatic regimes.

Climatic Regimes	Altitude (m)	Mean Annual Air Temp.(degree C)	Dominant Forests
Awal	< 1200	20-25	*Shorea robusta, Pinus roxburghii*
Kchard	1200-1600	15-20	*Pinus roxburghii*, mixed broad leaf forest
Lekh	1600-2200	1-10	Oak (Quercus) mixed forest

3. INDIGENOUS SOIL CLASSIFICATION SYSTEM

Farmers have a distinct and systematic criteria for soil classification. Soil are differentiated on the basis of colour, topsoil texture, depth and consistency. These factors, in combination with slope, provide information on infiltration, drainage, soil moisture retention capacity, organic matter content and stability.

3.1. Soil Colour

Soil colour can be used as a key distinguishing criteria by farmers. Some of the colour differences relate to the age of the soil, the origin or parent material, and the carbon content. The major topsoil colours used by the farmers to differentiate soils are shown in Table 4 alongside the scientific classification.

The colour categories noted by the farmers are a partial indication of organic matter content in the soil. At higher carbon content the soil colours are usually darker, the moisture content and cation-holding capacity are higher, and the structural stability of soil aggregates is greater. In addition, the very old soils in Nepal are deeply weathered and contain significant portions of Fe and Al. The former gives rise to the red soils which have a significant portions of kaolinite and distinct physical properties. Because of the long leaching processes, the red soils are generally low in phosphorus.

3.2. Texture

Among the most important physical properties of soils considered by farmers is soil texture. Soil texture involves the size of individual particles and arrangement of soil particles into groups or aggregates. These properties determine nutrient-supplying ability of soil solids and the supply of water and air necessary for plant root development activities. The size of particles in mineral soil (texture) is not readily subject to change, and remains constant. The farmers are aware of the fact that the texture of a given soil can be changed only by mixing it with another soil of different textural class. Farmers incorporate large quantities of sand and silt through irrigation water to improve the physical properties of red clay soils for potato cultivation. The textural classes differentiated by farmers in the field are listed in Table 5 below and their equivalent USDA soil texture classes are also provided. The farmer's textural classifications are used primarily for crop selection and soil management. Heavy textured (chimte) soils require higher labour inputs than light textured (domat) soils for ploughing and other agronomic activities. Moisture content in relation to texture is also used as an index for workability of the soil.

Table 2. Local khet land classification.

Names	Landform Position	Slope (degree)	Terrace type	Management limitations
Bagar khet	Valley bottom, floodplain	1-3°	Pata < 1m terrace risers	Prone to frequent flooding
Khola khet	Stream banks, stream terraces	5-10°	Ghara <1m terrace risers	Stream bank erosion
Sim khet	Head hollows, foot slopes of colluvial slopes Spring or seepage areas	3-10°	Ghara/Pata < 1m terrace risers	Poor drainage, high water table during monsoon
Ghol khet	Valley floor depressional	1-3°	Pata/Ghara < 1m terrace risers	Poor drainage, high water table during monsoon
Khadi Daldale khet	Valley floor swamp	1-3°	Pata/Ghara < 1m terrace risers	Poor drainage, high water table
Gairi khet	Valley floor, intermediate terraces or foot slopes	1-3°	Pata/Ghara <1m terrace risers	Imperfectly drained, high water table during monsoon
Tari khet	Old river terrace/fans (TARS)	1-5°	Pata/Ghara <1m terrace risers	Irrigation water, low fertility status, prone to surface wash and gullying
Pakho/ Tadi khet	Ridge Tops/Fan	1-5°	Pata/Ghara <1m terrace risers	Irrigation water, low fertility status, prone to surface wash and gullying
Ghara khet	Moderately/gently sloping hillside (colluvial slopes)	10-15°	Ghara, <1m terrace risers	Low terrace maintenance cost and surface erosion problems
Kanle khet	Steeply sloping hillside	15-25°	Kanle, >1m terrace risers	High terrace risers, High terrace maintenance, severe surface erosion
Phagata khet	Steeply sloping hillside	25-30°	Kanle, >1m terrace risers short narrow terraces	High terrace risers, bullocks cannot be used for ploughing, high terrace maintenance cost, severe surface erosion
Surke khet	Very steep Hillside	>30	Kanle >1m terrace risers, long narrow terraces	High terrace risers, bullocks cannot be used for ploughing, high terrace maintenance cost, severe surface erosion

Table 3. Local bari land classification.

Name	Landform Position	Slope (degree)	Terrace Type	Management Limitations
Tar Pata Bari	River terraces (TARS) Fans, Ridge tops	1-5	Pata <1m terrace risers, wide sloping terraces	Low fertility status, surface wash and gullying, moisture deficiency
Pata Bari	Moderately sloping hillside	10-20	Pata, >1m terrace risers, sloping terraces	Severe surface erosion and mass wasting with slope disturbance
Ghar Bari	Gently sloping hillside, FANS, TARS Accordant Ridge Tops	5-10	Pata, <1m terrace risers, wide sloping terraces	Surface wash and gullying
Kanle Bari	Moderately to steeply sloping hillside	20-25	Kanle, >1.5m terrace risers, sloping or nearly level terraces	High surface erosion and mass wasting with slope disturbance, high soil fertility requirement
Surke Bari	Strongly sloping hillside	25-30	Kanel, >1.5m terrace risers, sloping terraces, long narrow terraces	High surface erosion and mass wasting with slope disturbance. Narrow terraces, bullocks can't be used, low fertility status. Marginal areas
Khoriya Bari	Strongly sloping hillside	25-30	Kanel, >1.5m terrace risers, sloping terraces, long narrow terraces	High surface erosion and mass wasting with slope disturbance. Narrow terraces, bullocks can't be used, low fertility status. Marginal areas
Khar Bari	Moderately to strongly sloping hillside	20-30	Kanel, >1.5m terrace risers, sloping terraces, long narrow terraces	Marginal areas for thatch grass producing
Karalo Bari	Gently sloping hillside, FAN	5-10	Pata, >1m terrace risers, wide sloping terraces	Surface wash, gullying low fertility status
Gagrine Bari	Gently to moderately sloping colluvial slope	5-20	Pata >1m terrace risers, sloping or level terraces	Severe surface erosion and mass wasting with slope disturbance. Coarse gravelly terraced, high leaching & infiltration capacities

3.3. Soil Depth

Soil depth has been one of the most important criteria used by farmers in selecting land for farming. Deep soils (gahiro) generally have higher moisture-retention capacities than shallow ones. Shallow soils restrict the penetration of plant roots and affect the soil's moisture-retention capacity. Deep soils (>1m depth) do not restrict the distribution of roots in the soil profile and plants are able to absorb a considerable proportion of their moisture requirement from the soil layers. Farmers prefer soils with a good rooting depth of more than one metre, and are aware of the factors governing the uptake of nutrients and use of soil moisture by plants.

Table 4. Local soil colour classification system.

Local Colour Classification	Munsell Soil Colour Chart
Kalo (black)	10 YR 3/1-4/1 dark greyish brown-very dark greyish brown
Rato (red)	2.5 YR 4/6-5/6 - red
Huluka Rato mato (light red)	5 YR 5/6-6/6 Yellowish red- reddish yellow
Khairo mato (brown)	7.5 YR 4/2-5/2 Brown - dark brown
Physro (grey)	10 YR 5/1-5/2 grey - greyish brown
Kharani mato (light grey)	7.5 YR 7/ 10 YR 7/7 - light grey
Jogi mato (yellow)	10 YR 6/6 - 7/6 - 8/8 brownish yellow - yellow

Table 5. Indigenous terms for texture classification.

Local Name	USDA Texture Class
Pango	Silty loam/silt
Balaute	Sand
Domat	Loam
Balaute Domat	Sandy loam
Balaute Chimte	Sandy clay loam
Domat Chimte	Clay loam
Chimte	Clay
Gagren	Gravelly
Masino	Fine
Kharso	Coarse

3.4. Soil Consistency

Soil consistency has important significance for soil tillage and land management systems. Farmers do not have many distinguishing criteria, but know that wet red clay soils are sticky and slippery while sandy soils are non-sticky and non-slippery. "Rato mato chiplo bato" a term used to note that red soils are slippery has significance to farmers in that these soils have poor infiltration capacities. Major local terms used for classifying consistency are provided in Table 6. The terms used for classifying soil consistency may be simple, but are meaningful and easily understood by farmers for management practices.

Table 6. Soil consistency classes and scientific equivalents.

Local	USDA	Soil Texture
Chipplo (chap-chape)	Sticky, plastic	Clay (fine)
Khasro	Loose, non-sticky, non-plastic	Sands (coarse)
Lasailo	Slightly sticky, slightly plastic	Loams (medium)

4. RELATIONSHIPS BETWEEN INDIGENOUS CLASSIFICATION AND SOIL NUTRIENTS

A set of 200 soil samples were available to compare the indigenous classification with the scientifically measured results. First, the differences in the soil colour classes recognized by the farmers were compared, and secondly the land classification and terrace systems favoured by the farmers were compared against the inherited soil chemical conditions.

4.1. Comparison Between Indigenous Soil Colour Classes and Soil Chemical Conditions

All soil samples were sorted into three broad colour classes well recognized by the local farmers. The chemical properties of the soils falling into the three classes were then analyzed and compared. As was shown in a previous paper by Shah et al. (1995), elevation, parent material and land use all affect the soil composition. A stratification based on elevation (< 1200m, > 1200m) and agricultural land use (irrigated vs. rainfed) was made before separating soil colour. The results, shown in Table 7, indicate that significant differences could be discerned in a number of cases. The dark greyish soils usually have the best pH in all high elevation sites while the light grey-yellowish class had the lowest pH, in all sites regardless of use. In contrast available phosphorus values were consistently lower in all red soils. All light grey to yellow soils had the lowest cation exchange capacity and exchangeable Ca content. This reveals that the farmers are well aware of the unique differences between soil colour and its associated properties. The chemical variables displayed in Table 7 are to a great extent related to inherent differences in soil parent materials but the impact of management is also evident.

4.2. Comparison Between Indigenous Agricultural Land Classes and Soil Chemical Conditions

The 200 soil samples originating from the Bela-Bhimsenthan test area were sorted according to the twelve indigenous khet and bari classes and the results were compared statistically for a number of nutrients. The indigenous land categories listed in Tables 3 and 4 were grouped into three categories: very desirable sites, moderate sites, and poor sites for crop production. We then sorted all soil samples according to these three classes and determined the relationships or differences in selective soil nutrient conditions (Table 8). The best differentiation was found in terms of cation exchange capacity and exchangeable Mg and, to a lesser extent, in exchangeable K. Most of these are at least in part related to differences in parent materials.

Although there is some overlap in the range of conditions the separation between classes is sufficient to suggest that there is a reasonable relationship between the indigenous classification and the associated chemical conditions related to parent material. Since organic carbon is low in all soils in the watershed, the cation exchange capacity is primarily inherited from the parent material. The rate of weathering and the differences expressed in the indigenous classification is at least partially reflected in the scientific data. Exchangeable cations are usually influenced by management particularly by the application of chemical fertilizers. Since few farmers apply lime or use potassium fertilizer, K and P also reflect inherited conditions. Variables that are more easily influenced by management (N, P, Ca, pH) did not show a significant relationship.

Table 7. Comparison between indigenous soil colour classification and soil chemical conditions.

Soil Colour	Munsell Soil Colour Class	Land Use	Elevation (m)	pH	Avail. P (mg/kg)	Cation Exch. Capacity (meq/100 g)	Exch. Ca (cmol/kg)
Dark greyish	10 YR 3	khet	> 1200	5.8	19.6	14.8	10.1
Red - reddish yellow	2.5 YR 5-6 5 YR 5-6	khet	> 1200	5.4	5.6	12.3	5.1
Light grey - yellow	7.5 YR 4-7 10 YR 5-7	khet	> 1200	5.0	28.2	9.4	4.4
Dark greyish	10 YR 3	khet	< 1200	5.1	84.3	6.2	2.5
Red - reddish yellow	2.5 YR 5-6 5 YR 5-6	khet	< 1200	5.6	10.8	13.8	5.8
Light grey - yellow	7.5 YR 4-7 10 YR 5-7	khet	< 1200	4.8	34.4	9.1	3.9
Dark greyish	10 YR 3	bari	> 1200	5.2	36.6	10.9	5.6
Red - reddish yellow	2.5 YR 5-6 5 YR 5-6	bari	> 1200	4.9	13.3	14.3	4.1
Light grey - yellow	2.5 YR 5-6 5 YR 5-6	bari	> 1200	4.7	37.1	7.9	3.2
Dark greyish	10 YR 3	bari	< 1200	4.7	14.1	12.1	3.5
Red - reddish yellow	2.5 YR 5-6 5 YR 5-6	bari	< 1200	4.8	7.2	12.4	3.1
Light grey - yellow	7.5 YR 4-7 10 YR 5-7	bari	< 1200	4.6	18.1	8.6	2.8

Table 8. Possible relationships between indigenous soil classification and soil chemical conditions.

Land Use	Indigenous Names	Quality	CEC (cmol/kg)	Exch. Mg (cmol/kg)	Exch. K (cmol/kg)
khet	Ghol, Gairi, Ghara	Most desirable	8.6-14	1.4-2.2	0.15-0.35
khet	Kanle, Phagata, Surke	Moderate	10-12	0.95-1.49	0.17-0.25
khet	Bagar, Khola, Sim, Khadi Daldale, Tari, Pakho/Pata Tadi	Least desirable	9-11	0.7-1.3	0.1-0.21
bari	Pata, Ghar	Most desirable	10-12.1	1.5-1.8	0.3-0.4
bari	Tar Pata, Surke	Moderate	9-12.7	1.2-1.5	0.3-0.5
bari	Kanle, Khoriya, Khar, Karalo, Gagrine	Least desirable	6-10.1	1.1-1.2	0.11-0.3

The calibration of the indigenous physical properties of the soils has not yet been completed but is expected to show similar trends suggesting that the experience in soil management gained by the farmer has validity and can be very useful in extension work, particularly when dealing with the introduction of new crops or alternative management methods.

5. CONCLUSIONS

This paper documented the prevailing indigenous soil and classification system used in the watershed. Farmers have vast long term experience and recognize soil and site conditions that relate to crop performance and workability. These conditions are often difficult to measure scientifically. The key features in the indigenous land classification system in the watershed are landform type, topographic setting and drainage regime. The type of terrace constructed is well adjusted to the conditions and is cognisant of slope stability, drainage regime, seepage conditions and texture.

When the indigenous land classification scheme was grouped into three types, ranging from the most to the least desirable, a good relationship was found between the quality of the land and the extent of the cation exchange capacity and selected exchangeable cations, particularly those that are not readily affected by fertilizer and manure management.

The soil classification system used by the farmers is based on soil colour, texture, consistency and depth. Most of the indigenous classes can readily be converted into the commonly used scientific classification schemes. These conversion tables facilitate communication between the subsistence farmers and the scientifically trained extension personnel. More documentation and calibration is needed, particularly in the area of physical properties and soil performance in terms of biomass production. Additional research is needed to better document the indigenous knowledge on soil workability, soil performance and soil quality, all of which are notoriously difficult to measure scientifically. These are the most fruitful research directions since the potential benefits are great, particularly when new management techniques and new crops are being introduced into the indigenous farming system.

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Indigenous Water Management Systems in the Andheri Khola Sub-Watershed

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1. INTRODUCTION

With irrigation, farmers can increase their biomass production, minimize the risk of adverse climatic conditions and benefit from nutrient inputs through the irrigation water and associated sediments. Given these benefits and the increase in population growth, the demand for irrigation water has increased rapidly and, as revealed by the socio-economic survey, water shortages are common and increasing in frequency. Given the current infrastructure and population pressure in the Middle Mountains, the only option for feeding the local population is through crop intensification and a greater reliance on irrigation.

The prevailing monsoonal climate creates a distinct annual hydrological regime which can be characterized by an excess of water during the monsoon season, and water shortages during the dry season. The farmers have developed indigenous water management systems to cope with these two extremes. In anticipation of future conflict, it is timely to document the dominant indigenous irrigation systems in the watershed. The Andheri Khola sub-catchment in the Jhikhu Khola watershed was chosen as a case study. An indigenous streamwater diversion system in Baluwa (Devbhumi), and a spring fed system in Bela are examined in this paper.

The main objectives of this paper are to describe the indigenous water management systems in the sub-watershed, determine the amount of water available, document the organization and management of the systems, assess the current problems and future demands on water resources, and identify areas were improvements could be made.

2. BIOPHYSICAL SETTING

The Andheri Khola sub-watershed is situated between 800 m and 1700 m in elevation and covers 1135 ha. It services a population of 6120 individuals, who are divided into three distinct ethnic groups: Tamangs dominate the top of the watershed, Brahmins the middle portion, and Danuwar, the indigenous tribe, are most prevalent in the valley bottom. A subtropical to sub-humid moisture regime is dominant in the low altitudinal zones (<900 m in elevation) and this supports two rice crops followed by a combinations of cereal or cash crops. Sal (*Shoria robusta*) is the dominant tree species in this belt. The second zone (900 m- 1700 m) is characterized by warm temperate conditions with a humid moist climatic regime. Maize and beans followed by wheat and mustard or other cereals are typical crops in this belt. Salla (*Pinus* spp.), katus, banjh (*Castanopsis indica*) and chilaune (*Schima wallichii*) are major trees species (Jackson, 1994). Gurans (*Rhododendron arboreum*) are distinct near the top.

