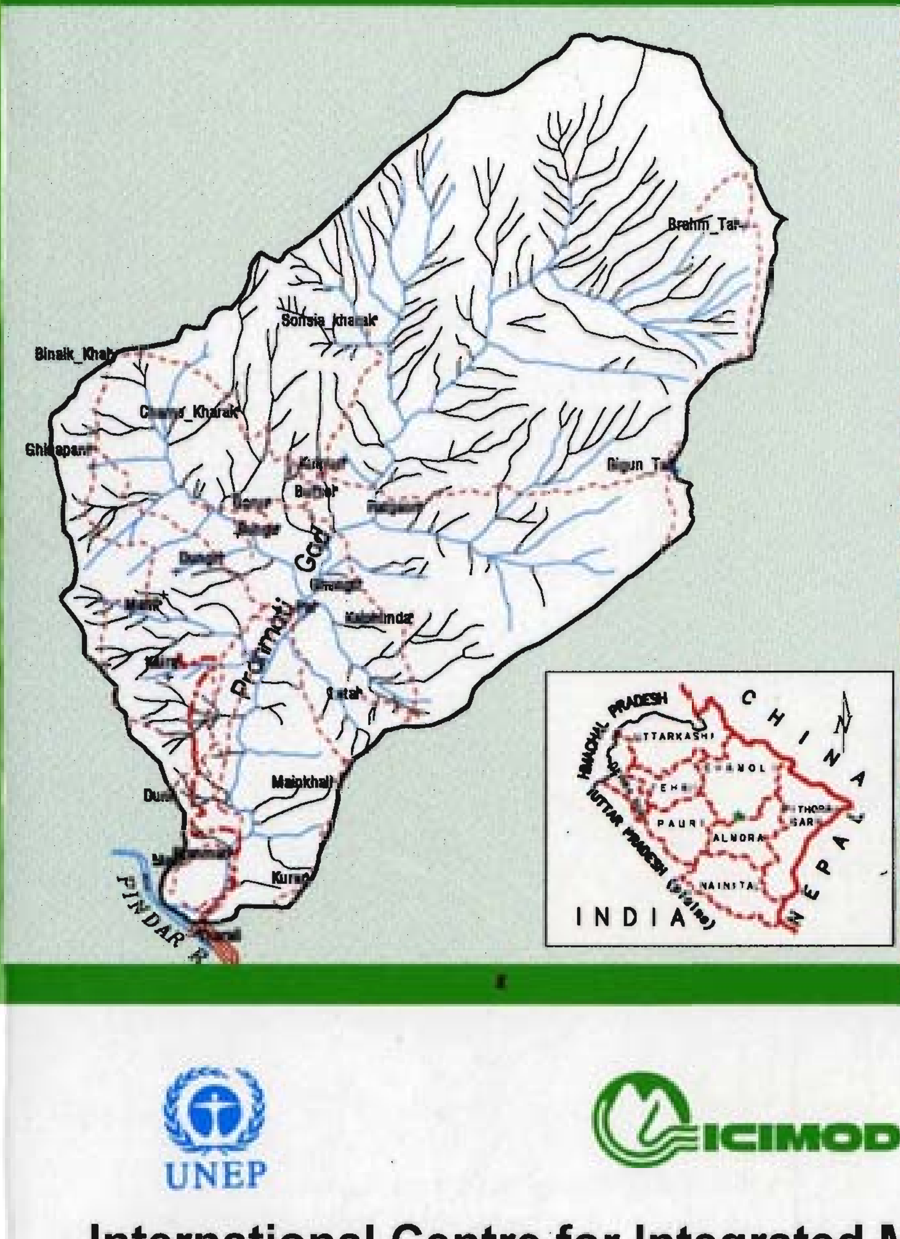
MENRIS CASE STUDY SERIES
No. 5

GIS Applications to Natural Resource Management and Development Planning in a Rural Area - Pranmati Watershed Garhwal Himalayas, India



UNEP
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International Centre for Integrated Mountain Development

Mountain Environment and Natural Resources' Information Service (MENRIS)
Kathmandu
July 1997

Cover photo: Map of Pranmati Watershed
Inset: IRS - 1B Satellite Image of Pranmati Watershed

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GIS Applications to Natural Resource Management and Development Planning in a Rural Area — Pranmati Watershed Garhwal Himalayas, India

Prepared by

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International Centre for Integrated Mountain Development (ICIMOD)

Mountain Environment and Natural Resources' Information Service (MENRIS)

Kathmandu

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FOREWORD

In the complex mountain environment of the Hindu Kush-Himalayas, development planning and decision-making for watersheds needs an integrated method of collecting, storing, and using information which is both concomitant and discrete.

Geographic Information Systems and Remote Sensing (GIS/RS) technologies are powerful tools that can improve the information base essential for sustainable mountain development. The strength of GIS/RS lies in their ability to integrate data and information on different subjects and from different sources using a common geographical reference. Since 1989, ICIMOD has developed a strong capability in the fields of GIS/RS through its Mountain Environment and Natural Resources' Information Service (MENRIS). Since the establishment of MENRIS, the G.B. Pant Institute of Himalayan Environment and Development (GBPIHED) has been a major partner in disseminating GIS /RS technologies in the Indian HKH region. The present case study provides a good example of application of GIS and Remote Sensing technologies for watershed development planning. The study demonstrates the power of such a technology to integrate and assimilate data from various sources, e.g., satellite images, census data, and field observations.

In the present study, the Pranmati Watershed, a representative micro-watershed, has been selected to depict the GIS/RS applications in natural resource management for watershed development planning. The Pranmati Watershed is based in the Ganges' system in Chamoli District of Uttar Pradesh in the Garhwal Himalayas. The text describes different aspects of GIS applications to natural resources' management and development planning. These applications are developed mainly for watersheds and village-level planning but could also be extended to any other unit.

This study is the result of a joint effort of the Norwegian Agency for Development Cooperation (NORAD), the Norwegian Agency for International Agricultural Development (NORAGRIC), the GBPIHED, the United Nations Environment Programme-Environment Assessment Programme-Asia and Pacific (UNEP-EAP-AP), and ICIMOD.

We express our sincere gratitude to NORAD, NORAGRIC, GBPIHED and UNEP-EAP-AP for infrastructural and financial support to this study. We wish to acknowledge the support extended by these and various other organisations whose officials and individuals have been of great assistance in the completion of this work.

Prior to this case study, ICIMOD published 'Applications of GIS for Natural Resource Management in Dhading District, Nepal' in 1992. It illustrated basic concepts and the use of GIS to demonstrate how data integration enables decision-makers and development planners to improve the management of natural resources. The second case study 'Application of GIS to Rural Development Planning in Nepal' was published in 1994. The illustrations presented both basic and advanced use of GIS and Remote Sensing applications in several districts of Nepal. The third case study was published in 1995, namely, 'Application of GIS for Planning Agricultural Development in Gorkha District of Nepal'. This study illustrated how decision-makers can (a) arrive at improved depictions of existing natural resources and infrastructure, (b) integrate natural science and socioeconomic data, and (3) use the information thus gained for improved area-specific planning and programme monitoring. The fourth case study 'Lamjung District Information System for Local Planning and Assessment of Natural Resources Using GIS and RS Technology' was published in 1996 and provides an extension to GIS knowledge and applications achieved in the previous three case studies. This fifth case study is the first depicting such applications in the Indian context.

Ghosh, S., Sen, K.K., Rana, U., Rao, K.S., and Saxena, K.G. from the G.B. Pant Institute of Himalayan Environment and Development (GBPIHED) are the primary authors of this study and have made an excellent contribution in preparing the final report. From MENRIS, Basanta Shrestha, Birendra Bajracharya, Govinda Joshi, and Mona Thapa provided assistance and support. Professor A.N. Purohit, ICIMOD Board Member and Ex-Director of GBPIHED, and Dr. L.M.S. Palni, Director of the GBPIHED, have been key mentors for this work. On behalf of ICIMOD we would like to thank them all for their contributions and the people of the Pranmati Watershed Area and various government/non-government officials for their cooperation. We would also like to express our sincere appreciation of the efforts made by Greta Rana and her editorial staff in preparing this document for publication.

Pramod Pradhan
Head
MENRIS/ICIMOD

Egbert Pelinck
Director General
ICIMOD

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GLOSSARY OF RELEVANT INDIAN AND LOCAL TERMS

Aloo:	Potato (*Solanum tuberosum*),
Anganbari:	Kindergarten and mother and child health care centre
Ayurvedic :	Based on traditional Indian herbal medical science
Banj:	Oak (*Quercus incana*), (*Quercus dialata / Q. semecarpifolia*)
Bhaikal:	*Princepia utilis* - an oil-yielding seed
Bhat:	Beans (*Glycine max*)
Bugyal:	Alpine meadow
Burans:	Rhododendron (*Rhododendron arboreum*)
Chir:	Pine (*Pinus roxburghii)*
Chiradh:	*Litseolea consimilis* - an oil-yielding seed
Chua / Ramdana:	Amaranth (*Amaranthus paniculatus*)
Chuli:	*Prunus americana* - an oil-yielding seed
Development Block:	Smallest planning unit
Gad:	Stream or river
Garhwal:	Western section of the Himalayan region falling within the Uttar Pradesh State in India, its boundary being demarcated by the district boundaries. The region is also populated by *Garhwali* speaking people.
Gehu:	Wheat (*Triticum aestivum*)
Gram Sabha:	Village council
Harijan:	the lowest social caste among Hindus enlisted among the Scheduled Castes by the Government of India
Jau:	Barley (*Hordeum vulgare*)
Jhangora:	Millet (*Echinicloa colunum*)
Lisa:	Pine resin (commercially tapped)
Mandua:	Finger millet (*Elusine corcana*)
Owa:	Barley (*Hordeum spp*)
Dhan / satti:	Paddy (*Oryza sativa*)
Panchayat:	Elected body of the Village Council
***Panchayat* Forest :**	Community Forest under the control of the village council (*Gram Sabha*), managed by people's representatives to cater to people's needs. The Forest Department carries the responsibility for providing technical inputs under the administrative control of the Revenue Department.
Protected Forest :	A class of forests set apart for environmental considerations.
Rajma:	Kidney beans (*Phaseolus lunetus*)
Reserved Forest:	Under the control of the Forest Department, which is also in-charge of earning revenue from commercial forests (Class II) and maintaining them to regulate the hydrological balance (Class I).
Ringal :	Temperate bamboo (*Thamnocalamus spathiflora*)
Van Panchayat :	Forest council consisting of elected members.

Abbreviations

DBH	Diameter at breast height (1.52 m)
ESRI	Environmental Systems' Research Institute
FCC	False Colour Composite (of image)
FSI	Forest Survey of India
FYM	Farmyard manure
GBPIHED	Govind Ballabh Pant Institute of Himalayan Environment and Development
GIS	Geographic Information Systems
ha	hectares
ICIMOD	International Centre for Integrated Mountain Development
ID	Identification number for a specific spatial feature
IRS	Indian Remote Sensing Satellite
MENRIS	Mountain Environment and Natural Resources' Information Service
NGO	Non-government Organisation
NORAD	Norwegian Agency for Development Cooperation
NORAGRIC	Norwegian Agency for International Agricultural Development
NRSA	National Remote Sensing Agency
PC	Personal Computer
RF	Representative Fraction (scale of map)
RMS	Root Mean Square (error)
RS	Remote Sensing
SoI	Survey of India
SML	Simple Macro Language (of Arc/Info)
spp	Species
TMU	Terrain Mapping Unit
masl	metres above (mean) sea level

N.B. Abbreviated forms of standard units of measurement are not given in the above list.

Data Sources

* Topographical Maps, 1963. Survey of India, Dehradun, India.
* FCC IRS-1B L2B 2 MAP-ID: 53N12. NRSA, Hyderabad, India.
* Primary Census Abstract, Chamoli District, 1981.
* Primary Census Abstract, Chamoli District, 1991.
* Rangers' Office, Department of Forests, Tharali, U.P.
* Public Works' Department Office, Tharali, U.P.
* Primary Data Survey by GBPIHED Team Members (1993-95).

Chapter 1

Management and Rural Development of Pranmati Watershed

1.1 Introduction

The watershed is an extremely important unit of natural resource management for sustainable development in the Himalayas. The basic objective of this study was to illustrate how integration of various types of data, such as remote-sensing data, census data, records from different administrative bodies, topographical data, and field observations using GIS can assist researchers, planners, project officers, and decision-makers in resource management. Creation of a spatial database is the first step in micro-level planning. This is followed by spatial analysis to help identify problem areas and, finally, the steps towards planning to mitigate problems are taken by marking out action areas. Taking a watershed as the spatial unit of study, appropriate physiographic and morphometric parameters were also taken into account to enable proper micro-watershed management.

1.2 Description of the Study Area

Pranmati Watershed (30°4'N and 30°13'N latitude and 79°28'E and 79°36'E longitude) (Plate 1) within the Pindar watershed is part of the Ganges River catchment area and situated in Chamoli District of Uttar Pradesh, India (see inset in Map 1, only the approximate geographical location is shown). Physiographically it is a part of the Garhwal Himalayas (part of the Central Himalayas). The planimetric area of the watershed covers 94.05 square kilometres, whereas the actual surface area of the sloping mountainous terrain is about 106 square kilometres.

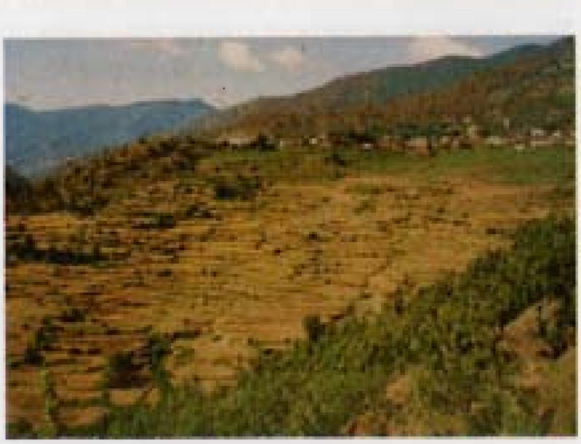


Plate 1: A general view of the watershed landscape of Pranmati at mid-elevations

Administratively the area is in the Tharali Development Block of Chamoli District. There are 21 revenue villages within this watershed, of which four (location code numbers 649, 650, 666, and 669) are only partly covered within the watershed (Map 2), as they are spread across the drainage divide. The important villages are Dungri, Gerur, Bunga, Ratgaon, and Kurar. The watershed comes under the jurisdiction of the 'West Pindar Range' of Garhwal Division. The entire watershed is a rural area with scattered villages with 10 to 90 households. The houses are made of stone, wood, and mud, with little use of cement. The sloping roofs are made of wood and covered with slate. The ground floor is usually for cattle, storage, and cooking. The upper floor has bedrooms and may also serve as a grain store (Plate 2). The people of the area speak *Garhwali* (a dialect of *Pahari*); although Hindi and English are used for educational and official purposes. The people are Hindu by religion and belong to different castes. Caste-wise segregation is prominent. The scheduled castes tend to own lands on the periphery of the villages.