To provide a comprehensive overview of irrigation, it is essential to first describe the rainfall distribution, the hydrological regime and the land use pattern in the study area.

2.1. Climatic and Meteorological Characteristics

Adequate moisture content, tolerable temperatures and modest evaporation rates are important factors that affect plant survival and growth. The watershed receives sufficient water during the summer monsoon season, resulting in a lush green plant cover. In contrast, the winter period is characterized by an absence of rainfall for at least 2 to 3 months during which vegetation cover becomes minimal and plant growth is restricted due to lack of moisture.

2.1.1. RAINFALL PATTERN

Rainfall information collected between 1990 to 1994 from two automated and two standard rain gauges is provided in Table 1, and shows that there is considerable spatial variability throughout the season.

Table 1. Total monthly rainfall distribution at two stations in the Andheri Khola sub-watershed.

	Total monthly precipitation at Bela (elevation 1279 m)					Total monthly precipitation at Baluwa (elevation 830 m)		
Month	1990	1991	1992	1993	1994	1992	1993	1994
Jan	0	29.6	7.4	14.5	51.2	nd	17.0	41.2
Feb	42.7	10.3	14.5	11.1	23.6	nd	11.6	18.4
Mar	36.1	52.9	0	30.1	11.0	nd	40.2	7.8
Apr	70.4	30.4	13.2	58.7	15.3	nd	80.9	9.2
May	165.4	108.8	78.8	150.0	116.9	0.0	83.3	77.6
June	198.7	166.7	143.7	136.4	111.5	180.8	154.6	314.0
July	317.7	275.4	318.5	222.1	267.8	480.0	203.7	248.7
Aug	284.9	185.4	172.9	279.0	305.1	213.0	338.8	310.0
Sept	142.2	182.9	128.7	100.0	168.6	132.0	111.1	215.4
Oct	26.7	0.8	35.2	13.5	0	32.6	9.3	0
Nov	0	0	15.8	0	10.4	12.3	0	12.3
Dec	0	13.2	8.4	0	0	3.9	0	0
Total	1284.8	1056.9	937.1	1015.4	1081.5	nd	1050.5	1254.6

Nb. "nd" indicates missing data.

If we analyze the upland station at Bela it is evident that 75 % of the annual total rainfall is concentrated over a three month period from mid June to mid-September (Table 2). The post-monsoon rains during the October - January period produce less than 7%, and storms during the pre-monsoon season (February - May) make up about 20 % of the annual precipitation.

Table 2. Precipitation distribution during key seasons at Bela station (1400 m elevation).

Year		1990	1991	1992	1993	1994
Annual total (mm)		1219	1036	904	996	1049
% of distribution	Pre monsoon (Feb - May)	22.9	19.1	11.5	24.6	15.6
	Monsoon (June - Sept)	74.9	76.7	81.2	72.6	78.7
	Post monsoon (Oct - Jan)	2.1	4.2	7.3	2.8	5.7

The rainfall intensity and duration relationship is of critical concern for water management since it determines the degree of problems the farmers will encounter in both maintaining terraces and in supplying moisture to each site without creating instabilities and degradation. A summary of the storm patterns and its effect on stream flow was provided by Carver and Nakarmi (1995).

2.1.2. TEMPERATURE VARIATION

An example of the maximum/minimum air temperature variations over 1994 is provided in Figure 1 (below). Over the 1990 - 1994 period, temperatures never dropped below 2.5 ° C and reached levels of up to 35 ° C. The diurnal temperature variations are highest during the dry season with average differences between 12-14 degrees. During the winter months, lower temperatures of 2.5-10 ° C restrict plant growth. At present, no temperatures below freezing have been recorded in the sub-watershed.

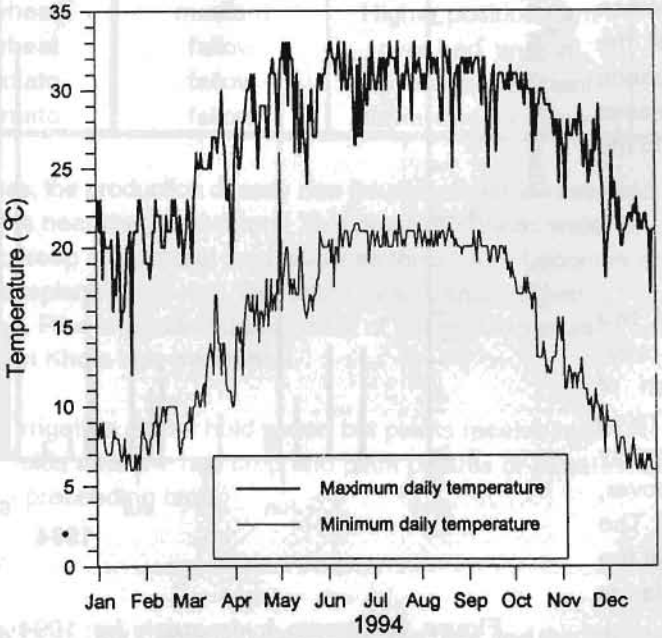

Figure 1. Minimum and maximum daily temperature variations at Bela station for 1994.

The dry season maximum and minimum temperatures have a significant effect on evaporation. Solar radiation is high when ground cover is at a minimum, and there are long breaks between rainfall events. Surface soils and water in ponds dry out quickly. Evapotranspiration, the amount of water transpired in unit time by short green ground-cover crops (Brooks, 1991), combined with evaporation from bodies of open water, represents the amount of water loss from the soil-plant system. It is highly dependent on the available solar energy. The difference between evaporation during the dry season and during the monsoon season is shown in Figure 2. The evaporation data from the Rampur Agro-meteorological station was used since it has similar environmental conditions to Panchkhal, the main agricultural centre in the Jhikhu Khola watershed. From Figure 2 it is evident that evaporation starts to increase in March and attains a peak in the May - June period when monthly rates of over 150 mm were measured. When the vegetation begins to cover the ground (as the monsoon season proceeds), evaporation decreases until it reaches minimum values in the November - February period.

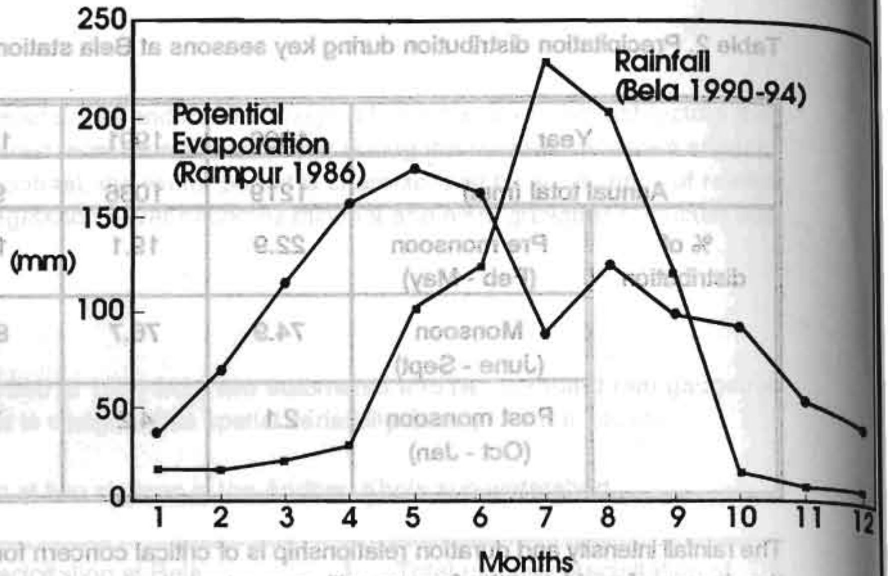

Figure 2. Distribution of moisture deficit in the sub-watershed.

2.2. Hydrological Regime

Stream flow was monitored at two stations, in the headwater sub-catchment and at the bottom of Andheri Khola. The discharge rates are highly variable and greatly dependant on rainfall, surface cover, infiltration rates and topography. The annual hydrograph at station 2 at the bottom of the Andheri Khola is provided in Figure 3.

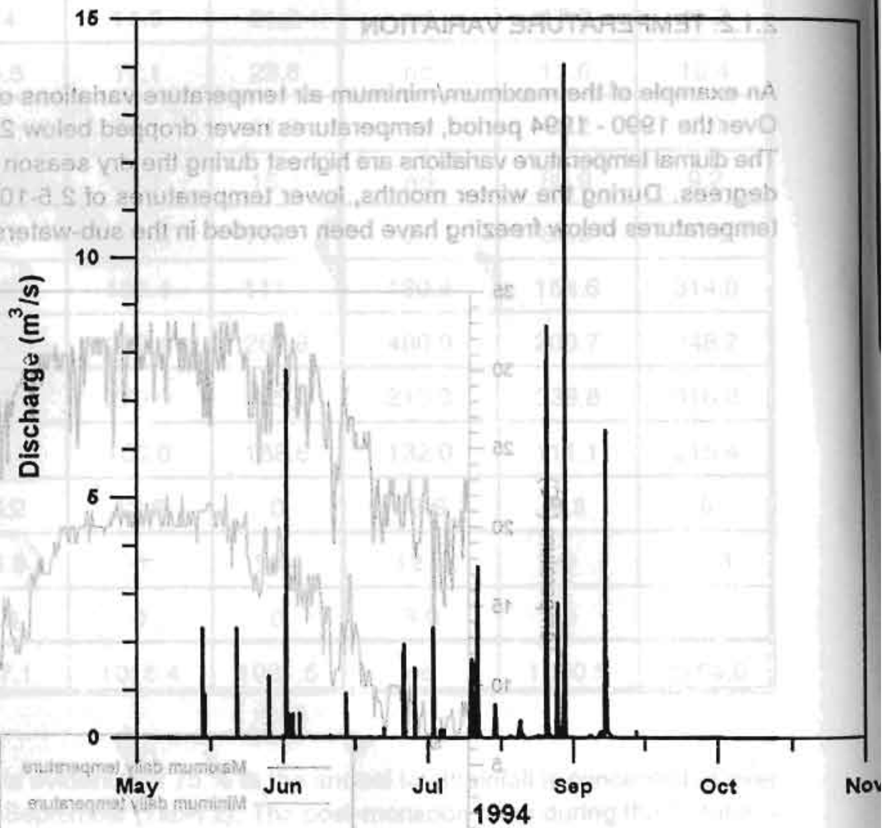

Figure 3. Stream hydrograph for 1994 at station No. 2 in Andheri Khola.

It is evident from this figure that base flow during the dry period is often insufficient for maintaining extensive irrigation. In contrast, excess water must be removed from the land during the monsoon season to minimize landslides and terrace failures. Water available in the stream is the primary source of irrigation water for agriculture.

2.3. Land Utilization

Rice is the main staple food in the watershed and the cultivation and irrigation practices have evolved over many centuries. The key changes in rice cultivation occurred about 10 years ago, when new, short-season rice varieties were introduced. These varieties replaced indigenous varieties such as marasi, taulia, and thapachiniya and resulted in a significant increase in the use of chemical fertilizers and irrigation water. The amount of irrigation water used is dependant on water availability, soil type, site conditions, and cropping system practice. The most commonly used cropping system sequences are provided in Table 3.

Table 3. Cropping sequences under different irrigation systems.

Cropping sequences under heavy irrigation			Position of the field	Water available	Comment
Summer	Winter	Spring			
rice	wheat	rice	Flood plain, lower level areas	All year round	High labour input
rice	wheat	fallow			
rice	potato	maize			
rice	tomato	fallow			
Cropping sequences under light irrigation			**Position of the field**	**Water available**	**Comment**
Summer	Winter	Spring			
maize	wheat	mustard	Higher position form river bed, ancient terrace and ancient alluvial fan, foot slope	Irrigation water is restricted to winter	Moderate labour input
maize	wheat	fallow			
maize	potato	fallow			
maize	tomato	fallow			

Due to water shortages, the production of early rice (hiunde dhan) is restricted during the pre-monsoon period to a few selective plots near the headwaters. This practice creates water shortages for downstream farmers who are compelled to keep agricultural land fallow as the stream becomes dry. As the monsoon rains arrive, all paddy fields are transplanted with rice. The entire family, shared (perma) and hired labour participate in the transplanting process. Rice is flooded during most of the growing season and a total of 58 ha are planted in this way in the Andheri Khola sub-watershed.

The fields under light irrigation do not hold water, but plants receive moisture from monsoon rains. Energetic farmers plough the fields after the rice crop and plant potatos or tomatos, taking advantage of residual soil moisture left from the preceeding crop.

3. METHODOLOGY

The springs and irrigation network were first identified in the field and the information was transferred to 1:5000 scale aerial photos. All wells and irrigation channels, as well as the irrigated fields and check dams, were incorporated into the GIS database. Water flow was measured near the springs and in different locations along the irrigation channels using a measuring cylinder and a Price AA current meter. A number of informal surveys were also carried out to identify the farmers' concerns and to learn about the current water distribution system, for both drinking and irrigation purposes.

4. WATER MANAGEMENT SCHEMES IN THE ANDHERI KHOLA SUB-WATERSHED

About 75% of all irrigation systems and drinking water systems in Nepal are managed by farmers groups (Shrestha, 1995; Pradhan, 1989b). In the Andheri Khola, all irrigation systems are organized and operated by farmers who are responsible for measuring the supplies, water allocation, frequency of use, construction and routine maintenance of the irrigation systems. Jurisdictional arrangements are of particular importance since the dependence on water is increasing due to agricultural intensification and population growth. Rain is the main source of water and most leaves the area as run-off while only a small portion infiltrates through voids into the soil matrix and surficial materials to provide groundwater supplies. The water availability is very uneven in the sub-watershed with the largest communities receiving the lowest quantity on a per household basis. Thirty-five natural springs were identified in the sub-watershed and these serve as drinking water supplies to the residents and provide the only source of stream flow during the dry season.

4.1. Springs and Drinking Water Systems

The flow of the springs was measured to determine the size of the available drinking water supply in the sub-watershed. Five wells are located outside the sub-basin and a small portion of the spring water leaves the watershed for consumption by external communities. As shown in Figure 4, the total daily supply was calculated to be 231 m^3/day, of which 89% comes from within the basin and 4% leaves the sub-basin. Most of the wells are located between 1200 and 1600 m elevation. An Intricate network has been developed to supply the widely dispersed residents with drinking water supply lines.

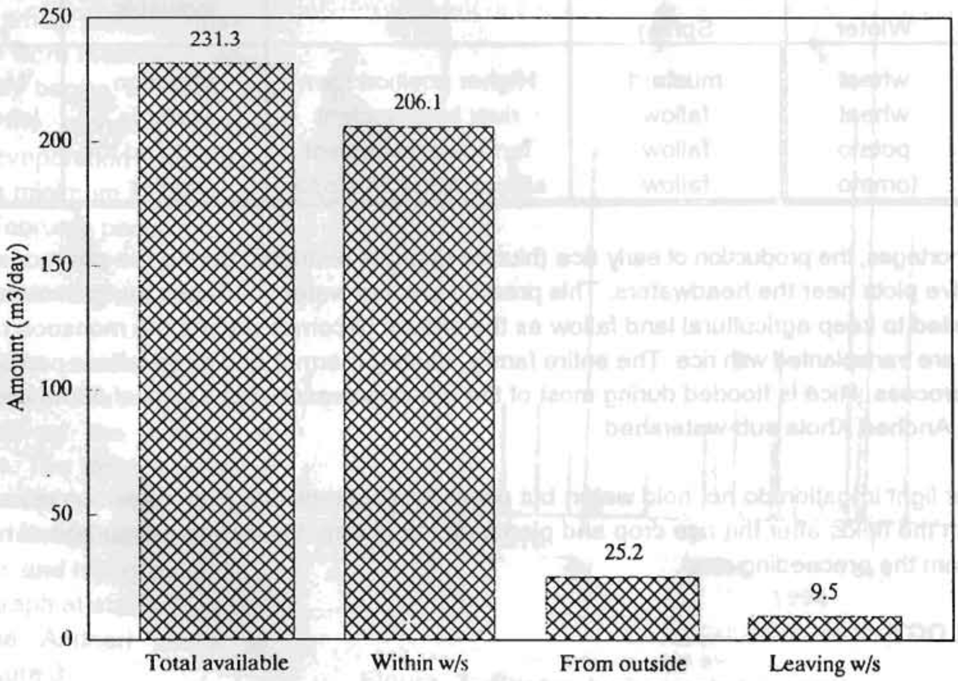

Figure 4. Available drinking water in the Andheri Khola sub-watershed.

Water from springs originating in common or religious lands is available to all. Long time users have greater user rights than a newcomer. Springs located on private land are managed by the land owner, but the spring can be sold in isolation of the land.

Table 4 provides an overview of the amounts of drinking water available to each household in the sub-basin. The community of Baluwa receives the least amount of water at 0.17 m^3 per household per day, while the people near the Kanjale Khet are the most fortunate receiving 3.35 m^3 per day. The supply around Dandaghar was calculated to be 0.4 m^3 per day and Bela has a rate of 0.59 m^3 per day/household.

Table 4. Drinking water distribution in the Andheri Khola Sub-watershed.

Serial #	Number of sources	Spring I.D.	Flow measured (L/min)	Number of households	Community benefitting
1	1	dw15	9.3	4	Kainjale Khet
2	1	dw25	6.5	4	Danda gaun outside w/s
3	3	dw22,23,24	18.6	20	Danda gaun
4	2	dw31,32	8.1	11	Chiuribot
5	1	dw29	4.2	6	Simpatle
6	6	dw2,4,10,12,17a,26	17.2	25	Free flow
7	1	dw18	1.3	2	Chundalya Patal
8	1	dw19	6.9	11	Patle gaun mathillo
9	1	dw28	3.6	6	Dharapari
10	1	dw21	10	20	Phulbari
11	2	dw3,6	16.3	40	Bela & Thumka
12	1	dw27	0.6	2	Jurelithumka
13	1	dw30	3.6	13	Talio Patale gaun
14	3	dw7,8,9	7.7	28	Dandaghar
15	1	dw17b	2.3	9	Dahal gaun
16	1	dw5	3.4	14	Chhaap
17	1	dw11	1.8	8	Dhami gaun
18	1	dw20	2.2	11	Lakaine danda
19	1	dw16	1	5	Patle gaun
20	5	dw1,13,14,33,34	36	307	Baluwa
Total	35		160.6	546	

Baluwa and Bela are two well-organized communities that consume large amounts of water. In Baluwa, spring water is first collected in intermediate chambers (average dimensions 0.6 x 0.6 x 0.5 m) established near the source. Black polythene pipe is used to deliver the water. The water distribution time in Baluwa varies from 3 to 4 hours per day, depending on the season and is directly related to water availability. Twice a day over a four hour period, all 25 taps receive about 35 m^3 of water which is collected in a storage tank with dimensions of 4 x 4 x 2.1 m. The water comes from 5 springs with a combined discharge of 36 L/min. Two springs with combined discharge of 16.3 L/min are used are used for the village of Bela. The water is first collected in an intermediate chamber with dimensions of 0.5 x 0.5 x 0.4 m and is then diverted to a main storage tank with dimensions of 3.7 x 2.4 x 1.4 m. There are two taps drawing water directly from the tank for the residents of Bela and a third tap for the residents of Chhaap down slope.

4.2. Irrigation Distribution Systems

Untapped spring, waste water, surface and subsurface flow areas are the main sources of irrigation water. Farmers tap the stream water from every possible site through a network of 72 diversion dams for irrigating 58 ha of paddy land. These irrigated areas act as a temporary water reservoir, holding approximately 29,000 m^3 of water (58 x 100 x 100 x .05 m, assuming only 5 cm of water depth). There is a general understanding that a new dam can only be established if it is at least 100 m upstream or downstream from an existing dam. The 72 dams were established at variable distances along the river, depending on ownership, channel conditions and topography. Given the current density, construction of new dams is difficult, but the farmers can and do readily modify existing dams, weirs and channels.

As shown in Figure 5, about 65% of the 72 irrigation systems are used on a year round basis, while the remainder are only used during the dry season. The channel cross sections of the indigenous system vary from 0.1 m to 0.8 m and the average size of a dam is 0.85 m in height and 5.8 m in length. Stream response to storms can have serious consequences in a high gradient river like Andheri. Peak flows can destroy all the dams (e.g. July/ August 1992, August 1993), and the resulting damage can require massive reconstruction efforts (Pradhan, 1989). Farmers may be compelled to shift the dam in response to heavy modification of stream channel by big flood event.

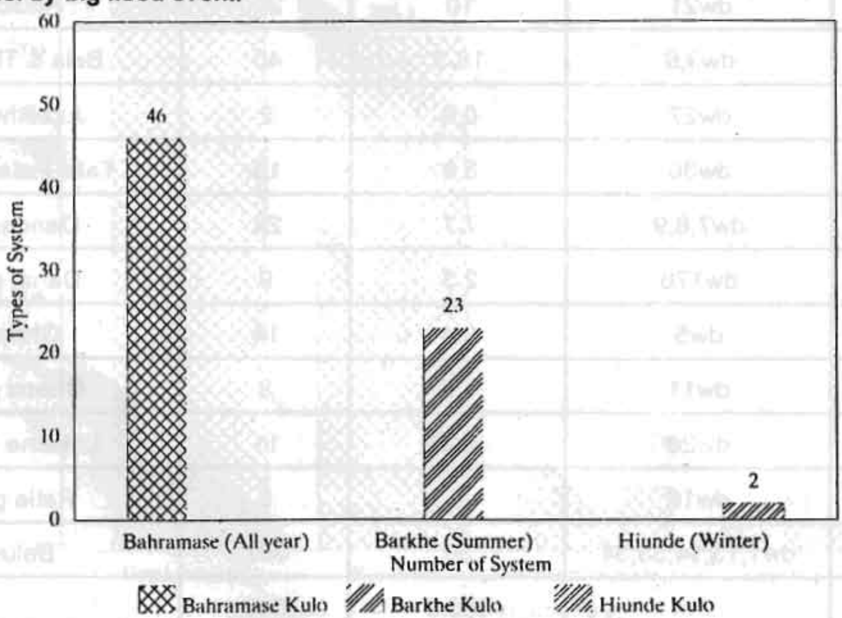

Figure 5. Distribution of springs, drinking water and irrigation systems in the Andheri Khola sub-watershed.

Local materials are used in the construction of the dams, with emphasis being placed on simple construction that can be repaired rapidly. As shown in Figure 6, diversion dams consist of simple stacking of rounded and sub-rounded stones which are interlocked by twigs. Gravels, sands and grass are used as packing material to minimize seepage. The weir sticks are usually 8 - 10" higher than the canal height to ensure that adequate amount of water can be provided to each irrigation canal. During flooding periods water can easily overflow the dam and canal.

Figure 6. Typical diversion dam used for irrigation in the Andheri Khola sub-watershed.

Only three dams were built with a gabion system (galvanized wire mesh filled with rocks). These are stronger and survived both the 1992 and 1993 flood during which most of the other dams were destroyed. Depending on the time of the flood, the dams are reconstructed very rapidly. The oldest irrigation system is more than a century old, and most of the other dams have been in operation for the past 50 to 65 years.

Depending on the season, water availability and the crop to be grown, farmers select different water application methods. Several methods of irrigation are used in the watershed and they include basin irrigation, furrow and corrugated irrigation, and wild flooding. In basin irrigation, small earth banks (levees, bonds or ridges) of 25-50 cm in height are constructed around each field and this forms a basin with an inlet and outlet to control the water (Stern, 1987). The basin is filled with water to about 15 cm of the top of bond. Regular input of water is needed to maintain puddling, and the excess is drained off. Rice is flooded because it provides adequate moisture to the plant at all times, the temperature can be maintained and the crop is partially protected from rodents. In furrow irrigation, a series of 25 to 40 cm size bonds are created. Cash crops such as potato, tomato, radish, cauliflower, and cabbage are planted on the ridge and water is applied to the furrows twice a day. The corrugation method consists of a system of closed channels about 5 - 10 cm deep laid down across the slope without raised bond ensuring equal distribution of water in a plot. It is well suited to soils ranging from medium textured silt loam to clay loams, which permit easy flow. This method can handle steeper slope than the furrow method. Wild flooding is carried out on steep slopes for low value crops where a uniform distribution of water is not a primary concern. This system is very common in the rain fed terraces (bari land) under wheat, maize and millet production.

4.3. Water Loss

One of the key problems with irrigation is the significant losses of irrigation water along delivery channels through seepage and evaporation. Farmers claim that half of the irrigation water is lost through seepage. The losses are greatest when the channel must cross areas of fractured bedrock, sections of sand and/ or gravely soil materials. An example of such losses is demonstrated in Figure 7, where the water flow in the distribution system was measured in two delivery channels. In the upper channel, almost 35% of the water is lost through seepage over a distance of 500 m. In the lower distribution system, the initial losses were small but the flow was reduced by more than 90 % over a distance of less than 1 km during a period when no water was diverted at any of the upstream measurement points.

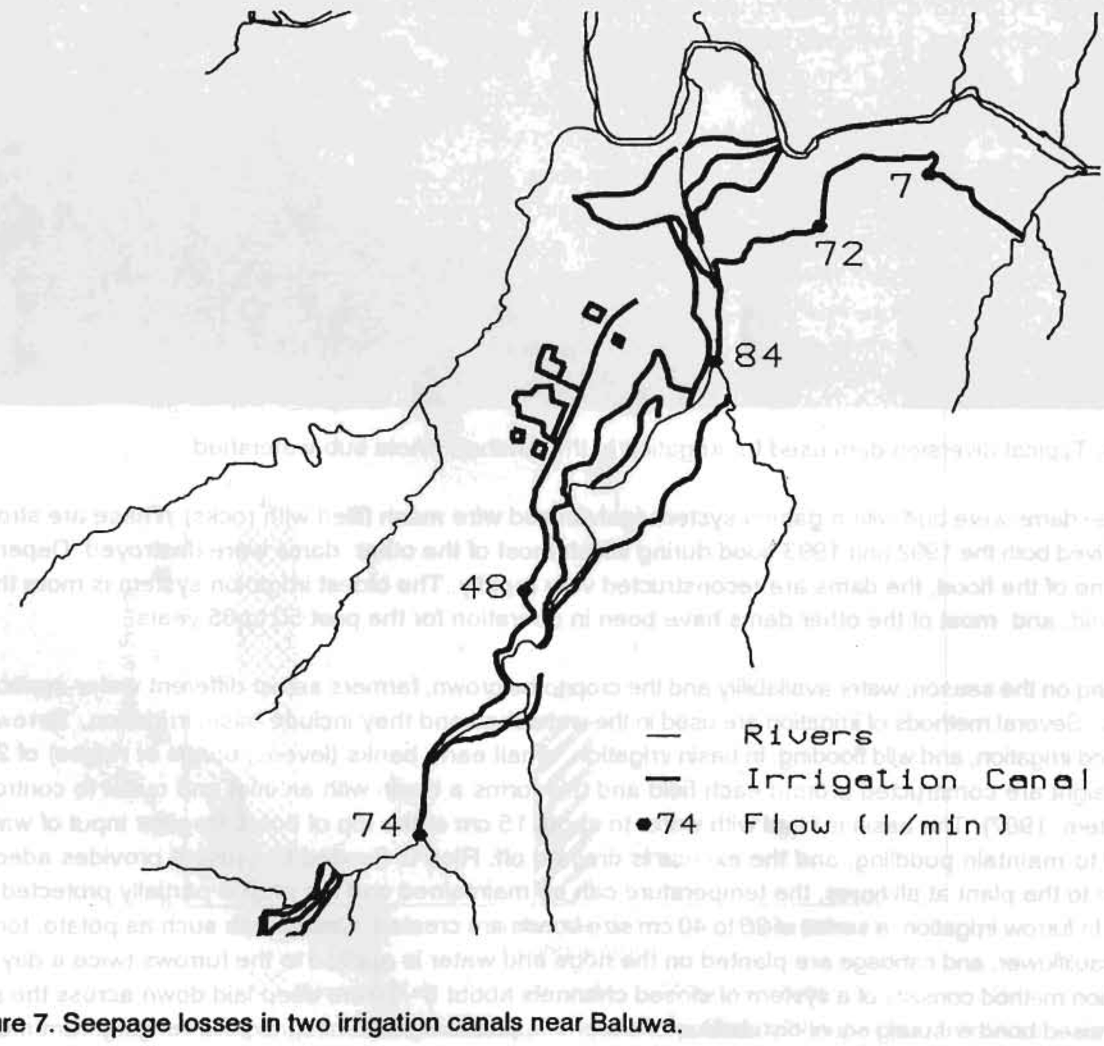

Figure 7. Seepage losses in two irrigation canals near Baluwa.

4.4. Organizational Structure and Water Allocation Policy

A proper and timely water supply depends upon how well the water allocation system is organized and managed. In a broad sense, three categories of farmer managed organizations are recognized within the study area: well managed organizations, informal organizations and anarchical groups.

In the well managed system, the farmers form a committee and conduct assemblies. Money is collected to maintain the system and the amount of water delivered to each field is based upon land holding. The committee is fully empowered to raise money and to make decisions regarding who will get water first. One year the distribution starts from top to bottom, and the next year the delivery sequence is reversed. The smooth operation of the system is dependent on the full control of the system by the community (Acharya, 1989; Pradhan, 1989a).

Informal systems are used for rice production. Before the rice plantation season, all beneficiaries of an irrigation system get together either at a dam site or on a field. They inspect the system and assess the amount of work required to fix it for the season. Contributions are made either in the form of labour or cash, the amount depending on the size of one's land holdings. If a farmer defaults on his participation for whatever reason, he can provide labour during the next term. Mutual understanding is the basis for smooth operation of irrigation systems in this category. Water distribution is made according to need or whose field is ready at the time. Farmers consult each other and adjust transplanting schedules accordingly. During the transplanting period, this system works reasonably well. Once all members have transplanted their rice, water distribution is decided according to need. During the monsoon season, there is frequent destruction of dams and canals, and the farmers' response is rapid. Everyone gets together at short notice to repair any damage and ensure the vital crop production.

The anarchical groups are common and have many beneficiaries, but they are often very disorganized. Once the water begins to flow at the end of the dry period, everyone has the right to water. In this situation farmers near the headwater draw water first, and the farmers below must wait. The system is unfair, but still operates. Frustrated farmers occasionally destroy the system.

4.5. Managements of Conflicts

When water is not delivered as expected, conflicts arise. These are human induced conflicts, which arise when one farmer steals water, destroys a structure, or operates an unauthorized dam. Such violations are generally rare, because water is very precious during winter and the supply is closely monitored. Violations result in crop failure and have devastating effects on the livelihood of the farmers. Attempts to resolve conflicts are first made at the farmers' level. Unresolved matters will be taken to a village chairperson. Complex problems are forwarded to the district office.

4.6. System Maintenance and Financial Arrangements

Continuous maintenance and repair is needed in order to guarantee a good rice crop. Therefore, the entire family participates in the management by providing physical labour and/or financial support. The proper management of water therefore becomes one of the most important tasks in the farmers' life. All water allocation systems in the study area are the result of either individual initiative or community efforts. Only one out of 72 systems received government funding for upgrading. Repair and maintenance is usually the responsibility of the beneficiaries.

4.7. Case Studies In Bela and Baluwa

To provide more detailed information, a brief description of case studies of the indigenous systems at Bela and Baluwa are presented.

4.7.1. BELA, A SPRING-FED DRINKING WATER AND IRRIGATION SYSTEM

Bela represents a community of 23 households and they receive their water from the Thulo Khola, 0.9 km above the village. Every drop of water is harnessed by systematically collecting inputs into a series of small ditches. A one inch-diameter black polythene pipe is used to conduit the water down to Bela were it is collected in storage ponds. Fresh water from Timure Kholchi, 0.8 km above the village, is collected in a distribution tank (3.7 x 2.4 x 1.4 m dimension) for human consumption. The overflow from the distribution chamber is directed into the first pond. Two taps connected to the distribution tank provide water at a central washing station to all community members, 24 hours per day. Waste water is directed to the second pond. Water thus collected in two ponds is reused for irrigation. Irrigation water users are divided into two major groups:

1. The Tripathi group includes three farmers who are located at elevations higher than the pond level, which means that pond water cannot be used to irrigate their fields. Each farmer is permitted to draw 5 hours and 20 minutes of water every fourth day (in turn), between 7 am and 12:30 pm, from the most convenient point in the supply line.
2. The Pathak group is comprised of 16 farmers who share water from the two ponds between 12:30 pm and 7 am. Every 17th day, a farmer is permitted to repeat his turn of taking a 6 hour supply of water. In both cases, it is the responsibility of the individual to ensure that the maximum amount of water is delivered to his fields. Should the farmer fail to use his turn, he will not get a replacement.

The irrigation water in Bela is primarily used for winter crops such as garlic, onions, radishes, tomatoes, cabbage, cauliflower and potatoes. Farmers use the limited water resources cautiously, respect other farmers' rights and follow the routine agreed upon. The total area under this irrigation system is about 100 ropani (5 ha).

All of the members have family relations in the community and have lived here for generations. It is a close knit community where everybody knows the agricultural activities of every farmer. Just after Dasain (which usually falls in October) the members of the irrigation system get together in a general assembly to discuss the troubles that they had faced over the past season. They inspect the problematic sites and identify solutions in a joint manner. Collective efforts have adequately solved all problems to date. Being a small group in a small area, the system functions very well. Any misunderstandings are solved through mutual consultation. No serious conflicts have arisen since the initiation of the system in 1960.

There is no provision made for collecting regular fee contributions according to land holding or crop yield. When need arises all members make a shared contribution. In 1992, each member provided NRs 500 to upgrade the irrigation system. A one inch black polythene pipe was laid between the water source and the collection pond to minimizing seepage loss along canal. Being a winter system, maintenance work is simple and easy. Farmers' response to problems is immediate and effective. They are prepared to make contributions once the matter is settled collectively.