Plate 2: A household in the watershed — the residential quarters are on the first floor and the ground floor is used as a store and cattleshed

The watershed is characterised by rich biodiversity, remoteness from motorable roads and the urban market, and vulnerability to rapid changes. Its natural environment makes it ecologically fragile. Lack of a motorable road and electricity in the watershed area indicate the level of seclusion. However, during the past 30 years, the area has been undergoing rapid changes in land use and, with the prospective new motorable road, the pace of change is likely to accelerate.

1.3 Approach

The approach adopted in the study was based on the following components.

1) The use of the topographic map of 1963 (RF 1:50000) as the base map for registration of geographical location, topography, and land-use status

2) The use of the 1993 IRS-1B image (RF 1:50000) supported by intensive ground truthing for mapping the present land cover-land use

3) The use of the Census of India's abstract data for demographic criteria.

4) The use of data from different government authorities to define administrative boundaries, planned roads, and others

5) The use of climatic data (1993-94) recorded during the study

6) The use of field observations for soil, crop, and livestock and phyto-sociological studies of vegetation

7) Various aspects of spatial data were automated by digitising them as separate coverages and defining attributes as required

8) The coverages were topologically corrected, intersection of different coverages and other spatial operations was carried out as necessary.

9) SML programmes and mathematical and statistical operations in 'tables' and dbase were used to derive the final statistics.

The following chapters analyse various aspects of natural resource and development dynamics.

Chapter 2

Database Development and Management for Micro-Level Development Planning

2.1 Introduction

Watershed management requires a three-tier management strategy focussing on: (i) a micro-regional planning approach, (ii) the analysis and appraisal of the biophysical and socio-economic environs, and (iii) agro-ecological zoning. The necessity for a micro-regional approach to planning arises primarily because the actual conditions of watersheds vary, depending on the local, biophysical conditions, population pressure, and natural resource conditions (Thapa et al. 1992). Due to the interdependence of biophysical environs and socioeconomic conditions both aspects need to be assessed for sound micro-regional planning.

The database can be updated in every respect. For village-level (i.e., *Nyaya Panchayat* level) planning, census data can be added every ten years in order to visualise demographic trends. The data in Arc/Info can be viewed in ArcView giving a better illustration for decision-makers. By using a specific growth rate, projections for the future are also possible.

2.2 Methodology

1) Available information from various sources, such as the Survey of India, Forest Department, Revenue Department, Public Works' Depatment, and District Administration, was used to compile the maps presented here. The Geographic Information Systems' software Arc/Info (from ESRI, U.S.) was used to prepare the database. The software was run on a PC-based platform for digitisation, analysis, and map preparation. Final outputs were processed on a IBM RISC based workstation.

(2) The Survey of India topographic sheets for 1963 on a scale of 1:50,000 were used as the basis for registration and digitisation. The maps were based on an International Modified Polyconic Projection.

(3) Climatic data collected from four recording sites in the watershed were used to extrapolate the temperature and moisture regimes.

(4) Elevation data were extracted from a topographical map on a scale of 1:50,000. Elevation and other parameters derived from contours (viz., slope and aspect) were segregated by isopleths for classification. Initially, contours were digitised at 20m intervals, later, for land classification, 200m intervals were selected. Aspects were manually segmented from the topo sheet.

(5) Mapping of natural resources, such as forest area, agricultural area, pastures, and wastelands, was based on revenue records, maps available with the Forest Department, and visual interpretation of satellite data with sufficient ground truth.

(6) Population data from 1981 and 1991 were obtained from the Census of India Abstract and the District Statistical Handbook. Demographic maps were prepared for each census year and comparisons made between 1981 and 1991.

7) Village boundaries were based on revenue maps of the Census of India (1981) and were fitted as closely as possible to the base map derived from topographical sheets.

8) Livestock data were collected by members of the team. To facilitate comparison, cattle, horses, sheep, goats, and poultry were converted into livestock units (or cow equivalents) which are based on food requirements (Lalwani 1988; Swarup 1991, 1993). This system presents animal population in cow units.

2.3 Results

(1) The database derived showed that the revenue map boundaries for villages in some places did not coincide with the topographical features on the topo sheet. Intensive ground work was carried out to match the boundaries.

(2) The watershed is a fifth-order river basin, with 240 first-order streams, 54 second-order streams, 14 third-order streams, and four fourth-order streams. The average bifurcation ratio (Rb) is 3.95 (Strahler 1952). Thus, the drainage network can be classified as mature. The total length of the drainage system is 262km, of which the first-order streams constitute 164.4km. The average drainage density is 2.79km/km^2 and the average drainage texture (i.e., number of stream segments per unit area) is 3.33 segments/km^2. Both perennial and seasonal streams are present in this watershed (Map 1). Seasonal streams generally have steep gradients, rapids and waterfalls, and a high proportion of bedload with which the channel is filled during dry season. Perennial streams, though fewer, are longer and provide water for powering, watermills and, to some extent, for irrigation and other needs.

(3) Altitudinal zonation of the watershed reflects a gradual rise in elevation throughout from a minimum of 1,120 to a maximum of 4,070masl at its northern limit at Jatropani (northernmost point of the watershed in Map 3). The longitudinal section of the trunk stream (Pranmati) shows a normal concave profile with a gradual descent and no major break-of-slope. It is only upstream of 2,400masl where the gradient is higher due to hard rock and a high rate of downcutting (Fig.1).

(4) The main part of the watershed has an average slope of 20^o - 30^o (Map 4). Areas with very high slopes (> 45^o) or very gentle slopes (< 10^o) are limited. Table 1 gives some indication of watershed area distribution in relation to slope classes, and Table 2 gives some indication of area distribution according to slope aspects.

5) As the trunk stream runs roughly from north to south, the topographic aspects of the landscape are predominantly south-east or west facing (Map 5).

6) One large landslide (0.20km^2) at the lower end of the major settlement is causing severe communication hardships to the local populace (Map 6). Minor landslides and landslips

Figure 1: Longitudinal Profile of Pranmati *Gad* (Stream)

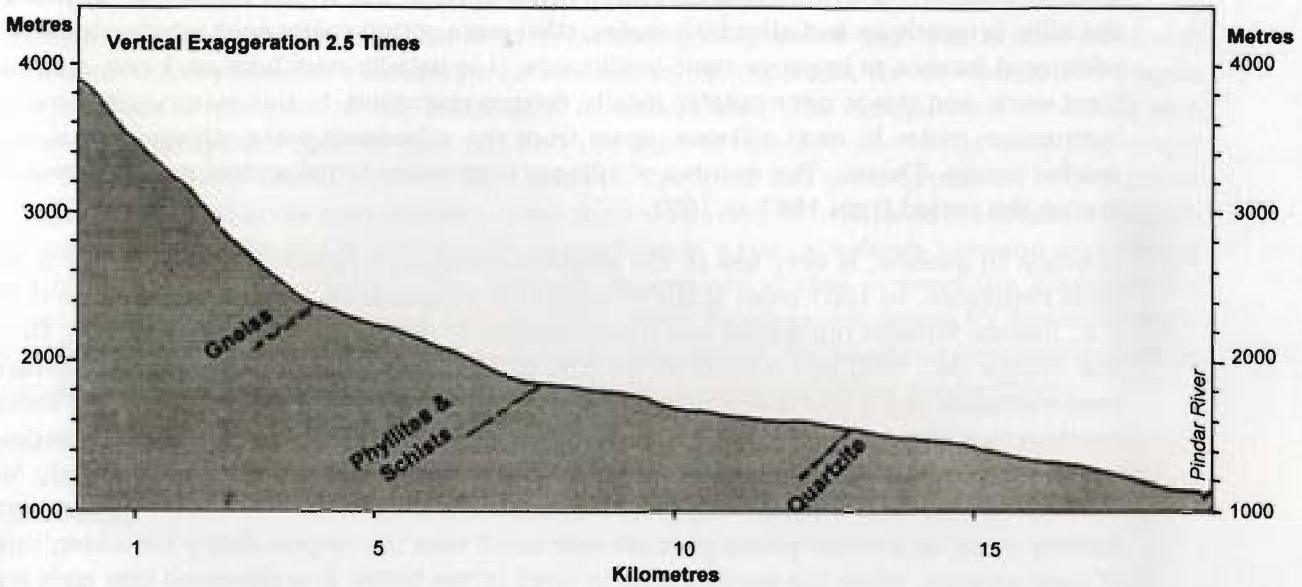


Table 1: Distribution of Watershed Area in Different Average Slope Classes

Average Slope (in degrees)	Geographical Area (ha)	% of Total Area
< 10	32.9	3.5
10-20	136.6	14.5
20-25	206.9	22.1
25-30	251.7	26.8
30-35	215.6	22.9
35-40	77.1	8.2
40-45	18.8	1.9
> 45	00.9	0.1
Total	940.5	100.0

Table 2. Distribution of Watershed Area in Different Slope Aspects

Aspect	Geographical Area (ha)	% of Total Area
N	14.1	1.5
NE	33.4	3.5
NW	68.5	7.3
E	207.1	22.1
W	231.8	24.6
SW	191.0	20.3
SE	103.5	11.0
S	91.2	9.7
Total	940.5	100.0

are found in various places, e.g., near the villages of Dungri and Ratgaon. Rockfalls are common in the high altitude region.

7) The transportation network in the watershed area is based on pack tracks and footpaths (Map 1). The road construction, once completed, will have a prominent impact on the ecosystem of the watershed (Map 6). The road has been designed to traverse the major landslide and will cut across agricultural lands and forests and, more importantly, through slopes which are more prone to slope failure, leading to an added loss of productive land.

8) Population density is far below the national average. However, in the context of the Himalayas (Swarup 1993), above 40 persons per km^2 is considered a relatively high density (Map 2), and it is to be noted that the entire village area is not habitable due to steep slopes, forests, rocky terrain, and land stability hazards. The villages having large areas of relatively gentle slope lands are more densely populated.

9) Sex ratio (i.e., number of females per 1,000 males) in the hills generally indicates that there are more females than males in rural areas. This is because the poor economic conditions in rural areas, *inter alia,* and the glamour of city life encourage younger men to

migrate from rural to urban centres for employment, which may not necessarily result in a better standard of living (Swarup 1993). Since agriculture, which yields low returns in the hills, is mostly looked after by females, their male counterparts seek jobs/business for additional income to improve their livelihoods. It is usually men who seek non-agricultural work, and this is not available locally, forcing migration. In this watershed, females outnumber males in most villages, apart from the scheduled caste villages and in the market centre, Tharali. The number of villages with fewer females than males increased during the period from 1981 to 1991.

10) Literacy, in general, is very low in the western Himalayan region. Female literacy is almost negligible. In 1981 most of the villages had female/male literacy ratios below 0.25 (i.e., literate females numbered less than a quarter of the number of literate males). Only one village (No. 668) had a ratio above 0.5. In 1991, the positive female/male literacy ratio increased to 0.5 and above in most villages. This low literacy ratio is a result of social customs that restrict the girl child from receiving education and a result of difficult access to school. Schools in every village would help to improve literacy rates, particularly for women. Another factor restricting female education is the low standard of living and high fertility rates, as a result young girls are entrusted with the responsibility for taking care of their siblings, while the mother goes to work in the fields. It is observed that girls are very eager to receive a proper education for a variety of reasons (Swarup 1993).

11) The scheduled caste population is distinctly high in certain villages (e.g., Harinagar, Darmola Chak Dungri) and significantly low (less than 30% mostly) in others, indicating social segregation in the area. In 1981, five villages had no scheduled caste population and in 1991 this number increased to seven. Harinagar (No. 661) had the highest (> 90%) percentage of scheduled caste population in 1981, and in 1991 it was accompanied by Darmola Chak Dungri. A comparison between 1981 and 1991 figures leads to the inference that out-migration of the scheduled caste population to sparsely populated or uninhabited villages has taken place due to shortage of agricultural land and fodder supplies.

12) Although greater numbers of villages show a rise (positive growth) in population in accordance with the average trend, some reveal a decrease (negative growth) (Map 7). This has been mainly due to out-migration of a section of the villagers to a neighbouring (previously uninhabited or sparsely-populated) village. Such incidences are known to have taken place in Darmola Chak Dungri (from Dungri), Pai (from Bunga), Sosia (from Kolpuri), and Koppar (from Ratgaon). The out-migration was induced by the need for agricultural land to meet the demands of the growing population and declining production from the existing agricultural land. The out-migration mainly involved the scheduled castes, though not exclusively.

13) The occupational structure of the inhabitants of this area is predominantly in the primary sector (according to the District Primary Census Abstract 1991); and most people are cultivators.

14) The livestock population includes cows, buffaloes, mules, horses, goats, sheep, pigs (only in the scheduled caste villages), and poultry. The density of livestock is particularly high (above 8 units per hectare) in large and populous villages such as Dungri and Ratgaon. Other villages have four to five units of livestock per hectare. Thus, improvement in fodder production would be a priority in Dungri and Ratgaon but not in other villages. The bovine population is reared for milk and milk products, organic manure, and draught power. Buffaloes are stall-fed, whereas cows are grazed on nearby open lands. Goats are fed upon agricultural wastes and oak fodder for six months and taken to alpine pastures for the warmer half of the year. Horses are fed on barley, grams, and grass. Sheep and goats are sheared twice a year, and some of the wool is spun locally.

2.4 Conclusions

Development programmes must be built upon ecologically sound land use in this particular ecosystem. Environmental considerations become more important for an ecologically fragile ecosystem as in the case of the Himalayan mountain area. The occupational structure also reflects the ecosystem-specific land use and the natural resource use in the area. The major land use is of forest lands, whereas land used for cropping and grazing/pasture is of a minor category (discussed in the next chapter). Since the productivity of farm lands is sustained through the inputs derived directly or indirectly from the forests, a critical balance between agricultural and forest land use is required. The available forests are unable to meet the sustainability criteria (Singh et al. 1984; Rao and Saxena 1994). Here, development action for agriculture will have to go together with forestry and tree-based occupations. Value-added production must be introduced and encouraged, in addition to efforts to improve biological productivity.

With the database created it will be easier than it was previously to identify resource-deficient or resource-surplus villages. Demographic conditions can also be assessed and decisions taken accordingly.

Chapter 3

GIS Applications in Monitoring Land-cover / Land-use Changes

3.1 Introduction

Land is a finite resource. Population pressure beyond the carrying capacity of this resource has caused environmental problems and affected the standard of living of the inhabitants. The availability of land in the hills is said to be greater than in the plains, if population density per unit area is considered. But the effective availability of land is also actually very low, if farm holding sizes and rights of local communities to government-owned forest lands are considered.