4.7.2. BALUWA, A STREAM FED IRRIGATION SYSTEM

The Baluwa (Devbhumi tar) irrigation system supplies water to 22 ha of ancient alluvial terrace land in Baluwa at the bottom of the sub-watershed. The area is located at an elevation of 800 m and with irrigation it is possible to grow a wide range of crops. According to agreements made with downstream users, the Baluwa irrigation system uses stream water from only mid-October to mid-March. The system is organized through a farmer's committee of 7 individuals, which are elected by the water beneficiaries themselves. Meetings are called once a year in order to evaluate the magnitude of problems. Repairing costs are estimated, money is raised, and an experienced local person is contracted to do the repair work. The committee keeps track of the work progress and expenditures.

The sole source for the Baluwa irrigation system is stream water from the Andheri Khola. Semi permanent weirs made of gabion wire mesh filled with rocks make up the diversion structure. The command area is divided into four zones, each embracing 110 ropani (5.5 ha) of land. The distribution follows a strict routine agreed to in the general assembly. During the first year of operation the farmers near the source get the water first, and the order is reversed following year. The farmer is responsible for diverting water to his field during the allocated time. Failure to obtain water during the allocated time is the responsibility of the farmer. Farmers are extremely alert when their turn for irrigation arrives. They put in additional effort to ensure an uninterrupted water flow to their fields. Water access time is proportional to the land holding size, 90 minute per ropani (.05 ha). In case of natural disasters, repair decisions are made by the committee.

A wide range of crops are grown on different landforms, each demanding a different portion of water at different times. The irrigated crops include tomatoes, wheat, mustard, potatoes, cauliflower, cabbage, okra, garlic, onion, broad mustard, and off-season capsicum.

There are few conflicts as far as dam repair, maintenance and canal cleaning are concerned. Farmers plan their crops according to irrigation water availability, which is rotated on a three week interval. Since their is no other water source, everyone relies on each other and it is rare for a farmer to steal water by diverting it during the night. In such cases the solution is to cut back the water allocation for the offender by twice the amount he stole and this is given to the other farmers. If the same farmer is caught for the same offence a second time, his turn is relinquished for the year. Third-time violations lead to expulsion from the committee. As far as we were told, only a couple of first level violations have occurred in recent history. Another problem is that downstream farmers may break the dam to draw water into their system. In such a case, the farmers prefer to fix the dam, make frequent inspections and ensure smooth water flow rather than to identify the rule breaker.

The Baluwa irrigation system was established some 100 years ago to irrigate sugar cane. The irrigation system was upgraded with significant technical and financial support by the government. The farmers were required to pay 12% of total cost in form labour and cash. Stone filled crate dams were built and the canals were cemented and covered in places. In 1990, the irrigation system was handed over to the user group who is now fully responsible for its operation and maintenance. Farmers raised NRs 5 per ropani of land in 1992. The money collected was enough for the 1993 repair work. In 1994, it was agreed to pay NRs 2 per ropani. Some farmers have lost interest in the system as water is becoming more scarce during the critical dry period. Since there are severe shortages, they don't consider the investment to be worthwhile, unless major changes are made in the collection method.

4.8. Farmers' Perceptions and Comments

Farmers are aware of diminishing stream flow and increasing water demand due to the introduction of vegetables for market production. They believe that some structures should be improved by using gabion and cement. A dam torn apart by a major flood may take from 50 to 150 person days for repair. Cement lining in the canals is another area that farmers feel could improve the efficiency of irrigation. This would reduce the seepage losses, providing a larger amount of water to the crops during the critical pre-monsoon period. Added storage capacity by the construction of a collection pond at higher elevation to capture more run-off at critical times is also a desired option. Most often these options are beyond the reach of the subsistence communities since the appropriate materials are expensive and unavailable in the watershed.

Farmers suggest that water shortages for both drinking purposes and irrigation have increased over the past 10 years. They feel that these shortages will become the main problem in the task of increasing biomass production for the rapidly increasing population in the basin.

5. CONCLUSIONS

Nepalese farmers know the value of water and have developed fairly elaborate indigenous water management systems. Many systems have been in use for centuries but there is clear evidence that the water supplies in the dry season are becoming limited due to crop intensification and a significant expansion of irrigated agriculture. Of the systems identified in this study, the community owned system with equal participation of all beneficiaries functions better than the privately owned and unorganized systems.

The diversion systems are built of local materials and can be repaired on short notice. Most systems function well and are adapted to the difficult environmental conditions. However, the maintenance of such systems is very labour intensive and two areas have been identified where improvement could be made. The seepage losses along the canals are significant and lining canals in critical areas with plastic pipes or cement would reduce these losses substantially. The problem with these improvements are cost and access to key materials. The second area is in the type of irrigation practiced. Most irrigation is based on flooding either the fields or furrows within the field. This requires large amounts of water and leads to large losses by seepage and evaporation. Trickle irrigation is an option that is currently being examined as part of the MRM project and its feasibility for the production of high value cash crops needs further investigation.

6. RECOMMENDATIONS

The introduction of gabion wire to the dam construction will improve water acquisition and reduce labour input for dam repair. Such structures can also be used to protect stream banks from undercutting irrigation distribution canals. They usually require little external material and can be built locally without difficulties.

Certain sections of canal need to be concealed by polythene pipe to reduce excess amounts of water loss. It is not possible to line the entire irrigation canal in these mountainous systems, but plastic or cement linings should be considered in critical sections of fractured bedrock zones and in areas were the canal must pass through coarse texture materials or unstable terrain.

The water collection ponds in Baluwa are on common land at the end of the canals. They should be improved and trees could be established around them to reduce evaporation losses. Water collected during the few winter rains could be used for winter vegetable crops.

Maintenance and a regular supply of water is essential. The drinking water committees are having difficulties providing water to the rapidly increasing population during the dry season. More reservoir storage capacity must be built for this season.

In many villages there is no provision for reusing the waste water locally. A better recycling system, such as that used in the Bela village, should be encouraged.

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The Jhikhu Khola Suspension Bridge

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1. INTRODUCTION

The main hydrometric station in the Jhikhu Khola watershed was established in 1989, about 3 km below the village of Baluwa . The drainage area at this point is 11,141 ha, and the stream cross-section at high flow is about 18 m wide. Initially, a gauge plate and an automated pressure transducer were installed at the site and in 1990, a cable way was constructed to facilitate high flow stream measurements during the monsoon period. Because of safety concerns and as a result of requests from local residents, it was decided in 1993 to construct a suspension bridge. Many people wanted to use the cable way during the monsoon season when it is almost impossible to cross the river. Also, the transport of goods over this time period is restricted. The cable way system was never designed for the transport of people or materials; it was built strictly to measure stream flow. Due to the apparent need and concerns about possible accidents, the construction of a suspension bridge was initiated in April 1993.

The bridge represents a link between science and development in that requirements by scientists and the local people were considered to be of equal importance, thus justifying the construction of a multi-purpose bridge. Given the limited funds available, an agreement was struck between the local residents and project personnel: the former provide free labour and the latter, finances, technical assistance and materials. The engineering was provided by Raj K. C. Lokendra, Structural/Geotechnical Engineer, and all materials were organized and transported to the site by the Nepali project staff.

2. DESIGN OF THE BRIDGE

A plan of the design is provided in Figure 1. The bridge was built over a three month time period under the direction of the Nepali team. The final results are provided in Figures 2 and 3. Some 20 villagers volunteered their time over a one month period to help with the earthwork and bridge assemblage. All components were made of steel and metal since wood supplies are very scarce in this part of the watershed. The entire cost of the construction of the bridge was about US $ 6000, and the project has been a success for both the MRM research project as well as for the local residents.

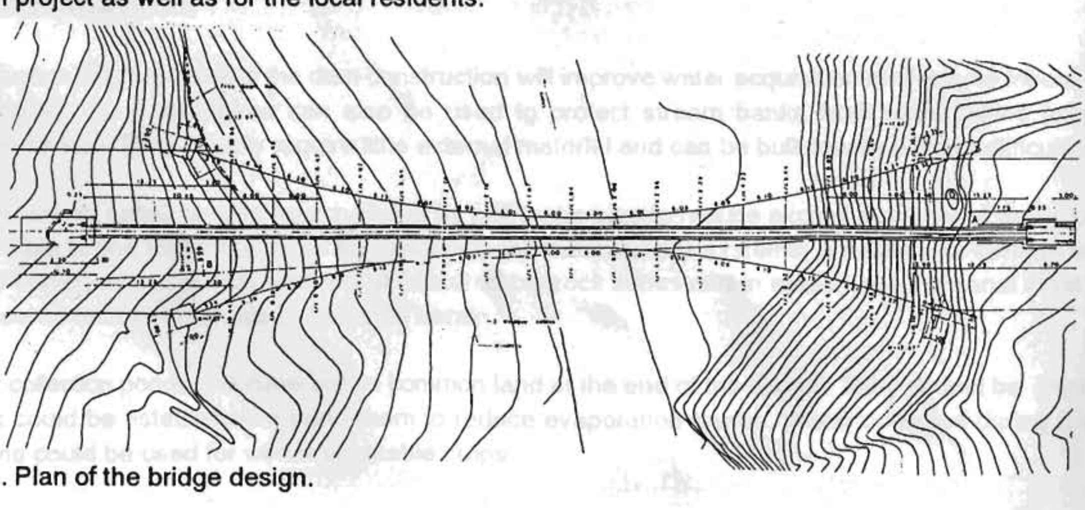

Figure 1. Plan of the bridge design.

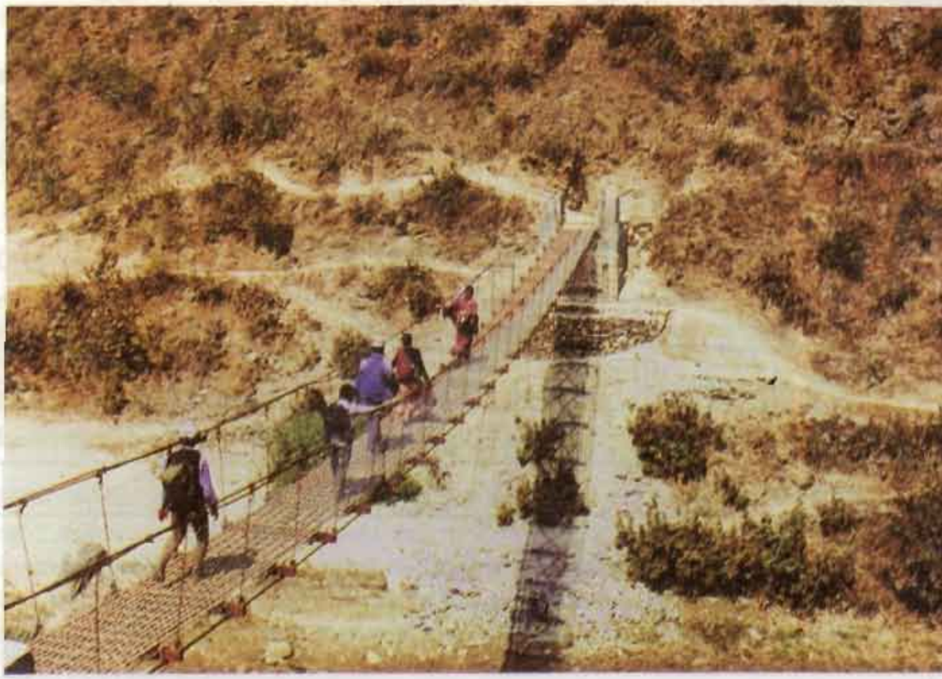

Figure 2. Final results of the Jhikhu Khola suspension bridge.

Figure 3. The Jhikhu Khola suspension bridge.

3. EVALUATION OF USE

To better assess whether the bridge is meeting the expected use, three separate surveys were conducted by the project staff to determine the number of people crossing the bridge on a daily basis. The results shown in Table 1 indicate that traffic is heavy even during periods when the river is small and when the bridge is not necessary.

Table 1. Results from the user survey of the suspension bridge.

Time of Survey (1994)	Observation Period	No. of People crossing
Monsoon Period (August)	10 day period	175 people/day
Pre-Monsoon (May)	7 day period	93 people/day
Post Monsoon (September)	5 day period	124 people/day

From a traffic perspective, it is evident that this project has been a success. From the scientific perspective it has greatly facilitated high flow measurements, as it provides a safer and more permanent platform, enabling us to obtain more frequent and precise measurements of stream flow and sediment transport.

4. CONCLUSIONS

Building a suspension bridge was never contemplated as part of this research project, but once initiated it proved to be a very worthwhile venture. Not only did it greatly improve our own scientific monitoring program, but more than anything else it provided a forum for close interaction with the local community. It demonstrated to the local people that we were not only interested in our research but also in the well being of the local community. The goodwill gesture of building a multi-purpose structure, as well as the trust gained through collaborating with the community in the construction, will have many long term benefits for current and future research in the watershed. As an example, we feel that socio-economic surveys in the watershed will be greatly facilitated in the future as a result of this joint project. We also anticipate that the farmers will be more receptive to new ideas for experimentation and environmental management. These benefits cannot easily be measured, particularly in the short term, but will likely have long term dividends.

Uses of Solar Power in the Jhikhu Khola Watershed

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1. INTRODUCTION

Ninety-five percent of Nepal's energy requirements is met with biomass sources. Hydropower, despite its huge potential, is currently producing only 0.6% of the total energy consumed in Nepal (Rokaya, 1993). Hostile geography and resource constraints restrict the use of electricity to urban residents (10% of total population). In the Jhikhu Khola watershed, electricity is accessible to only a handful of houses clustered along the road.

Our meteorological and hydrological stations are several kilometres away from the road and are not accessible by vehicle. Several of these stations are equipped with automated data loggers, collecting large sets of data which are downloaded regularly using a laptop computer. These loggers are powered by rechargeable batteries which need regular recharging and in the absence of accessible power sources, solar photovoltaic (PV) systems were selected as the most promising renewable energy source to recharge computer batteries at each site. The use of solar power has subsequently been diversified to include solar-powered water pumps for irrigation and electrification of our field research station and individual farm houses.

There are many encouraging signs that solar power can be used in many aspects of development (drinking water supplies, home power supplies, rural telephone services, etc.) and the present paper is intended to provide information on our experiences in using PV systems for research activities and farm development in the Jhikhu Khola project.

2. APPLICATION OF SOLAR ENERGY

The collection of solar power is relatively easy. The solar panel intercepts sunlight and converts the radiation into electrical energy. This power can be used to power a solar pump directly or can be stored in batteries where fluctuations in solar intensity are controlled through a regulator. The recharged batteries are used to generate light in the field research centre and power the computers and data loggers. Table 1 provides an overview of the solar panels, their capacity and their use.

A typical 53-Watt panel (rated 3.05 Amperes) will take 6.5 (20/3.05) hours to fully recharge a 40 Ah battery (a lead acid battery normally operates at up to 50% of its capacity).

2.1. Project's Research Activities

2.1.1. RECHARGING BATTERIES

All five tipping-bucket rain gauges, three climate stations and four hydrometric stations are equipped with data loggers which record data continuously. The data are downloaded with a portable computer once a month. Similarly, the hydrometric data loggers are connected to a pair of rechargeable batteries that are replaced every second month. Both computer and batteries are recharged in the field office when required, helping to speed up data acquisition and allowing the field staff to verify data in the field.

Table 1. The use of solar panel and batteries in the Mountain Resources Management Project.

Item	Capacity	Quantity	Application
Solar Panel (12 volt)	17 Watts	3	Lighting
	31 Watts	1	Charging Computer
	53 Watts	1	Charging Computer
Rechargeable Battery (12 volt)	6.5 Ah	16 (portable)	Hydrometric Data Loggers
	40 Ah	2	Lighting
	50 Ah	2	Computer + Lighting
	120 Ah	1	Computer + Lighting

2.1.2. PROCESSING SEDIMENT SAMPLES

Large numbers of sediment samples are collected during high flows of flood events. Solar-powered light has made it possible to process, analyze and filter the samples at night. Within a few hours, bottles are cleared for reuse. This saves time and is very effective in providing accurate and timely results. The use of energy efficient lights with portable batteries is extended to the gauging station where hydrometric measurements can now be made more effectively during storms which occur at night. A minor but important component is that the cleanliness in the kitchen has noticeably increased since lighting has become available.

2.1.3. REHABILITATION OF DENUDED LAND

The tree nursery, which is an integral part of the rehabilitation project, demands a regular supply of water to maintain seedlings and cuttings of various nitrogen fixing trees and grasses. During the dry periods (December - May), water shortages are acute and a regular supply is essential, especially to the transplanted seedlings which quickly reach wilting point. Andheri Khola is the only water source but it is about 200 metres away and about 35 metres below the nursery. The project introduced two solar pumps to lift stream water on a step basis to the nursery and the transplanting areas. Water is collected in drums at different sites, minimizing the water transport required.

The operational capacity of the first pump is lower than that of the second. The first pump uses 80 Watts (double panel) and delivers 150 litres of water per hour over a vertical lift of 12 metres. The second pump requires only 40 Watts and provides 270 litres of water per hour over a vertical lift of 20 metres. The technical details of pumps and panels are provided in Table 2. The differences in water delivery is associated with the efficiency of the pumps.

To meet our water requirements, the pumps operate a few hours a day lifting an average of 700 - 900 L/day. Water-efficient techniques such as trickle and sprinkle irrigation are applied to off-season crops namely capsicum, water melon, cucumber and strawberry, as well as to fruit trees (mango, lychee, etc.).

Table 2. Technical aspects of the two solar-pump installations.

		Pump A	Pump B
Panel Specifications	Manufacturer	Siemens	Siemens
	Rated Output (W)	40	48
	Voltage (V)	12	12
	No. Panels	2	1
Pump Specifications	Manufacturer	Flowlight	Minnesota Electric Technology
	Vertical Lift (m)	12.23	20.4
	Discharge (L/min)	2.5	4.6
	Installation Date	March, 1994	November, 1994

2.2 Rural House Electrification

Many villages do not have access to an electricity supply. Naturally, the bright light of the PV set drew many villagers to the research station. They frequently examine our set and enquire about the costs. In 1993 a PV set (a panel, battery, regulator and a fluorescent lamp) was given to a farmer (Bela, see Table 3) on a trial basis. Operation at the farmer level was smooth and in 1994 we extended the trial to a resource-poor female farmer in Jaretar. The project provided a PV set and operational instruction. Although the trial was designed for a single farmer (because of the low capacity of a 17-Watt panel and a 40-Ah battery), another two households joined and each received one light. The light is very efficiently designed consuming about 8 or 10 Watts of power. The farmers use the light for 1-3 hours per day. Solar power supply for light is now operating at three sites, including the project field research centre. The different technical specifications are provided in Table 3.

Table 3. Photovoltaic module used for light.

Items		Site 1			Site 2	Site 3
		Field Camp			Bela (north facing slope)	Jaretar (valley bottom)
Solar Panel	Number	1	1	1	1	1
	Watts	17	31	53	17	17
Battery	Number	1	1	1	1	1
	Ah	40	50	120	50	40
Light (fluorescent)	Number	1	5		2	3
	Watts	20	10		10	10
Ethnic Group		Various			Brahmin	Danuwar

Although the setup is new at Jhikhu Khola and the experience is too short to make big claims, the farmers nevertheless feel that it is a useful tool to:

- motivate children to complete school work in time (education)
- encourage female farmers to weave cloth in the evening (cottage industry)
- save kerosene, thus it lessens the smoke problem inside the house (health)

Significant results can be achieved through community-level installations. Shrestha and Sharma (1994a) indicate that the entire village (46 families) of Pulimarang, Tanahu, Western Nepal, is benefitting in many ways (adult education, hygiene, off-farm employment, birth control, etc.) from community-based, self-contained, home solar systems.

3. BENEFITS FROM SOLAR PHOTOVOLTAIC SYSTEM

The advantages that the project received from the use of the solar system are two-fold: economic and environmental, the first being more obvious than the second.

3.1. Economic Advantages

3.1.1. SAVINGS BY NOT USING KEROSENE LAMPS

Based on our previous experiences, we would need three pressure lamps (petromax) to conduct the intensive field work. This would have involved continuous expenses and repair. The operational cost during the lean period (October - May) would be about one third that of the peak season's (June - September). The breakdown of the costs is provided in Table 4 below.

Table 4. Breakdown of costs for kerosene lamps (Nepalese Rupees).

	Capital Investment	Operational Cost (per month)	
Item	Pressure Lamps	kerosene (L)	maintenance (mantle/glass)
Quantity	3	60	3
Unit Cost	1000	10	60
Subtotal	3000	600	180
Total	3000	780	

Nb. The operational costs for June - Sept and Oct - May are 3120 and 2080 NRs respectively.

The project's annual expenditure on light alone consists of capital investment + total running cost= 3000 + 3120 + 2080= 8200 NRs, if kerosene light is used. Because of their poor quality and extensive use under field conditions, these lamps usually do not last for more than one year. At least 10 nets are used every month and a new glass is required every second month. Depending upon the capacity, the cost of the Solar Power set ranges from NRs 15,000 to 37,000. Hence the initial solar investment would be paid off in 2-3 years, which is well below the lifetime of these solar systems.

3.1.2. SAVINGS BY NOT USING KEROSENE PUMPS

In a stream water lifting trial, we ended up using three kerosene pumps in a row to deliver water to the point of interest. Although the delivery of water is large, the associated cost of transportation of the fuel (kerosene) and the rental charge for one hour (minimum) at a time is considerable. Details are in Table 5.

Table 5. Breakdown of costs for using kerosene pumps (Nepalese Rupees).

Item	Quantity	Cost Per Unit	Total Cost
Pumps hired	3	80	240
Transportation	3	40	120
Kerosene (litres)	3	20	60
Total (per week)			420

If pumping is done once a week over the eight month dry period, the total annual cost would be 420 x 32 = 13,440 NRs. The cost of a solar pump, in comparison (depending on its capacity) is in the range of approximately NRs 30,000. Once again, the solar investment is paid off in 2-3 years.

3.2 Environmental Benefits

Locally-available, low-grade kerosene burns poorly and produces smoke. Spilling of kerosene from pumps into the stream-water is harmful to aquatic animals. Disposal of dry-cell batteries can adversely affect the ground water and the surrounding area. Solar PV systems do not have these problems.

The solar PV module has distinct advantages in that it minimizes environmental degradation (air pollution, greenhouse effect and acid rain) and the non-renewable resource savings can be significant (as shown below in Table 6).

Table 6. Environmental benefits in the Jhikhu Khola Project by using solar rather than kerosene power.

Power saved	2,700 kWh
Petroleum saved	4.8 barrels of oil
Coal saved	1,225 kg
Carbon dioxide kept out of the atmosphere	1,814 kg (a major global warming agent)
Sulphur dioxide kept out of the atmosphere	10.6 kg (contributor to acid rain)

Note: The calculations are based on (Schaeffer, 1991):

1 PV = 50 Watts
1 PV module will last 30 years
1 kWh of electricity is generated from 11,605 kJ (11,000 Btu)
6.59 million kJ (6.25 million Btu) = 1 barrel of oil
Coal required to generate 1 kWh = .454 kg (1 lb)
Carbon Dioxide emissions per kWh = 0.68 kg (1.5 lb)

4. SOME PROBLEMS ASSOCIATED WITH USING PHOTOVOLTAIC SYSTEMS

There are some limitations and constraints when using PV systems. Our experiences are as follows:

- initial capital investment is high for rural farmers
- it is easy to destroy the system, particularly the regulator; power regulators blew due to improper connection of the power terminals
- dry-cell batteries demand distilled water over time
- the solar pump demands clear water; regular cleaning of super fine filter is essential to optimize its delivery capacity
- the solar system operates inefficiently during monsoon season for two reasons: high sediment load in the stream water and low sunlight exposure due to frequent cloud cover. Fortunately, the water demand during this season is not great.

The life span of a solar photovoltaic panel and battery is 30 and 3 years respectively. Literature indicated that some materials in PV cells could be toxic which may be hazardous during production and disposal (Renewable Energy, 1994).

5. FUTURE TRENDS IN SOLAR ENERGY

The PV system is a useful achievement which has many positive effects on the life pattern of people surviving under global resource pressure. The system used is portable and ideal for remote locations. The set can easily be installed and dismantled within a few minutes. Upgrading of the system is easily done without requiring large modifications. Ever rising prices in nonrenewable sources of energy (largely petroleum products and coal) force us to use more alternative sources, and solar energy is a realistic alternative. Furthermore, solar energy's price is continuously decreasing, as revealed by the cost/Watt, which was US $1000 in 1960 and is now US $5.

The energy of the sunlight intercepted by the Earth every day is estimated to be 170,000 Terawatts or 2.5 million barrels of oil per day equivalent (bdoe), which is 10,000 times greater than the world population's annual energy requirements (Renewable Energy, 1994). The radiation in Pulimarang (Middle hill of Western Nepal) is measured to be 960 W/m^2 (Shrestha, 1994b). Massive research on thin-film photovoltaic cells hints that the cost of a PV module could be less than US $1 per Watt in the future (CRE, 1995).

There is now a wide selection of photovoltaic systems available in Kathmandu with the main suppliers being:

1. Solar Electricity Company Pvt. Ltd.
   GA 2-718, Bagbazar
   P.O. Box 249
   Kathmandu, Nepal
   Tel 225 253; Fax 977-1-414 653

2. Lotus Energy Pvt. Ltd.
   Cha 2-271, Bhatbhateni
   P.O. Box 9219
   Kathmandu, Nepal
   Tel 418 203; Fax 977-1-412 924

3. **Wisdom Light Group Pvt. Ltd.**
   Durbar Marg
   P.O. Box 6921
   Kathmandu, Nepal
   Tel 230 973; Fax 228 696

6. CONCLUSIONS AND RECOMMENDATIONS

The MRM project found that solar photovoltaic systems are very useful in field research and provide power to run laptop computers and backup batteries, operate solar pumps and provide rural lighting in individual houses.

The associated benefits are:

- running television and cassette players
- motivating school children to read
- creating off-farm employment (weaving and knitting)
- improving health conditions in the kitchen

The solar PV sets used in the projet greatly facilitated field-based research in remote areas. These trials should be continued since they have the potential to assist and improve rural development.

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Rehabilitation of Degraded Lands

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1. INTRODUCTION

Degraded sites, make up about 5% of the watershed, which are defined as surfaces that are dissected by gullies and rills, have minimal vegetation cover and are no longer under daily use except for collection of fodder and firewood. From the results provided by Carver et al. (1995) such surfaces are a major source of sediments and are likely the greatest single factor contributing to the annual sediment budget in the stream. Given the very intensive land use in the watershed these degraded sites represent the only land areas that do not contribute to consumptive biomass production. Agricultural intensification has led to shortages of cultivatable land and many marginal lands are being converted into agriculture. Until now there has been little emphasis on rehabilitating degraded lands because the task of stabilizing such sites, and returning the remaining soils into production is a formidable one. Few farmers consider the rehabilitation of such sites a viable option but pressure on the land, the continuous environmental problems caused by erosion originating from these sites, and the long term consequences on sedimentation downstream suggest that some innovative rehabilitation efforts are needed. The idea of a demonstration site was formulated in 1993 and a number of agro-forestry experiments have been initiated since that time.

The site chosen is located below Luitelgaun and covers an area of about 2.5 ha of very badly degraded land dominated by red soils. Over the past 20 years all trees were removed from the site and extensive and continuous collection of fodder and litter has resulted in massive rill and gully erosion. During every monsoon season massive headcutting and accelerated erosion occurs at the site and the off site impact on the stream and irrigation systems downstream are serious. A number of experiments were conducted in an attempt to improve soil fertility conditions, stabilize the gullies and introduce an agro-forestry system. An overview of the site at the time the experiments were initiated is provided in Figure 1.

2. EXPERIMENTS INITIATED BETWEEN 1993 AND 1994

There are no quick solutions to rehabilitate a site which is as degraded as that shown in Figure 1. A long term approach is needed because moving and redistributing the remaining soil material will not stabilize the soils and the nutrient status of all material at the sites is very depleted. The key issues are: (1) ameliorate soil nutrient conditions in the absence of large amounts of manure and fertilizer inputs, (2) stabilize the soils and eliminate or significantly reduce surface run-off, (3) provide a local supply of plant material that can be used for stabilizing the soils and improving the soil conditions and (4) improve the water availability at the site with appropriate irrigation systems that benefit the plants but minimize run-off.

The problem of site rehabilitation is not entirely solved by establishing a vegetation cover because farmers need production capacity, and there must be some economic benefits even early in the reclamation program. It is for these reasons that the following five experiments were initiated:

1. lime experiment using grasses and fodder trees,
2. gully stabilization project using checkdams and sisal,
3. establishment of a vegetable and fodder tree nursery,

Figure 1. Overview of demonstration site for agro-forestry experiments.

4. introduction of trickle irrigation and
5. development of an agro-forestry system with N-fixing fodder trees serving as hedgerows.

2.1. Lime Experiment Using Grasses and Fodder Trees

The problems of red soils, acidity and aluminum toxicity have been documented by Schreier et al. (1995). The pH of the red soils at the site range between 4.2 and 4.6, and in this range Al solubility is likely causing phosphorus deficiencies. The available P values at the site are all below 10 mg/kg, which is considered a very poor nutrient range. On a completely barren red soil surface and a 4x3 experiment was initiated in 1993 that included a lime/manure trial with grasses and fodder trees. The design of the experiment is provided in Table 1. A 40x3 m surface area was divided into 12 compartments of 10x1 m in size and a 40x1 m strip was used for the biomass trials. Segment A was used as a control, lime was applied to segment B, manure was applied to segment C, and a combination of manure and lime was applied to segment D. The third strip was left alone to determine natural recolonization rates.

Table 1. Design of plot experiment to improve soil acidity and determine plant response.

Segment A	Segment B	Segment C	Segment D
No additions	Limestone addition (rate: 20 T/ha)	Manure addition (rate: 20 T/ha)	Lime and manure (rate: 20 T + 20 T/ha)
Grasses	Grasses	Grasses	Grasses
N fixing fodder trees	N fixing fodder trees	N fixing fodder trees	N fixing fodder trees
No planting	No planting	No planting	No planting

To make the experiment realistic, the treatments were only applied once at the beginning. *Bauhinia purpurae, Litsea monopetala, Artocarpus lakoocha* and *Melia azedarach* were the main fodder trees, and *Desmostachya bipinnata, Typha angustifoloa, Imperata cylintrica, Eulaliaopsis ninata,* and *Saccharum spontaneum* were the main grass species used in the experiment.

During the first year we had significant insect and disease problems, and plant production was small because the soil surfaces desiccate significantly during the dry season. The plant response was much better during the second year, and the results so far indicate that for the grasses the combined treatment was the best while the fodder trees did slightly better in the manure treated plot. The lime application did increase the soil pH between 0.2 and 0.4 pH units two years after the treatment application. No natural revegetation occurred on the control plots or those reserved for natural regeneration with treatment, suggesting that the soil and site conditions are very difficult for the support of plant growth.

2.2. Gully Stabilization

Two headwater gullies were selected for a paired gully system study. One was left without modification and the other was stabilized using simple check dams, sisal and grasses. Each gully was surveyed with a theodolite in the field before the 1994 monsoon season and after the monsoon season . The same survey will be conducted at the end of the 1995 monsoon season. This will allow us to determine how much change has occurred in the gully headwalls and how much sediment was lost during the rainy season between unaltered and slightly modified conditions. Some 300 control points will be used to model the surfaces and erosion rates using 3D plotting routines.

2.3. Establishment of a Fodder Tree and Vegetable Nursery

As shown in the paper by Shrestha and Brown (1995), native nitrogen fixing fodder trees have been identified as appropriate trees for afforestation in the watershed. In order to rehabilitate such a large degraded area, a constant supply of plant material is needed. We decided to use an agro-forestry system where native nitrogen fixing fodder trees are planted in hedgerows and vegetables and other marketable crops between the rows to produce food, fodder and litter.

A nursery was set up near the Andheri Khola stream, and seeds and seedlings were collected from many sources over a two year period. The reasons for the establishment of the nursery were three-fold: (1) to make available a large number of native nitrogen fixing fodder trees for constructing hedgerows and for future distribution to farmers, (2) to provide a constant supply of marketable crops, and (3) to provide a centre for bio-diversity in native species.

It is often difficult to obtain the seeds of native nitrogen fixing fodder trees since the pressure for fodder is intense, and excessive lobbing of trees prevents blooming and seed generation. With the help of Mr. Batta and his group at ICIMOD, we were able to obtain an initial set of trees and grass species and subsequent efforts have yielded the results shown in Table 2.

The second focus was on vegetable production because growing basic staples between hedgerows is not an attractive proposition in these degraded sites. Since the site is in close proximity to the Kathmandu market it was decided to grow selective vegetables in the nursery for transplanting. This included cauliflower, zucchini, cucumbers, watermelons, sweet pepper, tomatoes and eggplant. Annually some 500 plants were produced, and at least half were distributed to the farmers as an incentive for collaboration in future on-field trials.

The idea is to demonstrate that if a crop with high market value can be grown the need for crop intensification (several crops rotations per year) is not as high. This would allow degraded sites to be at least partially productive while the process of soil amelioration is taking place.

2.4. Introduction of Trickle Irrigation

Since the soils are desiccated during the dry season and surface plant cover is minimal, it was felt necessary to introduce some irrigation capacity. As shown by Carver and Nakarmi (1995), surface cover at the end of the dry season is critical for erosion control, particularly when the first monsoon rains occur. This requires water, and the only way to bring water to the site is by pumping water from the stream to the various planting sites. To solve the elevation problem, a solar pump was installed and storage reservoirs were constructed to provide a constant water supply during the dry season.

Table 2. Tree and fodder species produced since January 1994.