Information on existing land use and land cover, its spatial distribution, and changes are essential prerequisites for planning (Anonymous 1992). Land-use or land-cover changes are critically linked to a combination of natural and human impacts. Changes in land cover contribute significantly to changes in the state of the biosphere and bio-geochemical cycles. These changes are driven by a complex set of interacting factors (Turner 1995). An improved understanding of the dynamics of land-use/land-cover changes provide a means for projecting the impacts of land use and future responses. Thus, land-use planning and land management strategies hold the key to development in the region. Geographic Information Systems (GIS) provide an effective tool for analysis of patterns and causes of land-use dynamics and for planning management strategies. This is even more important in mountainous regions where the physical constraints make it difficult to update the information frequently. The rural systems in the Himalayas are so diverse that careful consideration of location-specific attributes become a precondition for ensuring the success of development efforts (Saxena et al. 1994a).

3.2 Methodology

3.2.1 Building the Database

The base map was derived from the Survey of India topographic map (on a scale of 1:50,000). Broad land-use types, such as cultivated land, settlement areas, forest areas, bare rock surfaces, and wastelands, were digitised from this map. This provided the land-use / land-cover status for

1963 (Map 8). To simplify matters, only the planimetric area was considered. Visual interpretation of a geometrically corrected IRS image from 1993 provided the base for land use in the 1993 land-use / land-cover delineation (Map 9). An extensive field survey across the watershed provided the ground truth to support the visual interpretation. Two hundred and forty representative units of 0.1ha plots in the watershed were studied in detail.

3.2.2 Data Processing and Information Input

Both maps from 1963 and 1993 were digitised on common coordinates and the changes in land use were derived through overlay operations. As the extent of the study area was not too large, few errors occurred in fitting the geometrically corrected and geo-referenced RS image with the base map. Even when digitising from a remote-sensing imagery-based map, the RMS (root mean square) error was kept within a limit of 0.005. Various analyses of land-use changes in the period from 1963 to 1993 were interpreted. Statistical analysis was carried out using Arc/Info Tables and SML macros.

3.2.3 Methods of Analysis

Primary data collected from 1993 to 1995 were used to establish the database. Using overlay (UNION, INTERSECT, IDENTIFY) and Boolean operations with Arc/Info, the land-use changes from 1963 to 1993 period were identified (Map 10).

The average slope was calculated by constructing a grid of 0.5km x 0.5km squares. The number of contour intersections were counted and applied to the formula (Wentworth 1930) to derive the average slope for each square. Finally, isopleth lines were drawn to produce the 'Average Slope' map (Map 4, Table 1, Chapter 2). This map was 'intersected' with land-use maps to derive information related to slope-land use interaction.

Topographic characteristics, such as elevation zones and aspect (direction of slope face) were interpreted from the topographical sheets. Similarly, the land-use map was 'intersected' with these topographical parameters to derive the changes in distribution of various land uses with respect to these parameters over time. These changes are described in detail in the context of forest cover (Chapter 4) and agriculture (Chapter 5).

Land facing 'accelerated erosion' was identified based on present land use and average slope features (Map 11). Cleared land with moderately high slopes (greater than 25°) is likely to be vulnerable, and erosion risks increase when such land is close to human settlements or thoroughfares. Ecological habitats or '*biotic niches*' were demarcated based on an integrated consideration of temperature, slope, aspect, elevation, soil moisture levels, geological features, and so on. These limits determine the vegetation distribution, land suitability, and, most critically, the growing period which determines the production potential of the land. This system of classification was an attempt to elaborate upon the agro-ecological zoning approach to meet the needs of micro-level resource evaluation and land development planning.

3.3 Results

1) Areas under major types of land use/land cover for 1963 and 1993 are given in Tables 3 and 4. Cultivated area includes all agricultural land and settlement areas. Forest areas include Village *Panchayat* forest (a patch of forest managed by an administrative body elected by the villagers and accessible to all villagers) and forests under the jurisdiction of the Forest Department. Alpine pastures occur generally above the elevation of 3,200masl on the southerly aspects in this watershed and are interspersed with large rocky surfaces. Alpine pastures have been grouped together with bare rock surfaces as details were not

available from the 1963 topographical map. However, such differentiation was possible from interpretation of the 1993 IRS image.

2) Changes in the area under major land-use and land-cover types were derived (Map 11, Table 5). This showed a significant increase in cultivated area as a result of conversion of previous forest or pasture land to agriculture. However, some areas also revealed an opposite trend where a portion of the agricultural area was afforested.

Table 3: Land Use / Land Cover 1963

Type	Area (ha)	% of total area
Cultivated	113.26	12.04
Pastures	10.96	1.16
Forests	704.15	74.87
Bare rock and Alpine meadows	112.13	11.93
Total	940.50	100.00

Table 4. Land Use / Land Cover 1993

Type	Area (ha)	% of Total Area
Cultivated	176.26	18.74
Pastures	18.84	2.00
Forests	615.60	65.00
(degraded forests)	(65.20)	(6.90)
Bare rock	62.34	6.63
Alpine meadows	52.00	5.53
Total	940.50	100.00

Table 5. Land-use / Land-cover Changes 1963-1993

Change in Land Use	Area (ha)	% of Total Area
New agricultural lands	9.504	10.10
New pastures	1.578	1.68
Loss of forest areas (to agriculture/pasture)	1.514	1.61
Regenerated forests	3.297	3.50

3) *Land vulnerable to accelerated erosion.* Significant proportions of agricultural and grazing land are likely to be facing accelerated soil erosion (Plate 3) due to overuse of sloping land (more than 25° average slope). Land protection measures are necessary in these areas (Map 11). Such measures include building very gently sloping (less than 4°) terraces for cultivation, promoting grass growth together with tree plantation on steep slopes, agroforestry in moderate slope areas, and proper tillage practices for soil conservation.

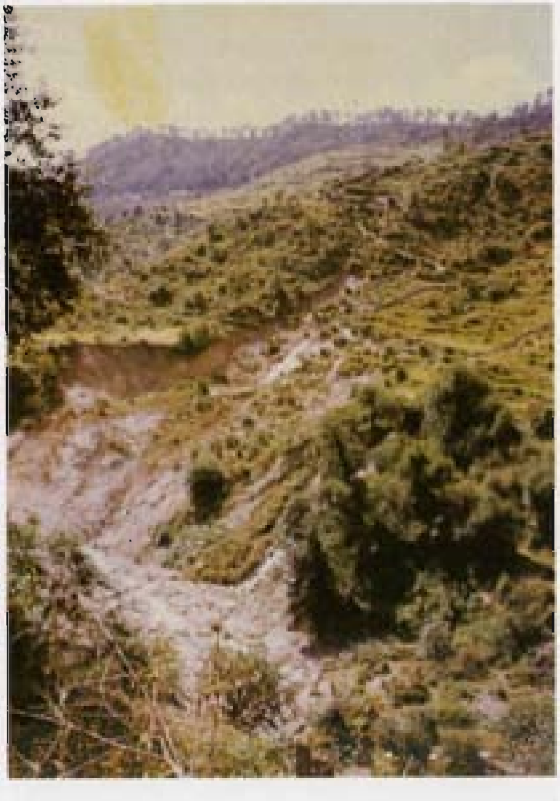


Plate 3: Erosion threatening agricultural activities

4) Since details of sub-classes of forest cover were not available for 1963, changes in forest cover density or type could not be derived. However, it can be inferred that total forest cover has decreased from almost 75 per cent in 1963 to 65 per cent in 1993.

5) However, details of changes in agricultural land and settlements could be analysed through comparison of their spatial distributions in 1963 and 1993. Changes in land-cover/land-use were found to be greater near settlements (Map 12). Agricultural and settlement areas increased from 12 per cent in 1963 to 19 per cent in 1993 due to population pressure.

6) Sixteen micro habitats or *biotic niches* were discernible in the watershed (Map 13). These are distinguished by different temperature and moisture regimes and, thereby, their vegetational characteristics. This map can be used to determine the bioclimatic conditions of different categories of land, such as agricultural extensions and regenerated forests, and for crop suitability tests for agriculture and forestry.

3.4 Conclusions

Changes in land use were inferred for the period from 1963 to 1993. Cultivated land had increased significantly at the expense of forests and pasture land. Large tracts of degraded forests were located adjacent to newly-extended agricultural lands, but degradation could not be specified spatially or quantified due to the lack of data for 1963. The extension of agriculture to higher altitudes has been mainly brought about by increase in potato cultivation for economic development. Various aspects of agricultural land extension have been discussed in the following chapters.

The encroachment of government forest areas was found mainly to have been practised by rich villagers. The fact that the offenders employ labourers to set up stone walls to fence the encroached land suggests that the economic conditions of the concerned people are good. On the other hand, new settlements have been established on village wastelands and open forests within the village, mainly by the poor and scheduled castes. The government policy to support scheduled castes led the poor to unite and migrate to uninhabited villages (as in the case of Darmola Chak Dungri during the last 15 years) and bring uncultivated village land (cultivable wastes) under agriculture.

Chapter 4

APPLICATION OF GIS AND REMOTE-SENSING TECHNOLOGIES TO FOREST MANAGEMENT

4.1 Introduction

Remote Sensing has proved its potential for providing information on forests and GIS help to integrate the information from various sources and on different themes. Remote Sensing can help in: (a) forest mapping with the possibility of classifying various forest types into crown density classes (Singh 1991, NRSA 1983, FSI 1989); (b) monitoring land development programmes, e.g., afforestation (Saxena et al. 1991); (c) forest biomass mapping using appropriate models which relate field-measured biomass data to remote-sensing derived maps (Tiwari 1994); and (d) charting fuelwood and fodder availability maps through the assimilation of field measurements of quantitative proportions of fodder-yielding trees, and field verified annual fuelwood fall data into a forest biomass map derived from remote sensing (Saxena et al. 1991). Wood constitutes the main source of energy in the watershed. Domestic needs for fuelwood are met by collection from the forests (Plate 4). Overexploitation of forest resources is occurring due to the economic needs of a growing population (they sell firewood, often in the form of logs, to urban areas) (Plates 4 and 5). Trees are rarely found on crop lands. Agro-horticultural systems are lacking here (Saxena et al. 1994a).

The Pranmati Watershed covers 94.05sq.km., of which 61.59sq.km. (about 65%) is under forest cover (Table 3, Chapter 3). However, the crown cover varies greatly depending on the vegeta-

Plate 4: There is plenty of fuelwood, but market forces encourage harvesting for export of even unsplit larger branches/ logs

Plate 5: Export of fuelwood to an urban market

tion type and human use impact. Pine (*Pinus roxburghii*) and oak (*Quercus incana*) dominated mixed forests have dense crown cover at lower elevations. At higher elevations, rhododendrons in association with other oaks (*Quercus dialata / Q. semecarpifolia*) form dense cover. The pine wood has value as timber and its selective felling is regulated by the government. Forest fires do considerable damage. To some extent, aspect affects the type of vegetation, causing deviations from altitudinal control. Southerly- and westerly-facing slopes tend to be warmer, hence vegetation distribution limits are pushed to slightly higher altitudes. The Alpine meadows (not considered here under forest area) are part of the natural vegetation which occurs above 3,000 to about 3,400masl. Pine and oak forests near settlements have become degraded largely due to lopping (cutting of branches) and felling. These are identified as open pine and oak forests (Plate 6). Excessive lopping is denuding oak forests throughout the Uttar Pradesh hills. *Ringal* (*Thamnocalamus spathiflora*), a species of temperate bamboo, is found growing profusely as an undergrowth in mixed forests. Other types of undergrowth consist of *Princepia utilis, Pyracantha crenulata*, and others. The trees comprising the mixed forests are *Q. dialata, Q. semecarpifolia, Lyonia ovalifolia, Neolitsea umbrosa, Cornus capitata*, and *R. arboreum*. Round timber, fuelwood, resin, and bamboo are the important forest products found in the area. Local knowledge on diverse uses of forest products is quite rich.

Plate 6: Trees are lopped excessively to meet the fuel and fodder requirements

4.2 Methodology

The forest areas (depicted in green) on the topographical sheet of 1963 were accepted to depict the extent of forest cover in 1963 (Map 8). This area extended even outside the marked reserved forest area directly under the control of the Forest Department. The 1993 status was visually interpreted from the geometrically corrected and geo-referenced IRS FCC image, taking into consideration the hue, intensity, and altitudinal position in each case. The image was interpreted in respect to vegetation type and crown cover density (Map 9). The differences between the 1963 and 1993 maps with respect to total forest cover were interpreted to be the actual changes in forest cover (Map 10). The results were verified in the field and necessary corrections were incorporated.

Phyto-sociological studies of different forest types were carried out on the basis of altitude, aspect, slope, and so on. Study of tree cover, density, diameter at breast height (DBH, i.e. at 1.52 metres from the ground), and regeneration of tree species were conducted.

The vegetation crown cover density was classified and qualitatively defined as follows: >60% = Dense Forest; 30% - 60% = Open or Degraded Forest.

A Forest Classification map (administrative status) was derived from the working plan maps (originally on a scale of 1 inch : 2 miles) of the Forest Department (Map 14).

Changes in total forest cover were identified in different categories, e.g. transformation to pasture land and transformation into agricultural land (Map 10, Table 6).

4.3. Results

1) The altitudinal distribution of forests shows that the proportion of forest cover is a maximum of 2,400-3,000masl and 1,200-1,600masl elevation zones.

2) In 1963, almost 75 per cent of the total watershed area was shown to be under some kind of forest cover (Map 8), whereas in 1993 it decreased to about 65 per cent (Map 9, Table 7).

3) The distribution of tree species was mapped by combining information on altitude, aspect, and vegetation features as interpreted from the RS image.

Table 6. Extent of Deforestation (1963-93)

Changes	Area (ha)	% of Total Area
Forests to Agriculture	90.5	84.0
Forests to Pastures	1.6	14.6
Forests to Landslides	0.1	1.4
Total Deforested Area	92.2	100.0

Table 7. Vegetation Types as Interpreted through Visual Interpretation of an IRS Image from 1993-Supported by Field Study

Vegetation Type	Area (ha)	% of Total Area
Dense mixed forests	223.30	23.24
Dense oak-rhododendron	195.70	20.81
Dense oak	13.30	1.42
Open oak*	39.70	4.23
Open oak-pine	6.20	0.66
Dense pine	118.20	12.58
Open pine*	19.20	2.05
Total	615.70	65.00

* Degraded forest

4) The legal administrative status of forests is depicted in Map 14.

5) Degraded forests have a distinct relationship to cleared lands, including the agricultural areas (Map 15). Degraded forests are on the periphery of agricultural lands and in easily accessible areas.