Plant Species (Nepali Names)	Number of seedlings produced	Number of seedlings planted at the site
Sissoo, *Dalbergia sissoo*	2093	207
Khayar, *Acacia catechu*	887	91
Nimaro, *Ficus auriculata*	441	7
Palowinia elengata		47
Flemengia, *Flemengia macrophylla*	342	623
Teprosia	1487	256
Sapan, *Cassia siamea*	57	509
Delonix	50	36
Sunhemp, *Crotolaria pallida*	1615	1000
Bakaino, *Melia azedarech*	399	156
Rato Siris, *Albizzia procera*		60
Tanke, *Bauhinia purpurea*		153
Kalo Siris, *Albizzia lebbek*		183
Kutmiro, *Litea monopetala*		82

The water is stored in oil drums and galvanized containers, and a very low cost trickle irrigation system was initiated below a number of storage containers. A network of many small 3-10 mm size hoses was connected to the tank, and a inexpensive flow controller was added to the end of the tube. The optimum rate is a 2 L/hour controller. The outlet is placed next to each plant, and water is applied by gravity for about 1-2 hours per day, depending on crops and time of the year. An example of the system is provided in Figure 2. The results obtained to date are encouraging because the method is water-conserving, and the problem with sediment inputs into the irrigation water was solved by including sediment filters in the irrigation system.

Figure 2. Example of a trickle irrigation system.

2.5. Development of an Agro-forestry System with N-fixing Fodder Trees Serving as Hedgerows

The experimental site was divided into 30 x 30 m sections, and simple 1 m wide terraces were constructed on top and bottom of each section. Hedgerows of native, nitrogen fixing fodder trees were planted on the terraces at the top and bottom of each segment. The terraces were built across the slope, and in order to improve tree survival, an initial treatment of 4 t/ha of manure was applied to each terrace, and in selective rows, lime was applied at a rate of 3t/ha. This was a once only treatment and will not be repeated. A plan view of the design is provided in Table 3, showing the location of the different hedgerows, species used, and treatment received.

The tree seedlings were planted in two rows in each terrace with 50 cm spacing between trees. The first year survival rate of the fodder trees was 86% and after one year we found that most hedgerows reacted more positively to the lime treatment than those without lime treatment.

The actual performance of the different species was variable, and the results provided in Table 4 showed that Sissoo was the most successful tree at the site with plant heights of up to 255 cm within one year. Siris performed significantly better in the lime treated site and Khayar did not respond to lime. After one year, the most successful colonizer was Sissoo and the poorest Kutmiro.

All land between the hedgerows was used for agriculture (mainly vegetable and fruits), and a number of pioneer crops were planted to establish organic matter, and use nitrogen fixers to overcome the nutrient deficiencies inherent in the site. The most interesting experiments are to be initiated in the upcoming season. Once the hedgerows are well established, they not only fix nitrogen, but their litter adds organic matter to the soil. Three sites were set up to incorporate the first hedgerow cuttings for augmenting organic matter in the soils. The hedgerows are designed to be cut back regularly so as to produce fodder and firewood and to minimize the shading effects for agriculture. The experiments are designed to measure the rate of fodder tree material decomposition, the rate of organic matter accumulation, and the rate of soil nutrient improvement from this composting and green manuring practice. The first input is scheduled for August 1995 since the hedgerows will be sufficiently developed at that time to survive cutbacks.

Table 3. Plan view of hedgerow experiments with nitrogen-fixing species.

	Plots of 30 x 30 m in size used for nitrogen-fixing fodder tree experiments				
Fodder Tree Species Lime Experiment Parent Material	Siris A1 No Lime Quartzite	Gully Experiment			
Fodder Tree Species Lime Experiment Parent Material	Sissoo B1 Lime appl. Quartzite				
Fodder Tree Species Lime Experiment Parent Material	Khayar C1 No Lime Quartzite	Field Camp, Vegetable Garden, Soil Rehabilitation Experiments			
Fodder Tree Species Lime Experiment Parent Material	Tanke D1 No Lime Quartzite	Siris D2 Lime appl. Red Soils	Kutmiro D3 Lime appl. Mixed	Bakaino D4 No Lime Saprolite	Sissoo D5 Lime appl. Red Soils
Fodder Tree Species Lime Experiment Parent Material	Siris E1 Lime appl. Quartzite	Bakaino E2 No Lime Red /mixed	Tanke E3 No Lime Saprolite	Kutmiro E4 No Lime Siltstone	Siris E5 No Lime Red Soils
Fodder Tree Species Lime Experiment Parent Material	Soil Rehabilitation Experiments	Sissoo F2 No Lime Quartzite	Khayer F3 Lime appl. Quartzite	Bakaino F4 Lime appl. Quartzite	Sissoo F5 No Lime Red Soils
Fodder Tree Species Lime Experiment Parent Material		Empty Plot		Paulowinia No Lime Quartzite	Paulownia No Lime Quartzite

3. CONCLUSIONS

The activities at the demonstration site have created significant interest and many curious farmers regularly visit the site. Initially there was much scepticism, and the idea of rehabilitating badlands was considered too daunting a task for the subsistence farmers. However, the successes during the first year have been sufficiently encouraging that some farmers are starting to rehabilitate other adjacent sites. The seedlings supplied by the project are freely distributed and this has created considerable goodwill with the community. It is hoped that this will lay the foundation for future collaboration in terms of on-farm trials with nitrogen fixing crops and fodder trees.

Table 4. Performance of hedgerow species.

Plot No.	Species	Treat-ment	Height (cm)	% Survival	Height (cm)	Diameter (cm)
			at planting	180 days after planting		
A 1	Siris	T 1	36	57	50	0.5
D 2	Siris	T 2	14	84	25	1.4
E 1	Siris	T 2	17	98	37	1.5
E 5	Siris	T 1	12	100	18	1.5
B 1	Sissoo	T 2	84	100	255	7
D 5	Sissoo	T 2	83	96	124	6.4
F 2	Sissoo	T 1	75	100	160	6.4
F 5	Sissoo	T 1	31	97	43	3.6
C 1	Khayar	T 1	37	100	79	2.4
F 3	Khayar	T 2	9	98	11	0.5
D 1	Tanki	T 1	46	87	79	3.4
E 3	Tanki	T 1	36	89	32	1.5
E 2	Bakaino	T 1	32	52	40	1.3
D 4	Bakaino	T 1	22	89	31	0.5
F 4	Bakaino	T 2	13	52	25	2.2
D 3	Kutmiro	T 2	11	89	11	0.5
E 4	Kutmiro	T 1	9	89	9	0.5

Treatment = T 1: 4 T /ha Manure only, T 2 : 4 T/ha manure and 3 T/ha lime

Although the experiments are only in the early stages some preliminary conclusions can be made:

1. The establishment of a tree nursery, which focusses on the production of native, nitrogen fixing fodder trees, has been very successful by providing a continuous source of seedlings needed to stabilize the degraded area but also by acting as a distribution centre while maintaining the gene pool of key N-fixing native species.

2. Sissoo (*Dhalbergia sissoo*) has proven to be the best pioneering species. It had the best survival and growth rates and responded well to lime treatment. This species appears to be best suited for the desiccated and nutrient-poor site conditions that exist at this low elevation site (800-900 m).

3. Soil amendments are necessary to ameliorate the overall physical and chemical conditions at degraded sites. The combination of N-fixing fodder trees, lime application and nitrogen fixing crops

appears to be an appropriate recipe for low input reclamation. The research today should be considered the first step in the long term program of stabilizing degraded sites, generating useful biomass early in the program and improving the depleted soil conditions.

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Spatial Information Systems and Their Role in Development Projects

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1. INTRODUCTION

Many agencies are actively promoting the use of spatial information systems in development projects and although there are many advantages to using quantitative computer techniques, there are many obstacles that make such investments questionable (Fox, 1991, 1995). Operating information systems in remote areas is a challenge and we feel that four components need to be met for successful implementation in a development project. The choice of hardware, and software are the first issues but these can easily be addressed if money is available. The issues of people and spatial data are also an integral part of using information systems. To be successful, access to skilled people is a prerequisite, but simply training individuals in computer skills is not the solution. Resource people trained in forestry, engineering, hydrology, soil science, agriculture, socio-economics etc. with an interest in computer skills are required. These individuals are rare and in great demand. The most critical issue is one of spatial data on biophysical and socio-economic resources. Data collection and conversions are critical issues and there are few short-term answers but many long term headaches. The purpose of this paper is to share our experiences in utilizing spatial information systems, discuss some of the difficulties encountered, and indicate the direction we have taken in the use of this technology.

2. RETROSPECTIVE

In 1988 we set up XT computer in Nepal to analyze the Land Resource Mapping Project data (LRMP, 1986). At the time this database was the only reliable spatially referenced resource data which covered the country systematically at a 1:50,000 scale (Schreier, 1990, 1991). The use of a PC-based GIS system (Terrasoft) was felt to be appropriate given the electricity problems in Kathmandu at that time, and the lack of technical support and skilled manpower available. GIS was introduced because it provided a perfect platform to integrate both bio-physical and socio-economic data in a quantitative manner.

We quickly realized that to use this technology successfully a long term investment was needed. Fortunately the International Development Research Centre (IDRC) in Ottawa was receptive to this idea and allowed us to purchase an updated computer system, and train the Mountain Resource Management (MRM) team in the use of GIS, portable computers, automated data loggers and database management. The team members were experts in geology, soil science, land use and geography but had limited computer exposure at that time. Over the six years of the IDRC project all team members received intensive annual training sessions in both Nepal and Canada, and this continuous training effort has resulted in the Nepali MRM staff being self-sufficient in the use of the GIS, generating the necessary spatial data in the field, maintaining a comprehensive computer database and analyzing information in an effective and efficient manner. This was achieved with a relatively modest financial investment, the purchase of a 286 AT computer in the initial phase (1989) and a 486 DX computer system in 1992. The success was due to the effort of the highly motivated MRM team which already had experience working in a interdisciplinary manner through their involvement in the LRMP project.

The major emphasis over the first three years was to develop a spatially referenced resource database for the watershed which required mapping of soils, geology, current and historic land use from aerial photographs and generating baseline data on climate, hydrology, erosion and soil nutrients.

Only after this initial effort was GIS effective as a tool to analyze, display and overlay information, and develop models and scenarios. Because the computer technology changed rapidly over this time period of the project, constant adjustments and upgrading were made in the equipment used and the training provided. With a modest investments it was also possible to expand the monitoring network and to generate large environmental databases that were focused on measuring processes and rates of change.

It was quickly realized that GIS was a very time consuming and data demanding technique and this led to the introduction of digital field-data logging equipment which enabled us to generate data that could not easily be produced by manual efforts. This also meant that we required access to power in the field which in turn lead to the introduction of solar panels in the project. With this evolving approach to using spatial information systems we were able to generate one of the most comprehensive resource databases for a single watershed in this part of the Himalayas.

While these are very positive steps it should be emphasized that in spite of dedicated efforts by the Nepali team it required a long time to reach the level of understanding of the resources discussed during this workshop. Even with this effort our understanding is still modest and restricted to the watershed and sub-watershed scales and additional efforts will be needed to relate this watershed study to the regional and continental scales as advocated by Grosjean et al. (1995).

3. GIS AND ITS EVOLVING ROLE WITHIN THE PROJECT

Initially we focused on GIS as the tool to integrate and display data in the many forms for which GIS is famous (overlay, 3D, selective queries, graphic displays etc.). The next step was to add modelling capabilities to produce "what if?" scenarios. We quickly realized that modelling is often more efficient outside of the CAD (computer-assisted drawing) in the database system. If the spatial integrity is maintained it becomes possible to link GIS and external modelling techniques and use the two in combination. Unfortunately , GIS processing of large datasets is slow even with modern workstations, and interactive model demonstrations are not easily developed, or readily portable. This lead us to explore Hypertext, which is defined by Comejo (1994) as "documentary treatment of data in multidimensional space". This is a generic computer software technology which enables us to combine databases, text, graphics, GIS, and images into an electronic document that is interactive and easy to run. A demonstration of the use of this technology was provided during the workshop in Kathmandu. Most of the GIS maps resulting from the project were incorporated into the Hypertext document and combined with text and images to produce a computer book of the project in multidimensional space. A low end DOS version was produced that can run on any PC computer with a VGA monitor and requires about 4 MB of hardware space. Function keys were incorporated to enable users to easily navigate through the document. The product is very portable and easy to use even in remote areas with access to simple computer technology. However, it has the disadvantage that the image quality is low (640x480 resolutions and 16 colours).

To overcome this deficiency a new window based version was produced which will run on any PC computer which supports 1024x768 resolution and 256 colours. The advantage of this new version is the improved graphic quality, windows operating platform, and its distribution via Internet. We anticipate that the full version will be accessible via the PAN-Asia network and can be accessed via Internet at your convenience.

The advantage of hypertext documents is that they can be distributed free of cost, no software needs to be purchased, the programs are easy to learn, and since all the images, maps, graphics and data were generated by the project team no copyrights are needed for free and wide distribution. While we are very excited about the new product it should be noted that the end product is not an interactive GIS where a user can change data or assumptions and test the response interactively. Instead it is a computerbook that contains over 100 photos from the watershed, more than 70 graphs and GIS maps illustrated with text and annotation.

4. WHY HYPERTEXT AND WHO IS THE AUDIENCE

We view hypertext as a new initiative to make scientific information more attractive to managers and politicians, to serve as an educational tool for students, and to communicate scientific results more widely and at a reduced cost. To produce all the GIS maps, photos and graphics in colour in a conventional book format would be prohibitively expensive and we would only be able to produce a few copies. With the Hypertext document of the MRM project the production costs are modest and the distribution cost is minimal. We view this as an appropriate technology for development and hope you will get a chance to view it over the worldwide web.

5. FUTURE DIRECTIONS

Since the development of these techniques is ongoing we should indicate that a host of additional options are open in the development of an even more comprehensive communication tool. The first is the production of a CD-ROM and with it the addition of sound and video images. This requires access to more elaborate technology which is not yet readily available in the developing world. However, we anticipate that this technology is readily transferable, will be cost effective in the near future and will foster better communication, information exchange and development.

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Identification of Key Resource Issues: Discussion and Recommendations

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1. INTRODUCTION

The aims of the workshop were not only to present updated information on recent research findings relating to resource management in watersheds in the Middle Mountains, but also to identify gaps in knowledge and areas in need of future research. From all the papers and presentations, it is evident that there are widespread and complex problems in sustaining the resources in this very intensively used environment. Most of the resource problems are the result of rapid increases in population, a lack of infrastructure and harsh, marginal environments. Until recently, the farmers have been able to meet demands for biomass production by increasing yields, and have intensified production by introducing multiple cropping systems and expanding cultivation into more marginal areas. However, there are signs indicating that resource constraints and degradation processes are increasing and that, at the same time, production is stagnating. Based on this workshop, a number of issues have been identified that require more careful consideration. These issues can be grouped into the following six categories, which are summarized below:

- land use dynamics and conflicts
- soil erosion
- soil fertility management
- irrigation and water management
- indigenous knowledge
- inequities and institutional issues

2. LAND USE DYNAMICS AND CONFLICTS

Agriculture has intensified, moving from a cropping intensity of 1.8 to 2.6 crops per year over a 10 year period. At the same time, there has also been a marginalization of agriculture revealed by the expansion of bari land onto steeper slopes. With cropping intensification and expansion it has been possible to increase biomass production, although both of these agricultural practices are problematic. The former is in need of greater inputs, while soil losses by erosion is the main concern of the latter. It has also been widely reported that yields are stagnating even under increased fertilizer input, which suggests future problems with sustaining the productive capacity in agriculture. The dominant cropping pattern has also shifted from a rice, maize and wheat dominated production to one based on market economics, which includes potatoes, tomatoes and vegetables.

There is contradictory evidence that forest production is increasing. Forest cover has expanded and the number of trees planted on private land has increased. However, the forest cover expansion is mainly in the form of pine plantations and sufficient information has been provided to suggest that the quality and diversity of the forest has declined. It was also shown that the deforestation and afforestation efforts follow in a cyclic manner. However, the concern is that recovery and afforestation are never sufficient to reach the previous peak of forest conditions, hence a slow, overall decline in the production capacity has been noted. Community based forestry is seen as a mechanism for improved management, but training community forestry managers is proving to be complex and present needs exceed the current training capacity. The demand for forest products has steadily expanded and includes all forest products (fuelwood, timber, fodder and litter). It has also been shown that small scale hydro is not necessarily reducing the pressure on fuelwood demand, and that its introduction creates a complex change in the local social structure. Forests play an integral part in agriculture and the lives of the local residents, and since they receives no inputs, the long term sustainability of the current production capacity is clearly in question.

The only non-productive land in the Middle Mountains are significant areas of degraded lands. Until recently no attempts have been made to revegetate such sites due to the enormous effort required for rehabilitation and the questionable production capacity to be obtained after reclamation is initiated. The planting of appropriate vegetation cover as part of an agro-forestry system has great potential but must be viewed in a long term context, since the initial establishment is slow. In addition, the long term benefits of this vegetation cover downstream, resulting from reduced sediment contribution to the stream and irrigation systems, must be included in any cost/benefit evaluations.