6) The loss of forest areas to other land uses (Map 10 and Table 6) was about 10 per cent of the total geographical area in the watershed, which implies that 14 per cent of the total forest area in 1963 was deforested over a period of 30 years. Encroachments on *Panchayat* forest lands towards the upper reaches of the watershed are common. These are gently sloping lands devoid of trees which have been tilled for potato cultivation for the last five to seven years. The climatic and soil conditions here happen to be extremely favourable for potato cultivation. Landslips and landslides have destroyed the forest cover. One such instance is near Kaira village where a large spectacular landslide exists. Such areas also exist near Dungri, Ratgaon, Letal, and Ghunguti. The proposed motorable road would lead to further destruction of forest cover. Thus, the rate and possibility of forest cover loss are threatening and must be minimised as far as possible.

7) Regeneration of forests between the period from 1963 and 1993 is given in Table 8. It was found to be the highest (41.8%) on east-facing slopes, followed by the west and northeast aspects. On the remaining aspects, the regeneration was moderate. The rate was low on southern slopes due to poor moisture conditions and human impact.

8) Regenerated forest types ('Agriculture to Forests' and 'Pasture Land to Forests' in Map 10) was mainly in the region of oak-rhododendron, dense pine, and in the dense mixed and open oak forests (Table 8). This regenerated forest area is only three per cent of the watershed area and 4.8 per cent of the forest area existing in 1963.

9) Forest regeneration was maximum in the elevation range of from 1,600-2,000masl with 20-30° average slopes. Such areas were concentrated in the southern parts of the water-

shed. This perhaps' reflects greater vigilance on the part of the Forest Department in the areas closer to their office which have less hostile terrain.

(10) The distribution of land use and vegetation types in different forest classes is given in Table 9.

Table 8: Extent of Forest Regeneration (1963-93)

Vegetation Type	Area (ha)	% of Area Regenerated
Dense mixed forests	6.6	19.9
Oak-rhododendron	10.2	31.0
Dense oak	1.4	4.2
Open oak	4.7	14.2
Open oak-pine	0.1	0.4
Dense pine	9.3	28.3
Open pine	2.1	2.0
Total Afforested Area	34.5	100.0

Table 9: Distribution of Land Use and Vegetation Types in Different Forest Classes (Based on 1993 RS Interpreted Vegetation Distribution and FD boundaries)

Vegetation Type	*Panchayat* Forests		Reserved Forests		Protected Forests	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Bare rock surface	-	-	-	-	62.3	11.5
Alpine meadows Small	0.3	0.01	-	-	51.7	9.5
pastures	4.6	1.8	-	-	14.2	2.6
Dense mixed forests	13.0	4.9	-	-	120.0	38.9
Oak-rhododendron	52.9	20.0	22.7	17.1	210.0	22.2
Dense oak	7.8	2.9	-	-	5.5	1.0
Open oak	19.4	7.3	-	-	20.3	3.7
Open oak-pine	2.4	0.9	3.8	2.9	-	-
Dense pine	21.0	7.9	81.0	61.0	15.9	2.9
Open pine	3.4	1.3	12.7	9.6	3.1	0.6
Cultivated	-	-	6.8	5.1	36.6	6.7
Landslide (major)	132.8	50.1	1.5	1.1	-	-
River bed	7.1	2.8	4.3	3.3	2.4	0.4
Total	265.1	100	133.0	100	542.3	100

4.4 Conclusions

Encroachments on forest lands have been excessive because of the neglect of forest resources by both the local people and the government. Much of the timber and firewood is not used by the villagers but sold in the market at Tharali. This trade operates through middlemen who promote the felling of the government forests by villagers (Plate 5). The market forces are threatening biological diversity both on the farms and in the forests of the region. Therefore, enforcement of forest conservation is necessary. Patches of chir pine forest are leased to contractors by the Forest Department for resin (local term, *lisa*) collection. Due to over-exploitation and carving of trunks on the up-slope sides, trees also become vulnerable to fires and natural fall. Forest fires are not uncommon in this region. The highland forests have an important protective role against the rampage of runoff water. But the protective function of the forests is constrained when exploitation crosses the threshold. Denudation of forests ultimately leads to a high influx of water in the lowlands and consequently high rates of soil erosion (Ghosh et al. 1995). Forests seem to be better protected when the local people are given the responsibility of managing them. In this way, they do not feel alienated from the forests. Environmental management objectives could be achieved if each settlement has a clearly-defined area to protect, care for, and use (Saxena et al. 1994).

Chapter 5

APPLICATION OF GIS FOR AGRICULTURAL DEVELOPMENT

5.1 Introduction

Plate 7: Agricultural fields in broader and gently sloping areas of the watershed after the millet/ cereal cropping. The terraces are almost flat here.

The Pranmati Watershed, covering 94.05sq.km. had 17.63sq.km. (about 18.74%) under cultivation in 1993. The agricultural land is mainly concentrated in the lower-middle area of the watershed (1,600-2,400masl). Agriculture is exclusively rain-fed. Irrigation facilities do exist, but these are few due to very poor maintenance and the indifference of the villagers. Almost 90 per cent of the farms are terraced (Plate 7). Only floodplain areas and lands recently brought under cultivation (for potatoes) are yet to be terraced. Previous attempts at irrigation set up by the government have failed within a short period. Most of the farming activities, except ploughing, are carried out by women.

Until recently, the agriculture was of a subsistence type. It is only during the last 20 to 30 years that cash cropping has acquired a place in local agriculture; and ever since the potato (*Solanum tuberosum*) has been a major cash crop. Traditionally, a number of indigenous crops (about 15) were grown here, displaying a very high diversity of cultivated crops. These crops are very suitable for the local climate and terrain. The main traditional crops are *mandua* (*Elusine corcana*) (finger millet), *chua* (*Amaranthus paniculatus*) (amaranth), *jhangora* (*Echinicloa colunum*) (millet), and beans (*bhat- Glycine max*).

There is a clear relationship between altitude, crop combinations, and crop rotation (Map 16). *Mandua - jhangora* — wheat are grown below 1,600masl. Between 1,600 and 1,850masl, rice-*jhangora-mandua* (or *bhat* / soyabean) and wheat (and mustard) — *owa* (*Hordeum spp*) (barley) and *jau* (*Hordeum vulgare*) (jau)are grown. In the 1,850-2,200masl region *chua-mandua* ('bhat'/ soyabean)-*jhangora* and potato-wheat / *owa/jau* (and mustard) are grown. In some less fertile pockets at this elevation *chua*, *rajma* (*Phaseolus lunetus*) (kidney beans), and potato-wheat mustard are cultivated. Above 2,400masl, up to 2,600masl, potato cultivation is conspicuous. It is predominantly this zone that comprises the newly-extended agricultural land and soil erosion has increased for various reasons.

Soil fertility on croplands is maintained from organic inputs derived from forests (litter and foliage) and livestock (cattle dung), with almost no chemical fertilizer input. The people of the watershed have an indigenous method of preparing farmyard manure (FYM) for the fields (Plate 8).

Plate 8: Leaf litter from forest floors used as bedding material is removed from cattlesheds and put into the manure pit. It will be used on the agricultural fields eventually.

5.2 Methodology

The agricultural land in 1963 was mapped from the Survey of India topographical sheets (Map 8). IRS image data supported by a detailed survey of agricultural land in the watershed confirmed the status of agricultural land in 1993 (Map 9). Agricultural land in this area included actual area cultivated, current fallow land, homesteads (settlement area) and cattle sheds. The agricultural lands associated with each village under crop rotation practices and land tillage methods were recorded in the field. The agricultural lands for 1963 and 1993 were separately intersected with physical parameters, such as altitudinal zones, average slope, aspect, soil, and geomorphic features. The agricultural lands for the two years were also intersected to detect spatial changes during the 30-year span. Extension of agricultural land in relation to elevation, slope, aspect, and bioclimatic zone was derived through intersection and the simple macro language (SML) programme.

Studies of crop rotation and yield of indigenous (local) crops and new crops were carried out for high (above 2,200masl) and low (below 2,200masl) altitudes separately. Suitability of agricultural extensions was assessed based on physical and biological parameters.

5.3 Results

1) Distribution of agricultural land in 1963 and 1993 was analysed in detail with respect to land elevation, average slope, and topographic aspects (Maps 16, 17, and 18). The distribution of agricultural land in the three physical categories (elevation, slope, aspect) during 1993 is given in Tables 10, 11, and 12 respectively. Changes in the extent of agricultural land in different elevation zones, average slope classes, and topographic aspects between 1963 and 1993 could be derived (Tables 13, 14, and 15).

2) Extension of agriculture between 1963 and 1993 (Tables 13, 14, and 15) was

Table 10: Distribution of Agricultural Land in Different Elevation Zones in 1993

Elevation Zone (m)	Area (ha)	% of Total Area
< 1,200	1.8	1.02
1,200-1,400	0.9	0.52
1,400-1,600	0.05	0.03
1,600-1,800	9.9	5.63
1,800-2,000	3.5	20.13
2,000-2,200	48.4	27.45
2,200-2,400	51.1	28.93
2,400-2,600	25.7	14.62
2,600-2,800	2.9	1.67
> 2,800	nil	
Total	176.3	100

Table 11: Distribution of Agricultural Land in Different Average Slope Classes in 1993

Slope Class (in degrees)	Area (ha)	% of Total Area
<15	16.7	9.6
15-20	45.1	25.9
20-25	50.9	29.2
25-30	40.7	23.3
30-35	19.1	11.0
35-40	1.1	0.6
40-45	0.6	0.4
>45	-	-
Total	176.3	100

Table 12: Distribution of Agricultural Land in Different Topographic Aspects in 1993

Aspect	Area (ha)	% of Total Area
N	0.2	0.1
NE	1.8	1.0
NW	31.4	18.0
W	40.2	23.1
E	26.4	15.1
SE	40.0	21.2
SW	34.4	19.7
S	3.0	1.7
Total	176.3	100

Table 13: Extension of Agricultural Land in Different Elevation Zones (1963-1993)

Class	Elevation (m)*	Area (ha)	% of Total Area
1	<1,200	0.35	0.36
2	1,200-1,400	0.41	0.44
3	1,400-1,600	0.06	0.06
4	1,600-1,800	2.68	2.82
5	1,800-2,000	9.74	10.25
6	2,000-2,200	26.26	27.63
7	2,200-2,400	30.08	31.65
8	2,400-2,600	22.51	23.69
9	2,600-2,800	2.95	3.10
10	>2,800	nil	0.0
	Total	95.04	1000.00

* Elevation in metres above mean sea level

Table 14: Extension of Agricultural Land in Different Average Slope Classes (1963-1993)

Class	Slope (in degrees)*	Area (ha)	% of Total Area
1	<10	11.06	11.6
2	10-20	18.31	19.36
3	20-25	25.13	26.57
4	25-30	25.09	26.53
5	30-35	13.35	14.12
6	35-40	1.01	1.07
7	40-45	0.62	0.66
8	>45	nil	0
	Total	95.04	100.00

* Average slope of land calculated as per the Wentworth (1930) method over 0.25km² grid squares

Table 15: Extension of Agricultural Land in Different Topographic Aspects (1963-1993)

Class	Aspect	Area (ha)	% of Total Area
1	N	0.20	0.21
2	NE	0.65	0.39
3	NW	13.05	13.80
4	W	22.25	23.53
5	E	14.95	15.81
6	SE	26.87	28.41
7	SW	13.60	14.38
8	S	3.04	3.18
	Total	95.04	100.00

found to be highest in the 2,200-2,400masl zone. Extension of agriculture to the 2,200-2,400masl range has been mainly in the form of cultivation of potatoes as a cash crop (Plate 9). Maximum extension occurred on the 20°-30° slopes as limited land was available in lower slope classes, while steep slopes are not conducive to agriculture (Map 19). With respect to the topographic aspect, maximum extensions were on southeast and west facing slopes. Warmer aspects are preferred for agriculture, hence, after the southerly slopes, east and west facing slopes that have moderate temperatures and moisture regimes are preferred for agriculture. Northern or northerly slopes are least preferred because of cool temperatures which limit yields in the prevailing ecological conditions (Map 20).

Extension of agricultural land into different bioclimatic zones was also investigated (Map 21).

Plate 9: Encroachment of open patches in the forests for potato cultivation at higher elevations. The stone wall demarcates the extent of individual encroachments and within are small patches of potatoes.

3) Crop rotation and production: There seems to be an overemphasis on potato cultivation in almost all villages, especially at high altitudes. Potatoes are the predominant crop and cover 60 per cent of the total cropped land at high altitudes (>2,200m). In the lower elevation areas, due to greater diversity of crops grown, the share of potatoes decreased to around 50 per cent (Fig. 2). Rice, though not predominant, is an important crop at lower altitudes where some irrigation is available (Fig. 3).

Figure 2: Area (%) under Crops (above 2,200m)

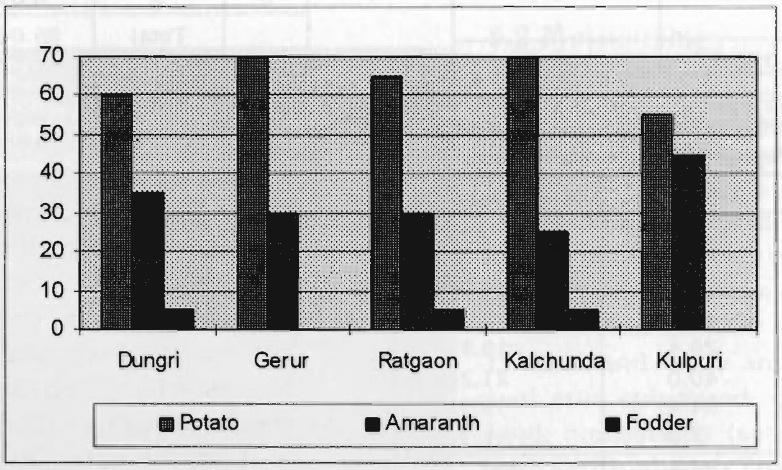
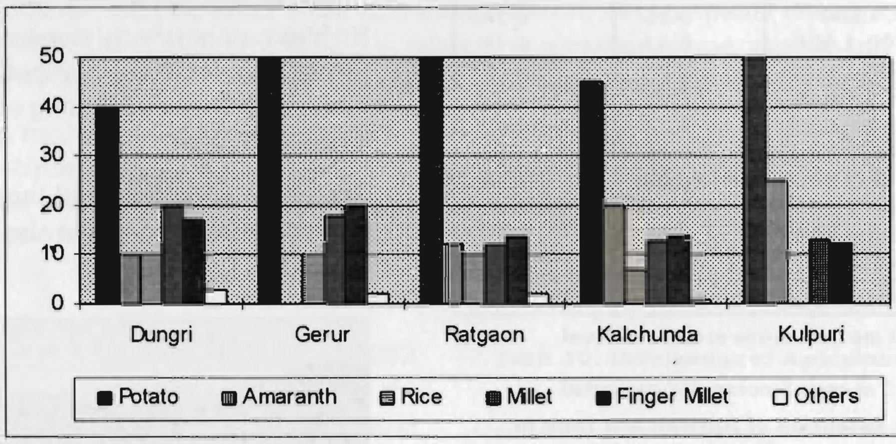


Figure 3: Area (%) under Crops (below 2,200m)



4) Crop yield: In general crop productivity in Garhwal district is quite low, even when compared with similar ecological regions of India such as Himachal Pradesh or Kumaon in Uttar Pradesh. Moreover, there has been little improvement over the years. This also reflects that the farmers in the area have not benefited from government policies for improving yields.

The yields for potatoes and amaranth (*chua*) at higher elevations are generally high, whereas yields of wheat are higher at lower elevations.

5) Suitability classes of agricultural land: Three suitability classes of all agricultural land, differentiating post - 1963 extensions, could be made: (i) the area suitable for cultivation

with no sustainability risks; (ii) the area where there is a need to improve crop and soil management practices; and (iii) those areas not suitable, thus the cessation of agriculture should be encouraged.

6) Soil characteristics from the farmers' perspective: Depth and texture are two basic parameters which normally guide farmers in identifying the land suitable for agriculture. Most of the area had a sandy loam to loamy sand texture. Some relatively flat areas had clayey loam. Soil depth was mostly of 20 to 80cm. In general, the soil could be considered moderately fertile from a regional perspective. A decline in soil fertility had been noticed by farmers over the past few decades. The decline in soil fertility is likely to have been caused by overuse of shallow soils and fall in input of organic manure per unit area of agricultural land, largely due to degradation. In comparison, soil depth exceeding 50cm, according to the farmers' perspective (Map 22) and that actually found by the terrain mapping unit (TMU) method, matched well. Subtle differences in soil quality are not fairly distinguishable by farmers. As a whole, it can be said that the farmers' perspective soil map is fairly well-matched with the TMU soil map. For a small-scale reconnaissance survey of large hilly terrain, a map based on the farmers' perspective could be a cost-effective means of soil mapping.

5.4 Conclusions

Diversity of agro-ecosystems (in terms of number of crops cultivated) is generally greater at higher altitudes (Rao and Saxena 1994). This diversity is gradually being reduced with the trend of growing more cash crops. The habit of eating wheat flour and milled rice purchased from the market has gradually become a status symbol. This has led to a reduction in crop diversity and increased the emphasis on cash crops. Soil erosion is aggravated by various agricultural features such as outward sloping terraces and cultivation on non-terraced slopes. There is a high degree of land fragmentation and the consolidation of holdings is not an easy task, keeping in mind the diverse agro-ecosystems and social impediments.

Various measures have been suggested to the villagers to check soil erosion and reduce sediment load in the streams (Ghosh et al. 1995). These include: (a) to restrict agricultural practices at high altitudes (above 2,600m) and regeneration of vegetation to save the lower lands; (b) to flatten the sloping terraces; (c) to ensure proper drainage of terraces which are not susceptible to erosion and which should be able to accommodate peak runoff; (d) to protect ridge tops with grass, shrubs, and tree plantation according to suitability and prohibiting cultivation on such sites as far as possible; (e) to make earth dams on channels and gullies on lower hill slopes; (f) to switch over from potatoes to alternative traditional or profitable cash crops; (g) to divert paths from gullied areas undergoing high rates of erosion; and (h) to check extension of agricultural fields to the edges of cultivable slopes by maintaining bunds and promoting hedge growth on the bunds and field peripheries.

Horticulture should be encouraged and provided with better orchard management technology in this region. This would promote growth of fruit and nut trees with exceptional possibilities. The World Bank Review (1987) of Horticulture in the North West Hill Region has suggested strategies for this.

Encroachment of cultivation on to marginal lands is taking place due to the increasing population pressure and growing importance of cash incomes (Plate 9). Increasing yields with the help of technological inputs would reduce the pressure on marginal lands. But, increasing crop yields and introducing the means of generating more income is not enough to prevent encroachment on marginal lands. Public awareness and decisions at village level concerning soil conservation and environmental protection must be firmly promoted.

Chapter 6

Potential of GIS Technology for Monitoring Impacts of Development Activities

6.1 Introduction

Creating infrastructure to provide support services is a government responsibility and, during the planning process, the government established norms to cover geographical areas with these services. Whereas, in the plains, the services can reach a greater number of inhabitants; due to (i) a higher density of population and (ii) easy accessibility (few geomorphic impediments). In hilly regions, the placement of these services in tune with the inhabitants' requirements is more difficult. Sometimes even the geomorphic features render accessibility seasonal (such as a river in spate or a snowy ridge acting as seasonal obstacles). GIS applications have potential for assessing support service requirements and their placement. This application has advantages over the conventional mechanisms, as multi-criteria analysis is not only feasible but much faster with GIS.

All the villages in the watershed are without electricity. Though the Pranmati *Gad* (stream) itself is harnessed for a hydel, the electricity generated meets the requirements of the semi-urban Tharali area. Previously there was no motorable road within the watershed. The nearest motorable road is close to its southern tip at Tharali. Now a motorable road is sanctioned by the government. This road takes off from the Tharali roadhead, passing through Kaira, Dungri, and Ghinapani, and will be connected to the road from Ghat in the northeast, across the watershed. Although the road starts on the left bank of the Pranmati Gad, it soon spans across and goes upwards along the right bank. As a consequence, it cuts across the large landslide to the south of Kaira village. The maintenance cost of such a road, over a constantly mass wasting slope, is going to be high, and, since it traverses dense forests, the impact on the environment is going to be negative.

The change in motion in safety engineering is leading the engineers to attempt development by explicitly estimating the risks. This step is necessary for public (non-technical) involvement in safety decisions, especially where technology choices are an issue (Covello et al. 1983). The potential of GIS for evaluating the feasibility and environmental impacts of different development interventions is demonstrated in this section.

6.2 Methodology

Methods of Soil Mapping

Two methods were employed to investigate soil: One, soils of the area were sampled randomly and classified by a conventional reconnaissance soil survey and, two, farmers' perceptions about soil from their practical experiences were solicited. With random sampling of soils, the area has been classified by the TMU system for soil mapping. Because of poor horizon development in the colluvium type of soil, TMU (based on slope, soil depth, and texture) provides useful mappable units. Considering the hill-specific characteristics, gravel per cent is included in the mapping unit, whereas the slope is dropped since major agricultural land lies under either slopes with low (6-13°) or moderate (13-25°) gradients, but forest lands are very intricate in terms of the nature of slopes. Thus, soil texture, depth, and gravel per cent were the criteria—with decreasing priority. Soil sampling was carried out by auger with low observation intensity for the forest area (1 per 25-50ha) and comparatively high intensity for agriculture (1 per 15ha). Farmers' perceptions about soil provides the simplest way of mapping soil (exclusively for agricultural land) and is quite representative of field observation.

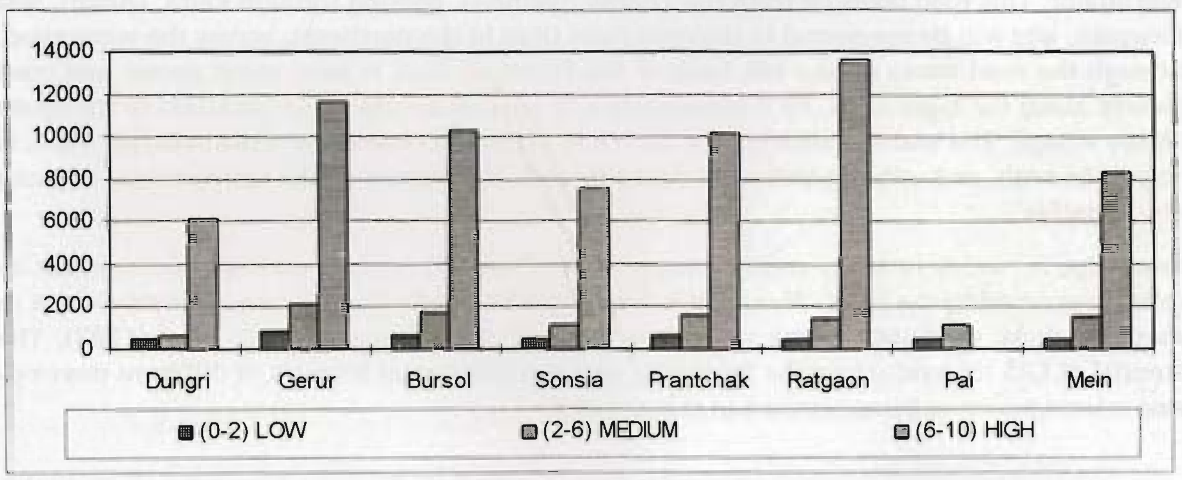
Soil Erosion

Soil loss from agricultural land was studied by means of a 'runoff plot' experiment (in 1993-94). It is simple and inexpensive (Djorovic 1978) and also convenient in remote hilly terrain. Since the average terrace size (10 x 3 m) is small, the experimental plot size (2.5 x 2.5m) was kept much smaller than the normally recommended plot size (20 x 2.5m). Runoff water was collected in a plastic drum and soil loss was calculated from the sediment load of a sub-sample of runoff water. Selected village-wise average soil loss (kg/ha) was generated from the data from three classes of terrace slopes (<2° : low, 2-6° : medium, 6-10° : high) (Fig. 4); only the outward terrace slope angle was considered. Crop-wise and elevation-wise the soil-loss study was also carried out in different villages.

Areas Viable to Agricultural Extension

Marginal lands at high elevation, on steep slopes and in shallow soil cover areas are also being cultivated, and as a result pasture lands and forest areas are being exploited. Expansion of agriculture is likely in future. Presently, wastelands or low altitude pasture are subject to encroachment (Map 23).

Figure 4: Field Soil Loss (kg/ha-1)
In Fifferent terrace slope classes



Erosional Impact of Agricultural Practices

This area is within one of the high (>1000 EI_{30}) mean annual erosivity' (EI_{30}) regions of India (Babu et al. 1978). Soil loss studies have been carried out, mainly in cultivated areas. The permissible limit of soil loss for agricultural practice is commonly fixed between two to 12 metric tonnes/ha/year. Considering the mountain ecology, poor soil growth (only a few areas have soil depths of over 150cm), less active soil masses due to the presence of gravel and boulders, and slow rates of soil formation, the lower limit (2,000 kg/ha/year) is appropriate for assessing soil loss from the watershed. Although the average slope of cultivated land ranges from 5° to 30°, the actual slopes of cultivated terraces are usually less than 10° (Plate 1). The rate of soil loss is found to be significantly higher from terraces with steep slopes (more than 6°) (Plates 10 and 3). Soil loss was also found to be significantly high from fields where potatoes grew, and greater than average from land under non-indigenous crops (e.g., rice) compared to land under indigenous crops (e.g., millet, finger millet, and amaranth). The magnitude of decrease in cultivable wastelands is an ideal index for reckoning the extent of its colonisation (Singh 1990), as these are the areas in which horizontal expansion of cultivated land takes place.

Plate 10: Agricultural fields in narrow and steeply sloping areas of the watershed during millet/cereal cropping. Note that the terraces are outwardly sloping and narrow.

Micro-hydel Proposal

Large hydro-electricity plants disrupt the natural drainage system and the agricultural as well as social systems. Even medium-large (50kVA) hydels involve a great deal of capital and generally their benefits accrue to urban areas. In a remote area which is devoid of modern transport services only micro-hydels are suitable. These would also cause least disturbance to water mills or natural drainage. Thus, a feasibility study for micro-hydel (<20kVA) was carried out and, based on discharge, gradient, and locational utility, seven sites were found suitable (Map 24). One such micro-hydel is operational in one village in the watershed with the active participation of the villagers (Plate 11). In fact, it is operated and can also be repaired by the villagers (Saxena et al. 1994b). The Pranmati *Gad* carries a lean season water discharge of nearly 0.25 cumec. One of the prominent tributaries, Kich *Gad*, has a good potential for micro-hydel power generation. Near Ratgaon, Pranmati *Gad* carries nearly 0.8 cumec of water in lean season and further down at Kaira Bagar the lean season discharge is nearly 1.5 cumec. The power potential of the watershed, estimated on the basis of minimum discharge, is in the order of 3,000kVA.

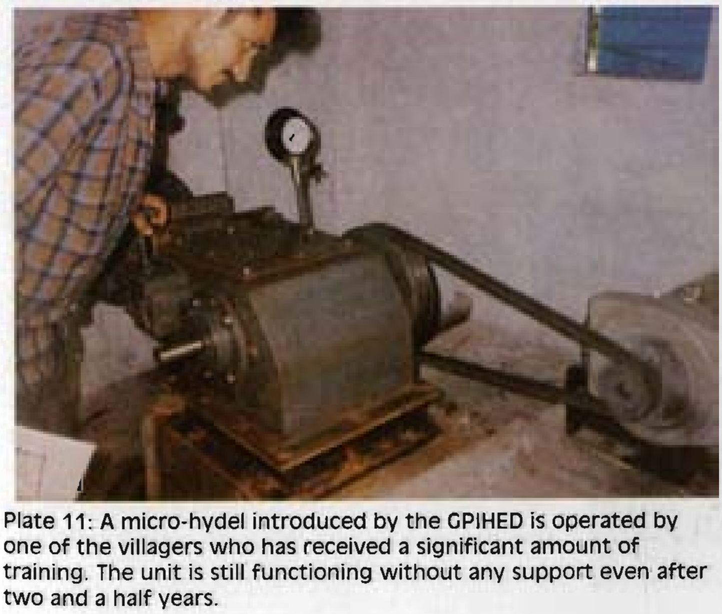


Plate 11: A micro-hydel introduced by the GPIHED is operated by one of the villagers who has received a significant amount of training. The unit is still functioning without any support even after two and a half years.

A 400kVA hydel power project at the entry point of the watershed is almost non-functioning due to the poor maintenance. However, a 200 kVA hydel project is being built by the U.P. Government (through the Non-Conventional Development Agency).

Road Feasibility Study

Since the entire watershed has a rock structure dipping at 50 to 65° towards 45°E of N, the slope aspect was interpreted into: (i) dip (not too stable), (ii) anti-dip, and (iii) along-strike faces. In the case of along-strike slopes, they are of two types, one with the rocks sloping outwards (which are considered to be very unstable for road construction) and the other with rocks sloping inwards (considered relatively stable). This criterion is the basis of risk assessment for road construction activities (Map 6).

6.3 Results

Micro-hydels and Water Mills

There are a number of water mills constructed on the streams near the villages. Water mills are used for grinding food grains. Seven micro-hydel sites (Map 24) have been proposed and one is operational on an experimental basis (Saxena et al. 1994b). Promotion of the generation and use of hydro-electricity would largely benefit the rural people both economically and socially (through child and adult education and mass communications) (Plate 12).