3. SOIL EROSION

Soil erosion is the biggest problem with farming and other land uses in mountain systems. The impacts of erosion have far-reaching effects both on-site and downstream but the concerns for agriculture and hydropower development are governed by entirely different processes. For dryland agriculture, soil erosion is most critical during the pre-monsoon season when vegetation cover is at a minimum. Some 60-80% of all annual soil and nutrient losses occur during one or two major storm events during this season. In contrast, the key problem facing hydropower dams is the infrequent occurrence of exceptionally large storms which devastate the watershed and result in almost catastrophic losses of reservoir capacity. This was illustrated most effectively at the Kulekhani hydropower project, where unusual climatic events were shown to have severe impacts on reservoir capacity. Interaction between energy production and watershed management is critical. In general, erosion rates are high, but farmers are managing water and sediments as well as can be expected in such mountainous environments. Soil erosion is most problematic for poor farmers working marginal land, while rice farmers benefit from the accumulation of eroded sediments. Conversion of steep grazing and shrub lands into agricultural lands should be decreased. Sites already converted may be afforested with fodder trees.

Extrapolation of the information from a watershed scale to a macro scale is not possible. Research should be focused on bridging the gap between micro and meso scales, as the jump from meso to macro may be too challenging.

An investment in soil conservation practices is critical but needs to be diverse and flexible in order to address the different processes and their effects. For example, the establishment of an early vegetation cover and the provision for sediment collection during the pre-monsoon season is most critical for the upland farmers. The maintenance of settling ponds, the retention of sediments throughout the entire watershed and provisions to reduce sediment inputs into reservoirs are key strategies for hydro-power development. In fact, the wisdom of constructing large reservoirs in the Middle Mountains must be questioned given the recent evidence in the Kulekhani, where the predicted rate of erosion was clearly exceeded by an order of magnitude.

4. SOIL FERTILITY ISSUES

There is an awareness that soil fertility is becoming one of the major issues that govern poverty and future production capacity in the Middle Mountains. The most critical issue is maintaining soil fertility management with insufficient inputs and increasing demands for biomass production. The response to the use of chemical fertilizers has been disappointing and reflects the problem of an inability to maintain sufficient levels of organic matter in the soils. Manure supplies are insufficient, so forest litter is being used in an extensive manner to supplement organic matter in agriculture. This results in the depletion of nutrients in the forest, while the input into agriculture is not enough to sustain double and triple annual crop rotations. Additionally, as pine becomes the dominant tree species in the forest, litter becomes dominated by pine needles, which have a poor nutrient content and leach soil cations during the decomposition process.

Acidification is the most serious soil fertility problem, and is influencing phosphorus availability. The inherited parent materials in the Middle Mountains are frequently acidic and the addition of acid-producing fertilizer is simply adding to the problem. Lime inputs need to be contemplated but responses might be disappointing since most macro-nutrients are also deficient. The problem of soil fertility is widespread with the poorest conditions found in the forests and grazing lands. Only the irrigated areas, which benefit from nutrient inputs through irrigation water and via sediments, have fertility conditions which can be considered adequate given the intensity of crop production.

Livestock plays an important role in nutrient management, as organic matter is essential to the maintenance of soil tilth. However, feed shortages limit manure production. A more extensive use of nitrogen fixing crops and fodder trees is needed to conserve the soils and to provide additional feed and organic matter.

Soil fertility decline and the resulting impact on production is a major concern. Improving soil inputs is becoming a formidable challenge. Soil fertility changes need to be related to production to illustrate the relevance of research to the farmers. The impact of chemical fertilizer and improved seeds on yield should consider the cost of inputs relative to the purchasing of food.

5. IRRIGATION AND WATER MANAGEMENT

The greatest concern of the farmers is related to water shortages for both drinking and irrigation. Springs are almost fully utilized as drinking water sources, reducing the flow available for irrigation. Irrigation systems have expanded in recent years, but further expansion will be difficult given the widespread shortages of stream base flow during the dry season. New water conserving technologies, such as sprinkler or drip irrigation, are needed in order to effectively utilize this scarce resource. An effective alternative to flood irrigation is to grow less water-consumptive crops that also have potential for marketing. An investment in water harvesting systems will aid in reducing labour requirements for women and help in the irrigation of winter crops.

Solar pumps, which provide an alternative to kerosene pumps, have been utilized to provide irrigation water to nurseries and cash crops. The potential of solar energy should be further investigated at a practical level, including study of its impacts on agriculture and the economy.

6. INDIGENOUS KNOWLEDGE

Indigenous knowledge must be promoted and supported. Farmers are acutely aware of the problems in the watershed, however, infrastructure support is required. There are many indigenous systems that could benefit from external inputs, but good documentation is needed before they can be effectively used as a communication tool between the farmer, extension workers and researchers.

Hill women provide the labour and knowledge in agriculture, livestock husbandry and forest management. They are likely much more knowledgeable on issues relating to forest management, fodder production and animal health than are their male counterparts. This became evident in surveys which included both male and female farmers.

Women are also more acutely aware of the processes of degradation since their working hours are increasing as the distances for fodder and firewood collection are increasing with forest productivity declines. This is particularly evident in the families of poor farmers that have small land holdings and must rely on communal forests and grazing lands.

7. INEQUITIES AND INSTITUTIONAL ISSUES

Large scale foreign aid programs are often inappropriate and do not target specific community groups such as women and the lower castes. The caste system and land tenure issues must be considered alongside any management options, as they are indicative of the farmers economic limitations. The invisible woman farmer must be made visible and become part of the system. Off-farm employment opportunities provide possible alternatives to the farming of marginal land, but with men migrating off-farm for work, the labour of women is increased. Dairy development has increased and provides cash income to the family, however, the increased number of buffalo increases women's labour for household gains but women rarely see any personal gain. Since women have no control over land or cash, the shift to a greater market orientation results in women being marginalized from the decision making process. Access to resources, credit, property and training for women are essential.

The very unequal distribution of land, which is greatly influenced by the caste system, is another issue that needs discussion and attention. Policies to foster community control over land and restrict absentee land holdings as well as the size of such holdings are a possible option. A land reform policy with better local participation should be advocated.

The collaboration between agencies has been discussed at length; however, the actions by individual departments do not practice an integrated approach. Better collaboration between Forestry and Agriculture, and between the energy producing agencies and the department of Soil and Water Conservation, are just two examples where improved integration is needed. The problem of interaction and collaboration between agencies is still large and major efforts are needed to foster better interactions to improve resource management and the decision-making processes. Currently, issues related to deforestation, soil losses and soil fertility declines are not addressed sufficiently within centralized government agencies. To alleviate the impact on marginal farmers, the need is at the farm level. These issues must be coordinated at the national level by fostering grass-roots approaches. The importance and empowerment of farmers requires promotion. Financial resources should be channelled toward farm level programs. Local based extension is essential in providing better links and feedback to farmers on research results.

The importance of extension and communication is illustrated by the adoption of research ideas by farmers, such as their adoption of melons first planted at the rehabilitation site. Farmer adoption of conservation approaches requires an understanding of the benefits of conservation and at the same time maintenance of their income generation requirements. The dissemination of technology requires a networking system.

8. RESEARCH REQUIREMENTS

Development programs can be made more effective if baseline research data is available. Unfortunately, there is a lot of uncertainty about resource data and a poor understanding of processes. The processes that lead to degradation need to be quantified, both in biophysical and socio-economic terms, before effective management options can be developed. An integrated approach is required to evaluate natural resource issues. Both biophysical and socio-economic conditions must be addressed. Long term monitoring is required for representativeness and process evaluation. The need for information and potential interventions has been stressed.

The problem of scale was addressed and it was shown that land uses influence processes at different scales. More research is clearly needed to document the impact of land use intensification on the long term production capacity of the soils. Simulation modelling and scenario development were found to be effective tools to illustrate potential effects but long term monitoring programs are needed to add credibility to such predictions. Linkages within and between mountain regions is advantageous for sharing techniques and technologies. Information sessions between researchers, newsletters or regional field based training are potential approaches. Genetic material may be exchanged within and between mountain regions. For example, Asian rice may be exchanged with Latin America and Andean maize. A biodiversity group could be established within Nepal to deal with crop variety / genetic pool issues and forest biodiversity. Farmer exchanges between mountain regions is proposed as a potential program for technique exchanges.

The questions of: "When do indigenous systems breakdown and how can outsiders contribute to halt the breakdown?" need more research attention. This requires a better understanding of specific reasons behind why indigenous methods work and how they evolve. This is particularly important in the case of soil classification and management, where changes in biomass performance are often masked by climatic variations and inherited spatial variability.

Representative watershed studies should be coordinated within different agro-ecological zones. Coordination of methods and study sites selection will facilitate comparison of results and extrapolations from one watershed to the next. Collaborative research work with the regional agricultural centres (LARC, PAC and NARC) should be encouraged.

9. CONCLUDING REMARKS

Dr. E. Pelinck, Director of ICIMOD, closed the workshop by applauding the flexibility and patience shown by participants and stressed the value of participant responses to the study team. The dynamic approach was stressed, with conflicts between different resource uses leading to integration. The traditional conflict between biophysical and socio-economic disciplines has been overcome by focussing on the issues. Technical and institutional solutions must be integrated. Both private and common management are required. Scientific and indigenous knowledge must be merged. Further emphasis should be placed on erosion processes, both natural and anthropogenic. The movement from a subsistence to a monetary economy makes the Jhikhu Khola representative of future watersheds as market opportunities evolve within Nepal. Other issues requiring attention include monoculture versus biodiversity and high yield versus traditional varieties. Future work requires dissemination of information relevant to policy for specific applications. That information should be distributed to the professional development community, NGOs, HMG staff, the scientific community and, ultimately, the farmers. From a national perspective information sharing is vital. ICIMOD will aid with information dissemination through support of the workshop proceedings. Future work should focus on water, bari lands and specific versus integrated applications. Emphasis should be placed on Nepali researchers, Canadian research partners, students and farmers. Future partners include: regional research centres such as NARC, LARC and PAC; line agencies such as the Ministries of Agriculture, Forestry and Hydrology; Nepali educational institutions such as the Institute of Engineering and the department of Geology at Tribhuvan University; and NGOs due to their community focus. Institutions within the Hindu Kush Himalayan region could benefit from collaboration and information sharing through coordination between member countries. Closer collaboration between the Andes, Himal and African Mountain researchers would also be advantageous.

Dr. John Graham, IDRC Singapore, thanked all participants, specifically input from HMG line ministries, regional research centres, other watershed studies, the Peruvian involvement, Swiss participants, ICIMOD and the study team. The research conducted in the Jhikhu Khola watershed is truly collaborative, including graduate students and farmer participation with 40-50 households actively involved in the project. IDRC's focus is on Research for Development with benefits to farmers both current and future. The Jhikhu Khola project has met this objective by combining excellent science with bottom up farmer participation. IDRC provides an internet link through the PAN-ASIA network to support information exchange with other research institutions and will include the results of the Mountain Resource Management (MRM) project. This will contribute to the knowledge base and open interaction with various agencies. There is a need for additional, comparative case studies and for long term research. Continued support for the MRM project by IDRC is proposed. The potential exists to link the MRM project with visitors from other countries and from within Nepal.

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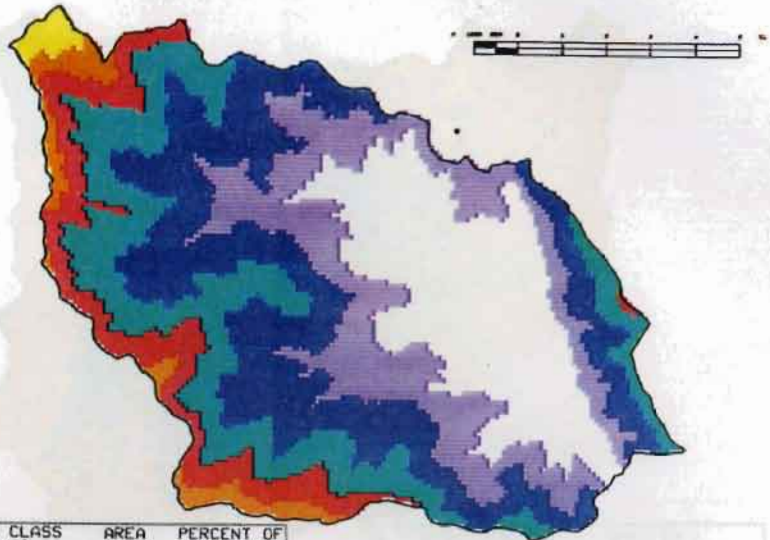
Appendix I - Plates

List of Plates

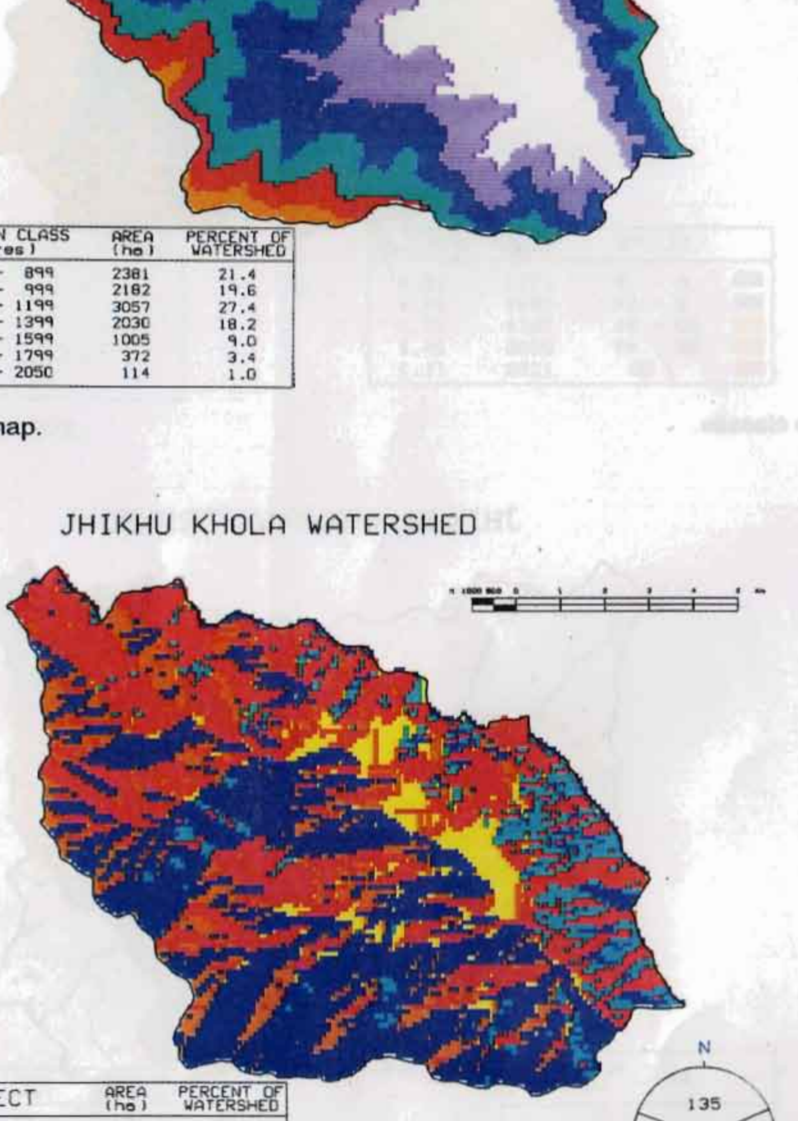
JHIKHU KHOLA WATERSHED



ELEVATION CLASS (metres)	AREA (ha)	PERCENT OF WATERSHED
750 - 899	2381	21.4
900 - 999	2182	19.6
1000 - 1199	3057	27.4
1200 - 1399	2030	18.2
1400 - 1599	1005	9.0
1600 - 1799	372	3.4
1800 - 2050	114	1.0

Plate 1. Elevation slice map.

JHIKHU KHOLA WATERSHED



ASPECT	AREA (ha)	PERCENT OF WATERSHED
FLAT	763	6.9
N, NE, NW	4336	38.9
EAST	1564	14.0
S, SE, SW	3678	33.0
WEST	800	7.2

Plate 2. Aspect map.