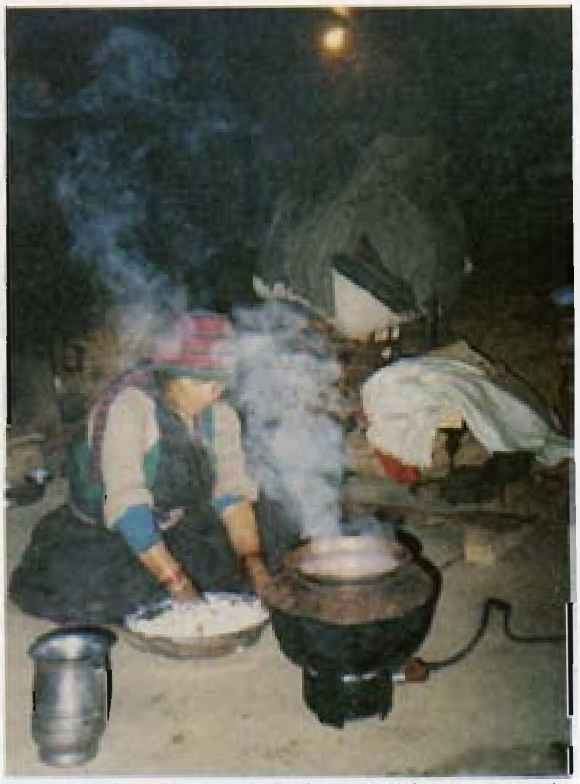


Plate 12: Light has brought cheer to this woman and reduced her drudgery. We expect the introduction, of electricity will reduce the pressure on forests and allow their regeneration

Road Construction

The route of the proposed road was evaluated and classed into three safety categories: very unsafe, unsafe, and comparatively safe zones (Map 6). The road should be built in the safe zone, which would mean following mainly the east bank of the Pranmati *Gad*, whereas the present plan is for the western bank. One way to avoid the erosional impact of the road is to set up cableways connecting villages to the nearest point on the road. Construction of footbridges could also solve the problem of connecting villages across the river. Land-use or land-cover analyses of a 250-metre buffer zone for the proposed road means that the forest area lying in this zone is likely to be adversely affected by road construction, while loss of agricultural land would force farmers to encroach on forest lands. A recent major landslide is being intersected by the proposed road (Map 6) which will aggravate the problem (Plate 13).

Plate 13: The recent landslide which the proposed road is to pass through. Mules and men face these hurdles to survive.

Food Processing

Edible oil is mainly extracted from mustard seeds with some contribution from *til* (sesame seed). The area is self sufficient in edible oil at present. Most of the oil is extracted by diesel-driven machine, since no electricity is available here. Traditional extraction processes are hardly seen due to poor yield and the labourious nature of extraction. Potatoes are overwhelmingly the predominant cash crop. Amaranth comes second as a cash crop. It has good market value, being used as an ingredient for a local sweetmeat. Since two to three per cent of the area is covered by leguminous plants and a substantial proportion of farmyard manure (FYM) is given to potatoes, the soil gets little nitrogen and other elements for other crops. Groundnut cultivation was introduced quite recently as an alternative or a supplement to potatoes. Yields are encouraging (nearly 19 Q/ha), but farmers are reluctant to accept this crop—largely due to the lack of market facilities.

Agroforestry, Fodder, Fuelwood

As such, no agroforestry is traditionally practised in this area. However, some oak trees growing in agricultural wastelands and on field bunds provide green fodder and the twigs are used for fuelwood. Green fodder is also collected from nearby mixed pine and oak forests. The stalks, straw, and husks of millet, finger millet, wheat, and paddy are used as dry fodder. Buffaloes are usually stall fed, whereas cows and goats are grazed on village community lands. Villagers take livestock to alpine pastures from June, and they return in September. Suitability classes of agriculture are shown in Map 25.

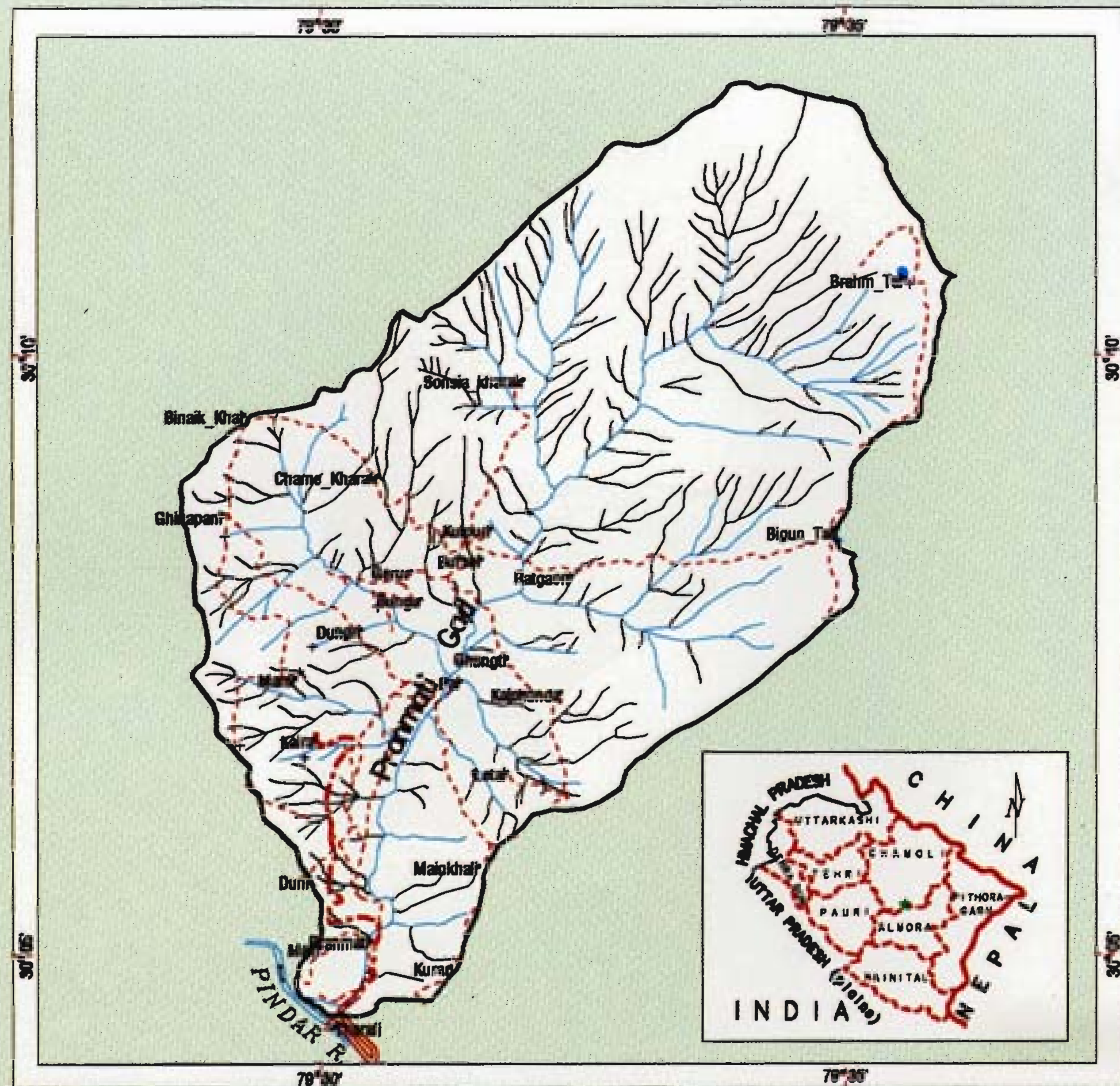
Support Services and Infrastructure

The distribution of schools and hospitals is shown in Map 26. Postal delivery service is available to all the villages, Bunga, and Gerur. Rural banking exists at Dungri. Medical services are not particularly satisfactory. A paramedical centre (Dhadar) and Ayurvedic clinic (Dungri) exist. There is a veterinary unit at Dungri. Primary schools are adequate in number but not well distributed, considering the difficult terrain that children face in reaching school

6.4 Conclusions

Development without proper planning is bound to reach unsustainable limits, especially in a world where population pressure and the drive to modernisation co-exist. External inputs to mitigate local problems and develop the area are not likely to be long lasting. Thus, development interventions must capitalise upon and add to indigenous development intervention capacities. Technological inputs, coupled with financial investments, are desired in the Himalayas, both for the people settled in the region and those residing outside. Careful planning is required to facilitate sustainable development (Saxena et al. 1994a).

Maps



Map 1

Pranmati Watershed
Garhwal Himalayas, India

General Features and Location

LEGEND

- Perennial streams
- Seasonal streams
- Lakes
- + Springs
- Pack track / footpath
- Metalled road (constructed)
- Road (under construction)
- Watershed boundary

KEY TO INSET

- International boundary
- State boundary (in India)
- District boundary (in Uttar Pradesh Himalayan region only)
- Study area

1 0.5 0 1 2km.

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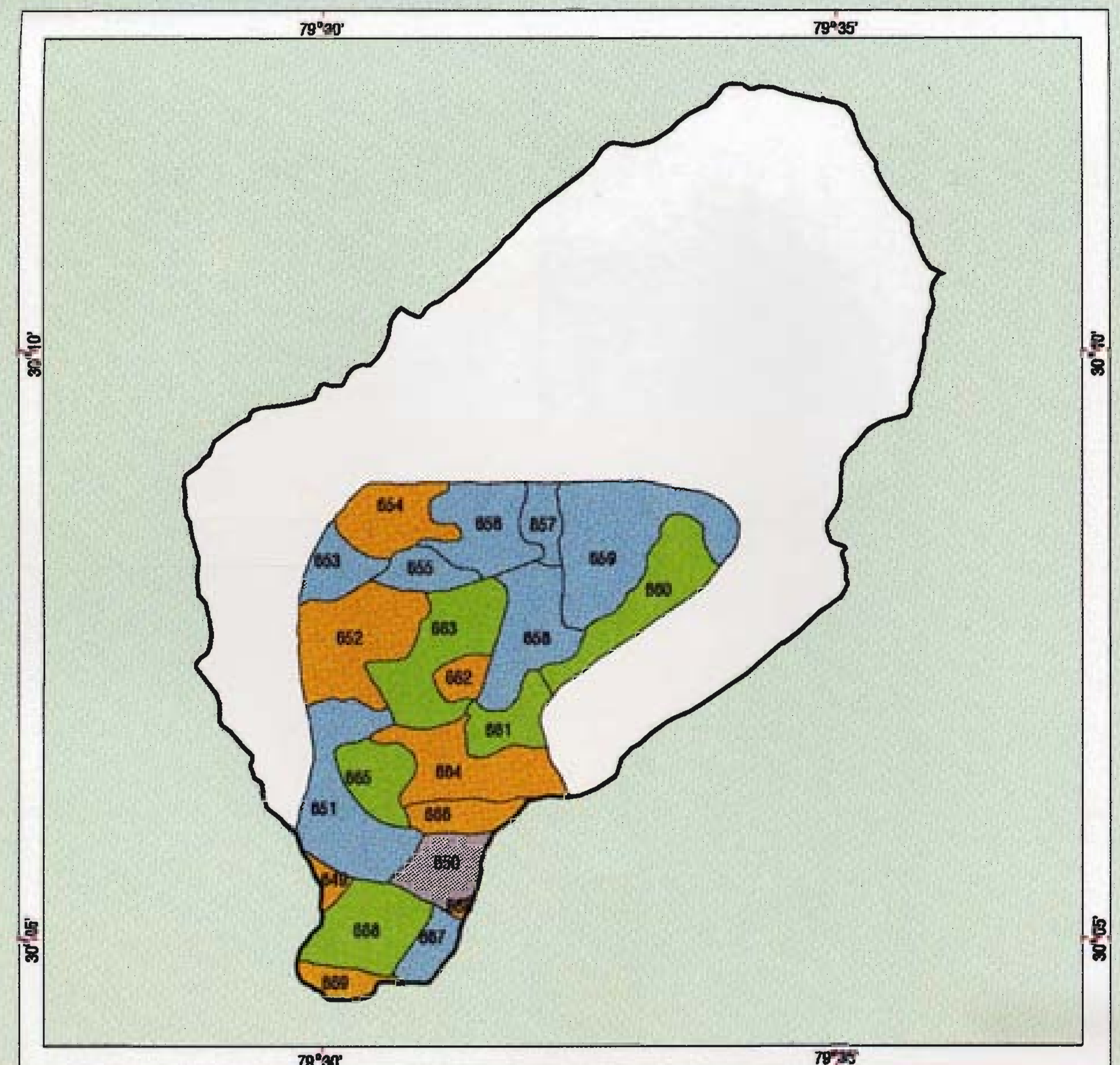

Map 2

Pranmati Watershed
Garhwal Himalayas, India

Population Density (1991)

LEGEND

Number of persons per square kilometre

- More than 40
- 25 to 40
- Less than 25
- Uninhabited

(PART OF THARALI BLOCK OF CHAMOLI DISTRICT, U.P.)
CENSUS CODE - VILLAGE NAMES

649 - Suna
650 - Mein
651 - Kaira
652 - Dungri
653 - Darmola Chak Dungri
654 - Ruisan
655 - Bunga Chak Goptiana
656 - Geirur
657 - Kulpuri
658 - Bursol
659 - Ratgaon
660 - Upri Chak Ratgaon
661 - Harinagar
662 - Guman Laga Gerur
663 - Bunga
664 - Kurar
665 - Thalamgira
666 - Partha Chak Kuni
667 - Sagwara
668 - Irdi Laga Suna
669 - Tharali

1 0.5 0 1 2km.

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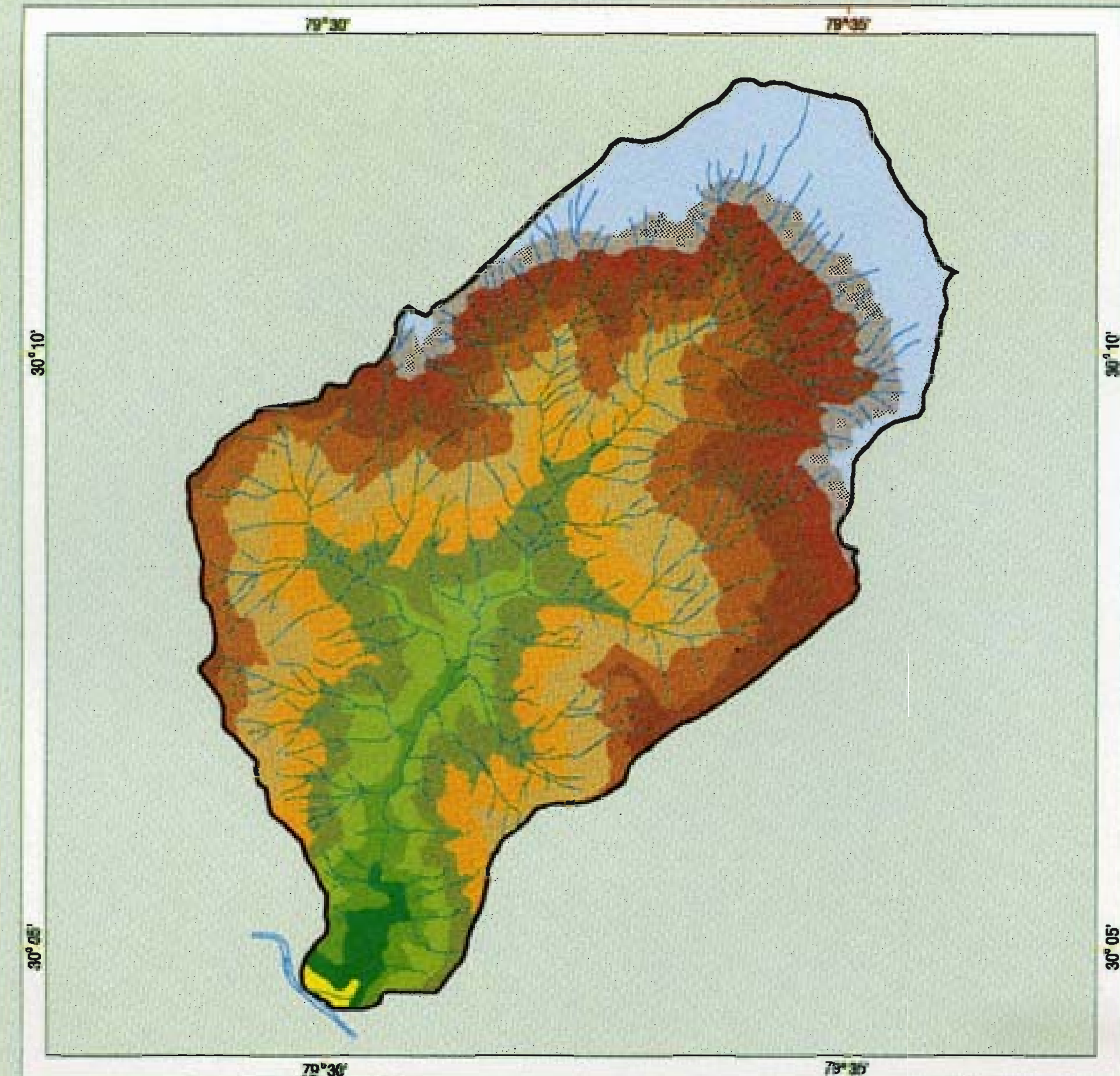


Map 3

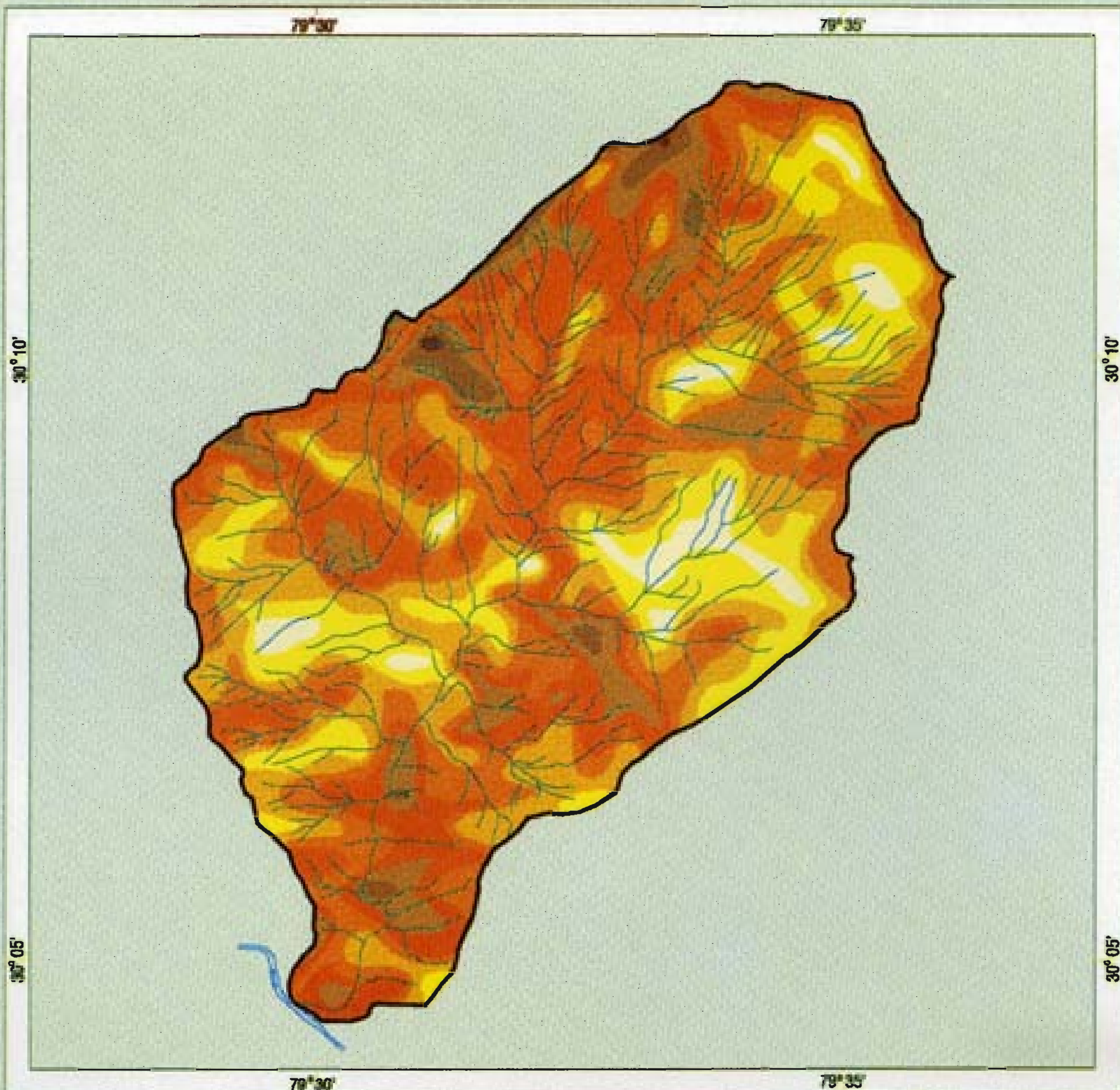
Pranmati Watershed
Garhwal Himalayas, India

Altitudinal Zones

LEGEND

- > 3200 metres
- 3000 - 3200 m
- 2800 - 3000 m
- 2600 - 2800 m
- 2400 - 2600 m
- 2200 - 2400 m
- 2000 - 2200 m
- 1800 - 2000 m
- 1600 - 1800 m
- 1400 - 1600 m
- 1200 - 1400 m
- < 1200 metres

1 0.5 0 1 2km.



Map 4

Pranmati Watershed
Garhwal Himalayas, India

Average Slope Classes

Average slope calculations based on the Wentworth method on a 0.25 sq. km. grid

LEGEND (Average Slope in Degrees)

- < 10 (329.0 ha)
- 10 - 20 (1365.8 ha)
- 20 - 25 (2068.8 ha)
- 25 - 30 (2517.1 ha)
- 30 - 35 (2155.7 ha)
- 35 - 40 (771.2 ha)
- 40 - 45 (187.7 ha)
- > 45 (9.6 ha)

1 0.5 0 1 2km.

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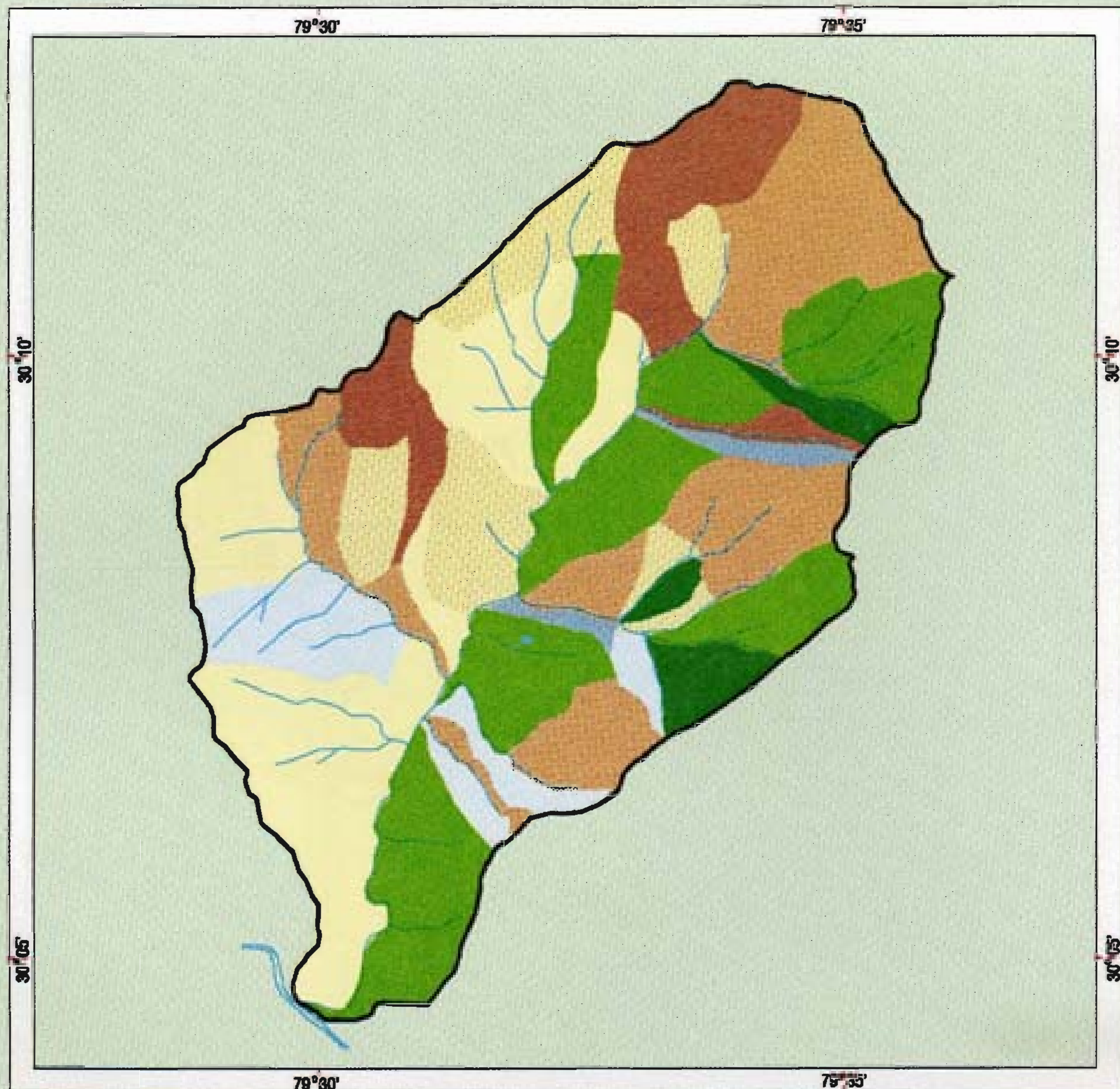
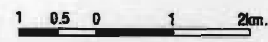
Map 5

Pranmati Watershed
Garhwal Himalayas, India



LEGEND

- North facing
- North-west facing
- North-east facing
- East facing
- West facing
- South-west facing
- South-east facing
- South facing



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GBPIHED

Map 6

Pranmati Watershed
Garhwal Himalayas, India

Erosional Impact of Proposed Motor Roads

LEGEND

- VERY UNSAFE
  Massive landslide (active)
  Unstable zone (fractures and crushed rock)
- UNSAFE
  Unstable slope (quasi-dip slope)
  Rockslip and slumping likely as rocks dip towards the road cut
- COMPARATIVELY SAFE
  Relatively stable slope (anti-dip slope)
  Rocks dip away from the road cut

- Metalled Road (constructed)
- Road (under construction)
- Road (proposed)

- Landslide
- Debris fan
- Rockfall
- Cliff
- Gullied/raviney land
- Severe bank cutting

(FOCUS: RELATIVE SLOPE STABILITY WITHIN 250 METRE BUFFER ZONE OF PROPOSED MOTORABLE ROAD)

1 0.5 0 1 2km.

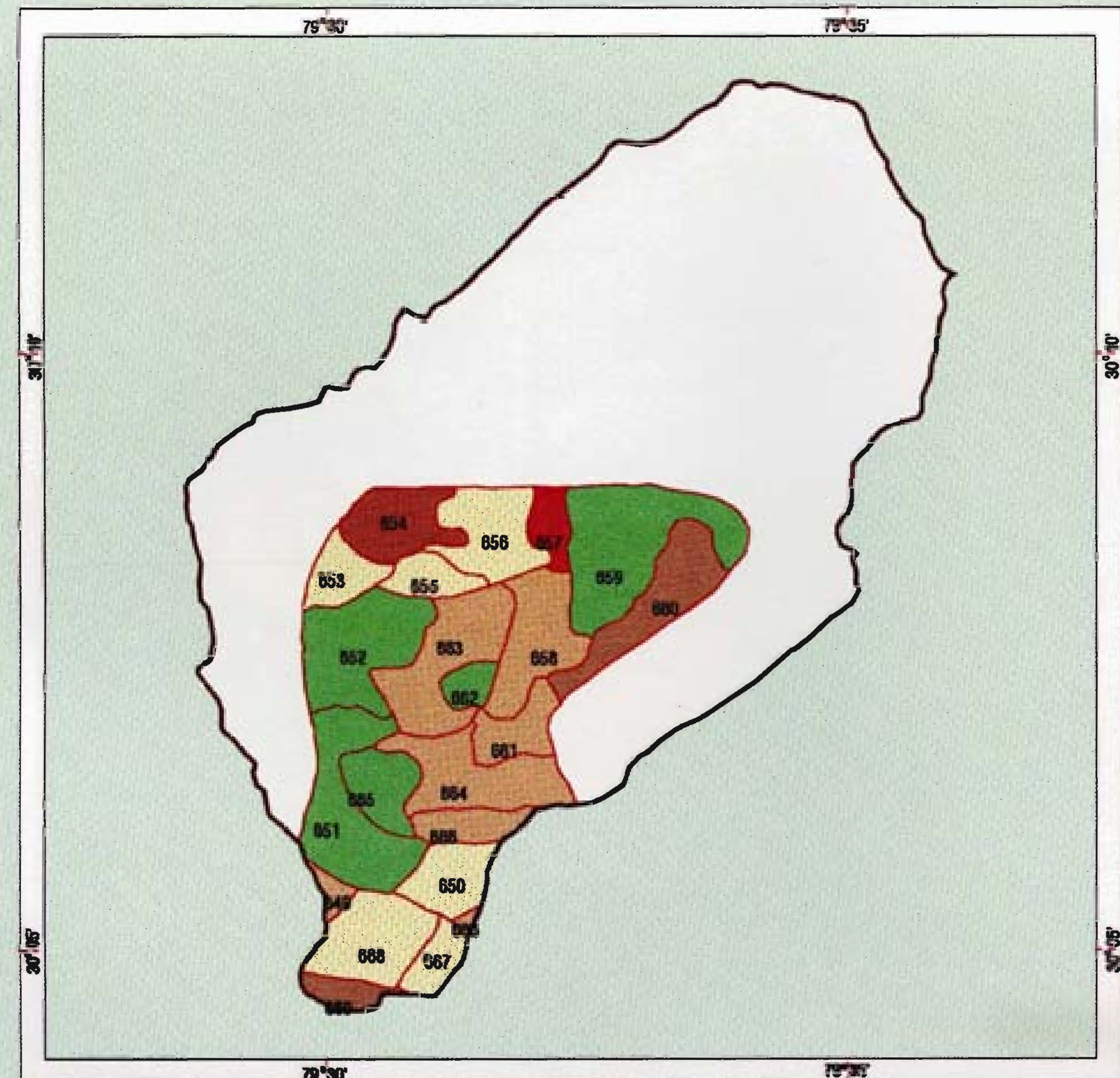
ICIMOD MENRIS '98

GBPIHED

Map 7

Pranmati Watershed
Garhwal Himalayas, India

Population Growth (1981-91)