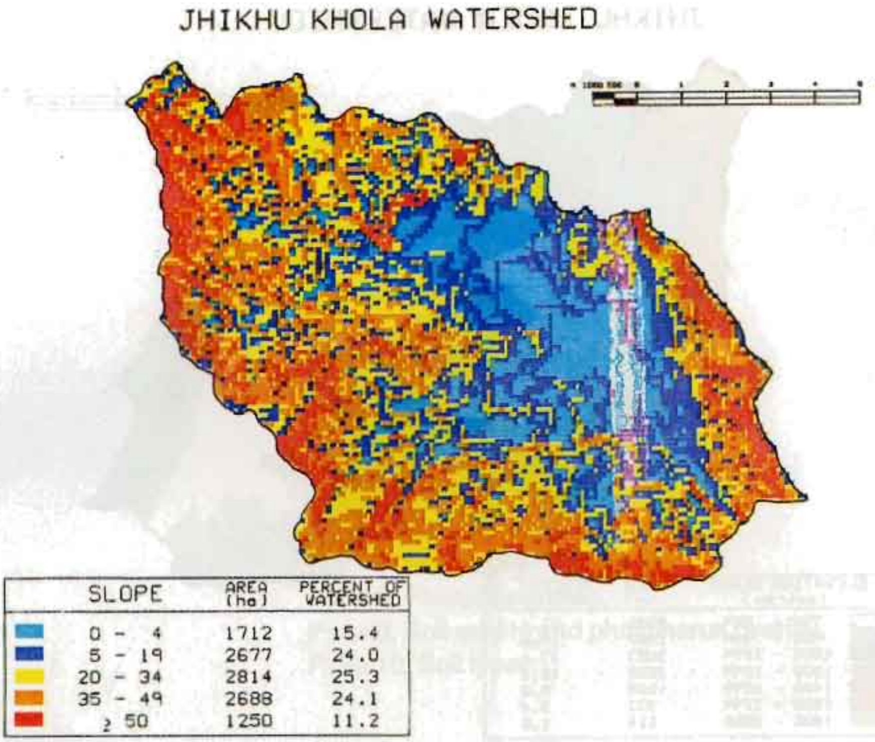


Plate 3. Slope classes.

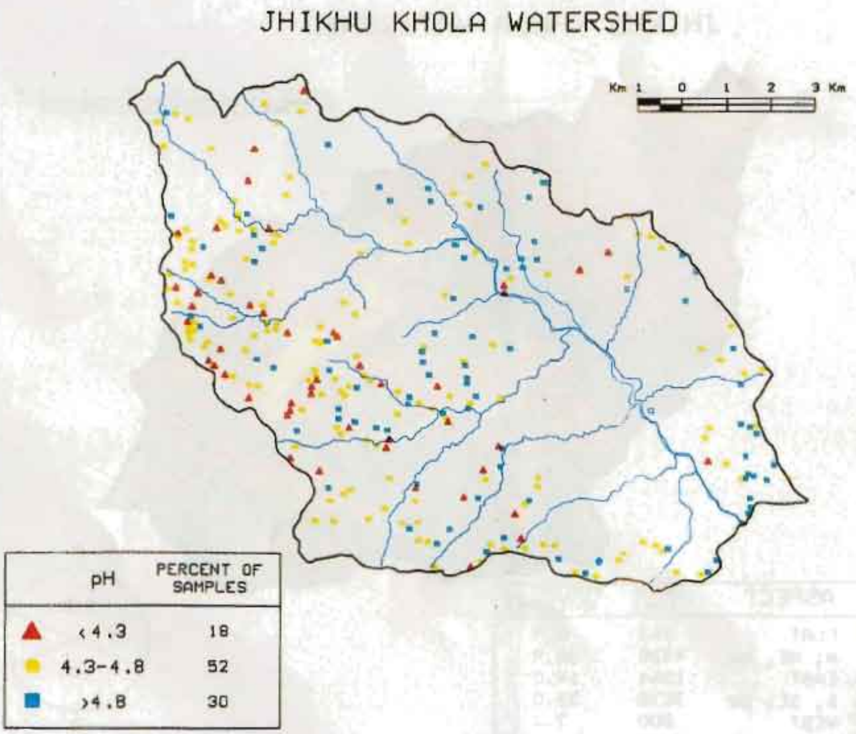


Plate 4. Soil acidity distribution.

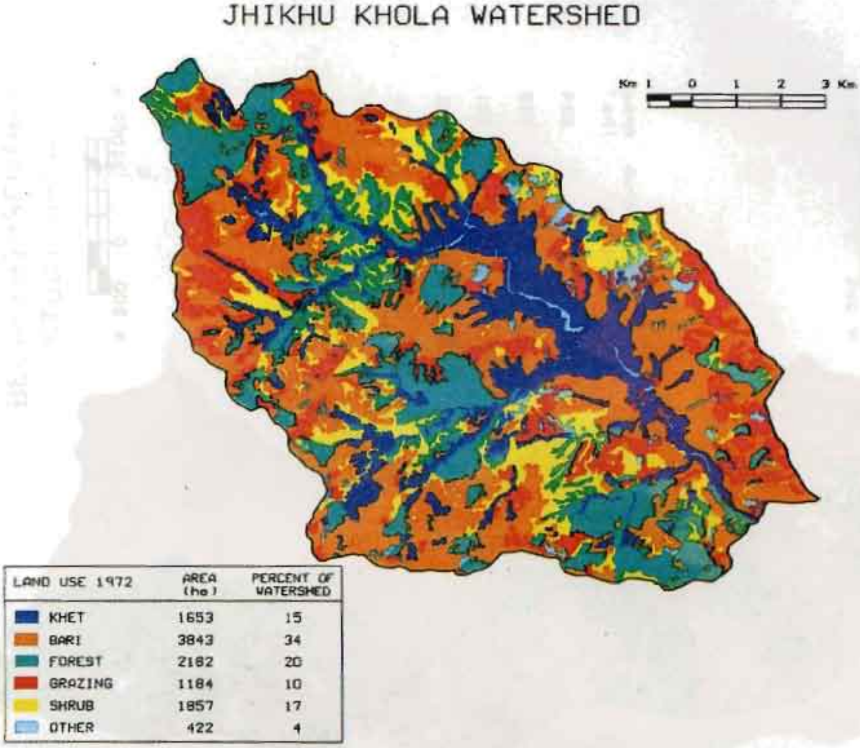


Plate 5. Land use map for 1972.

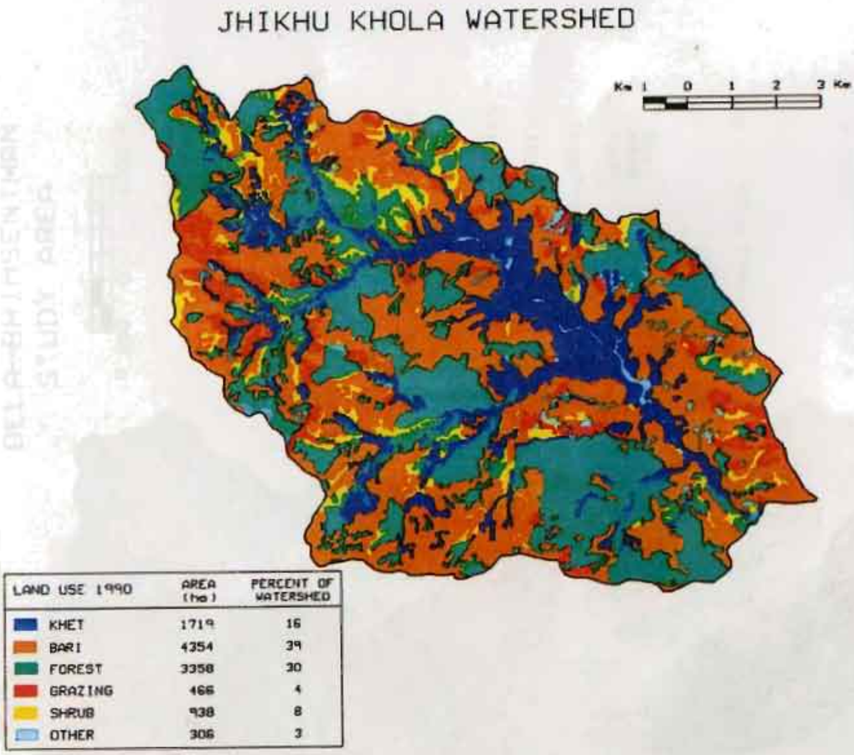


Plate 6. Land use map for 1972.

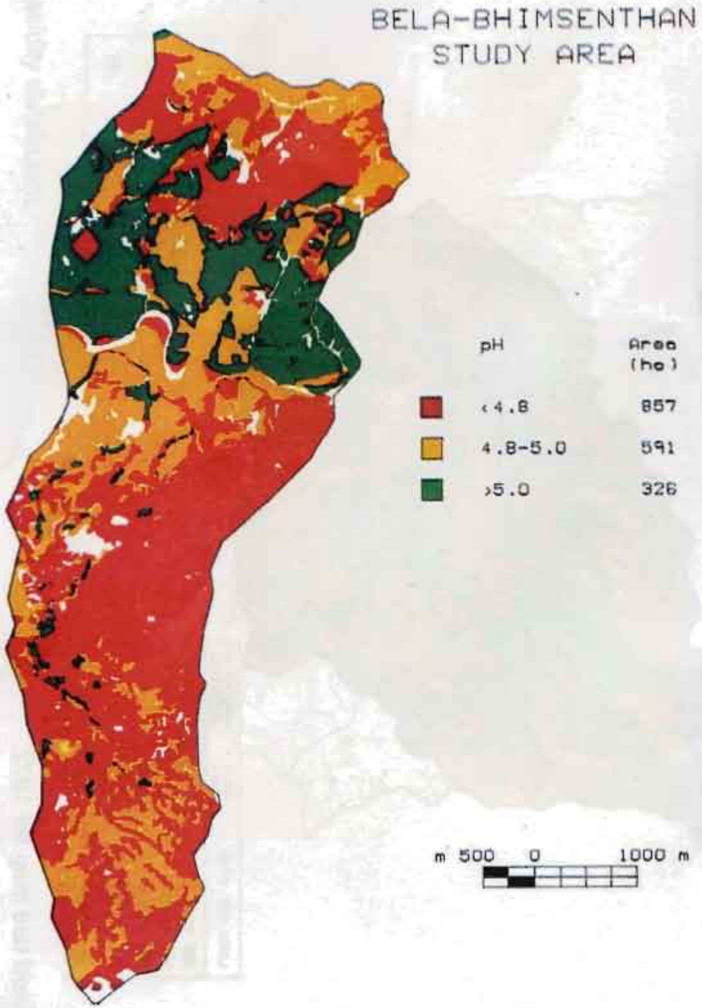


Plate 7. Soil acidity distribution.

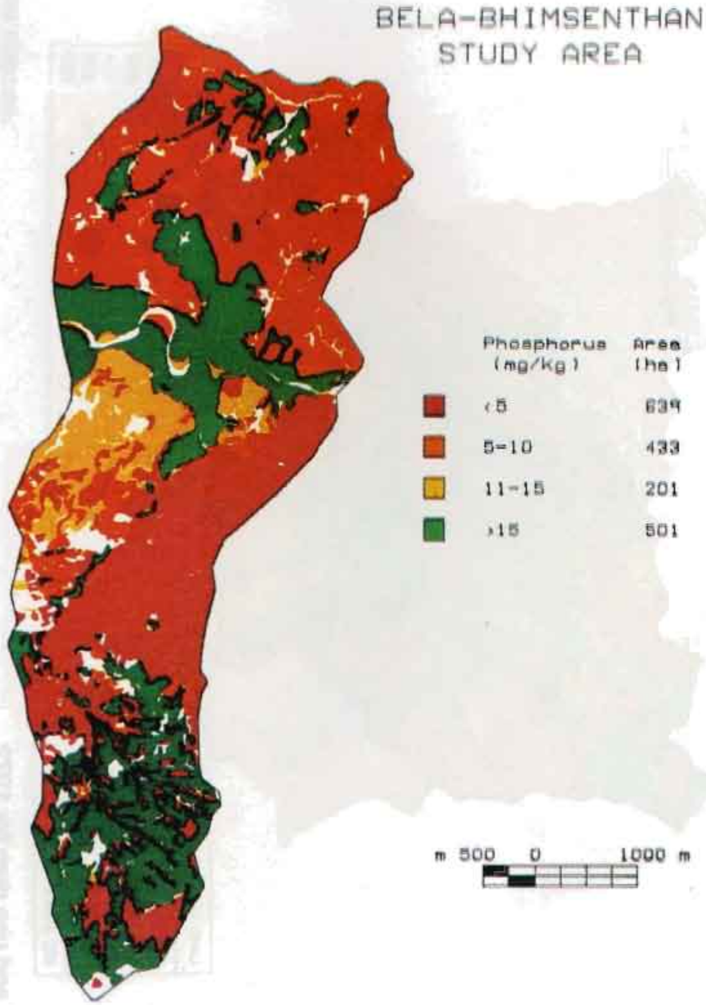


Plate 8. Phosphorus map.

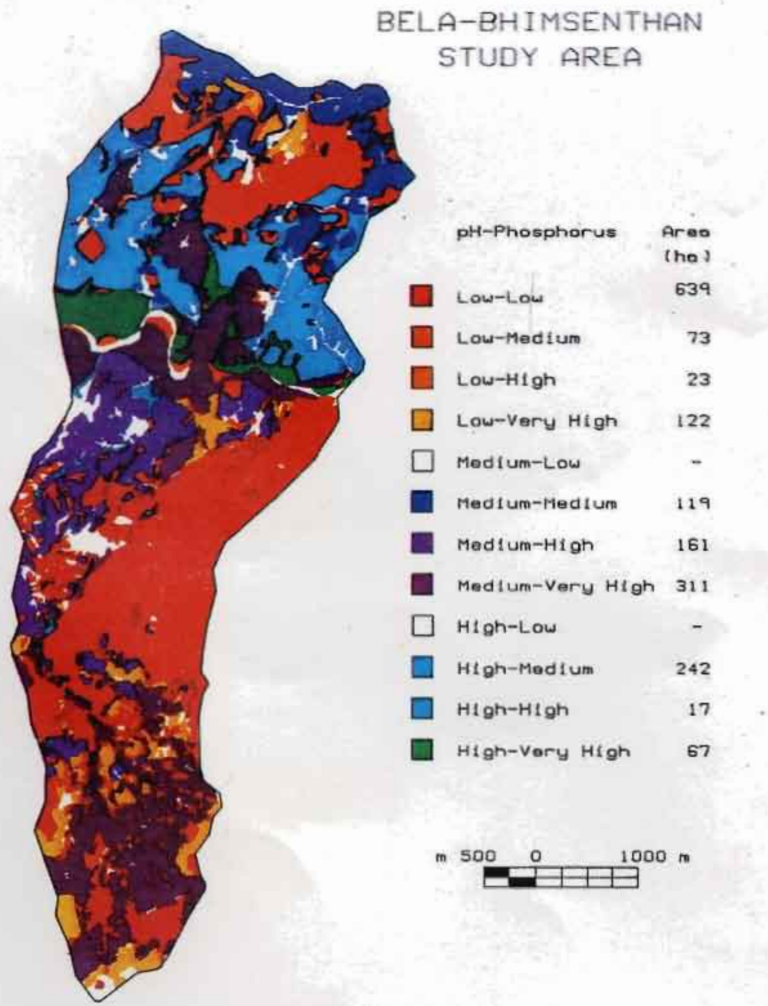


Plate 9. Soil acidity and phosphorus overlay.

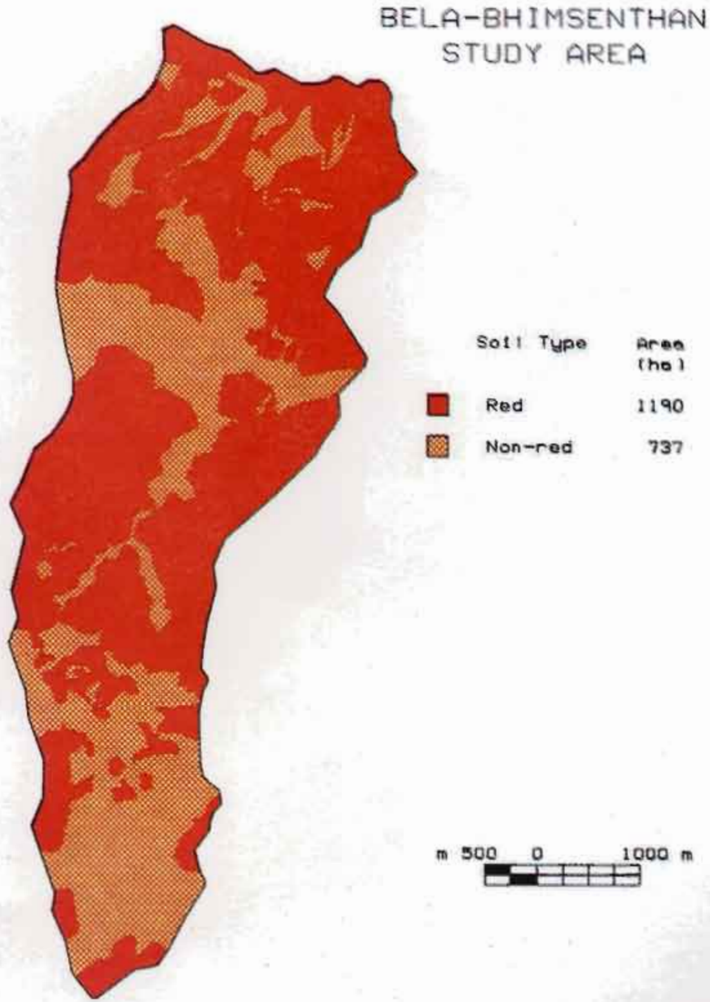


Plate 10. Soil types.

Participating Countries of the Hindu Kush-Himalayan Region

- Afghanistan
- Bhutan
- India
- Nepal
- Bangladesh
- China
- Myanmar
- Pakistan

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