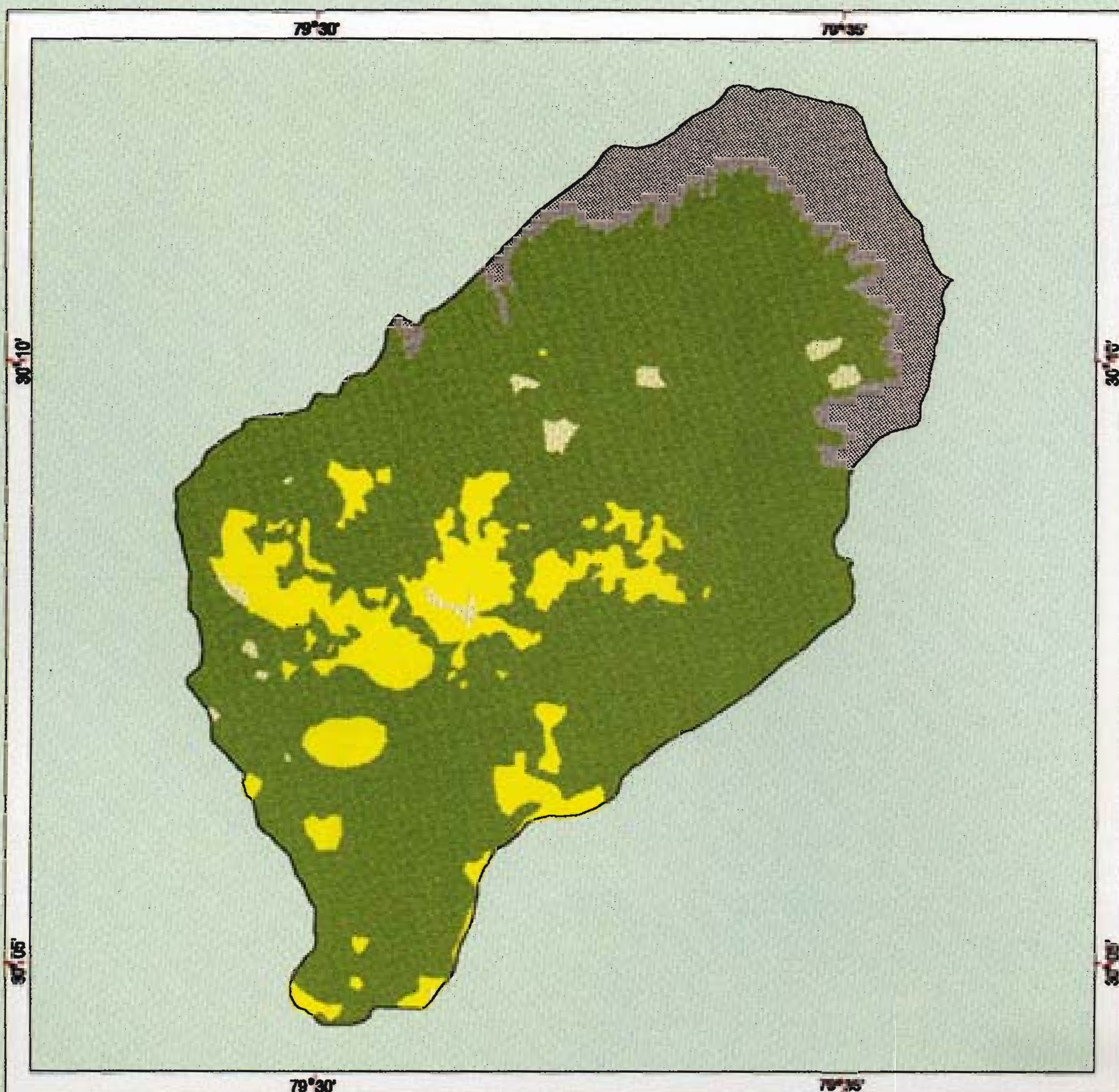
LEGEND

INCREASE
> 150%
100 - 150%
60 - 100%
20 - 60%
0 - 20%

DECREASE
-0.1 to -50%

1 0.5 0 1 2km.

GBPIHED



Map 8

Pranmati Watershed
Garhwal Himalayas, India

Land Use and Land Cover Map (1963)

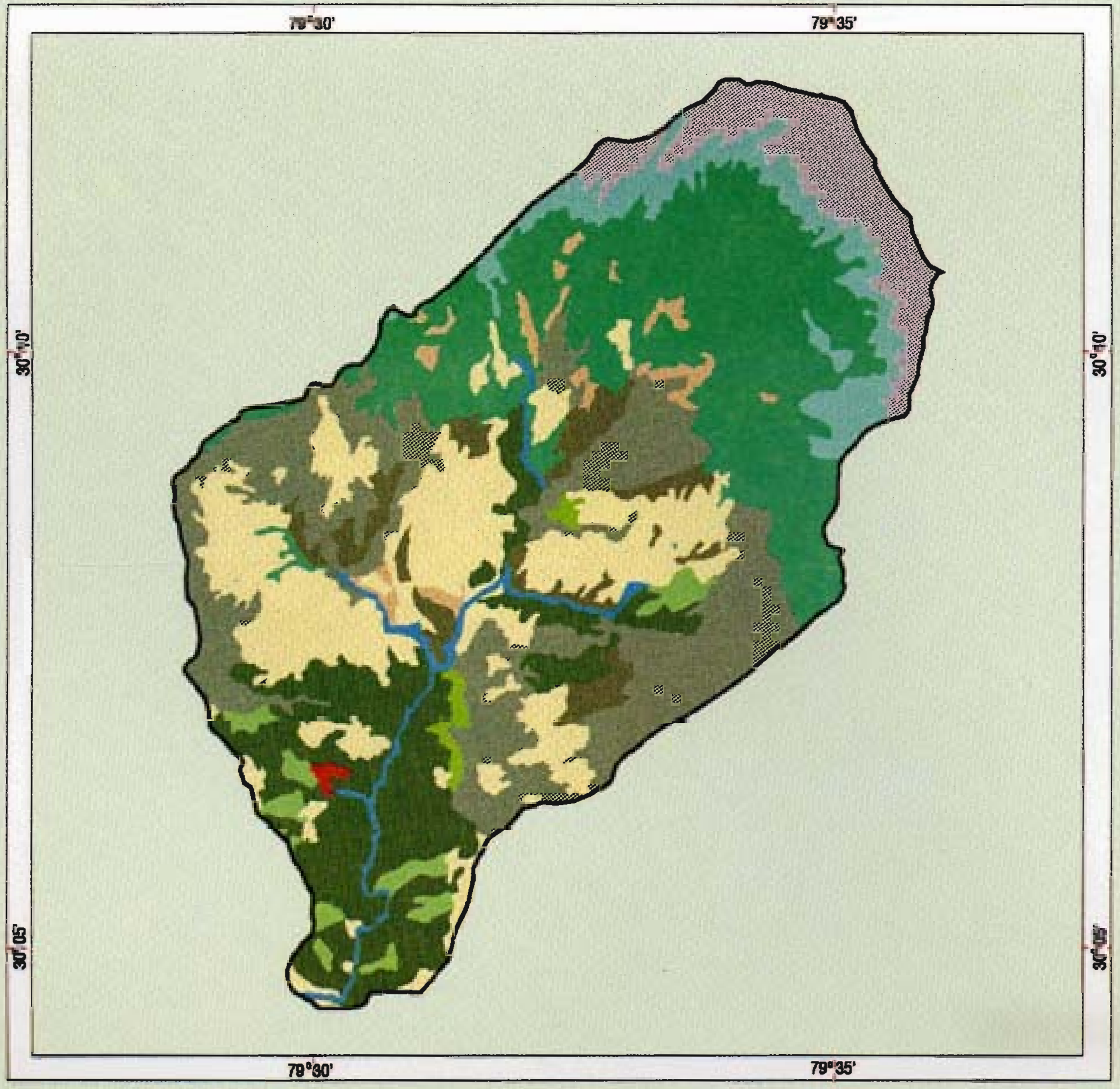
LEGEND

- Cultivated area with settlements (12%)
- Pasture lands (1.2%)
- Forests (74.8%)
- Alpine pastures, exposed rock & other areas (11.93%)

TOTAL AREA = 9405 HECTARES

1 0.5 0 1 2km.

ICIMOD MENRIS '99 GBPIHED



Map 9

Pranmati Watershed
Garhwal Himalayas, India

Vegetation Types & Land Use (1993)

LEGEND

- Exposed rock (6.6 %)
- Alpine pastures (5.5 %)
- Pastures (2.0 %)
- Dense mixed forest (23.24 %)
- Oak-rhododendron (20.81 %)
- Dense oak (1.4 %)
- Open oak (4.2 %)
- Open oak-pine (0.6 %)
- Dense pine (12.6 %)
- Open pine (2.05 %)
- Cultivated and settlement area (18.7 %)
- Major landslide (0.16 %)
- River channel and channel deposits (1.5 %)

1 0.5 0 1 2km.

ICIMOD MENRIS '98

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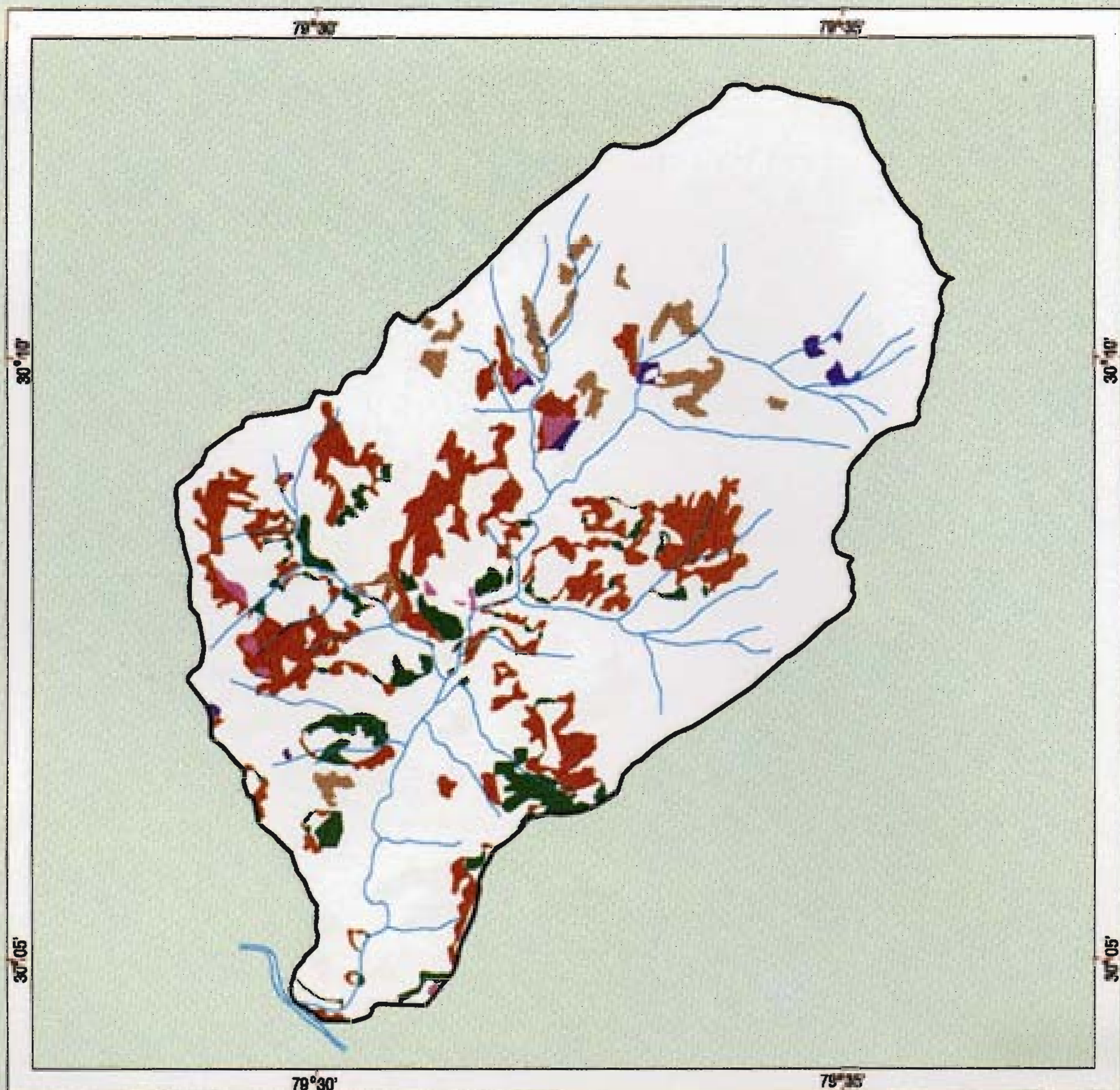


Map 10

Pranmati Watershed
Garhwal Himalayas, India

Major Land Use Changes (1963-93)

LEGEND

- Forest to agricultural land
- Forest to pasture or waste land
- Agricultural land to forest
- Agricultural land to pasture or waste land
- Pasture land to forest
- Pasture land to agricultural land

1 0.5 0 1 2km.

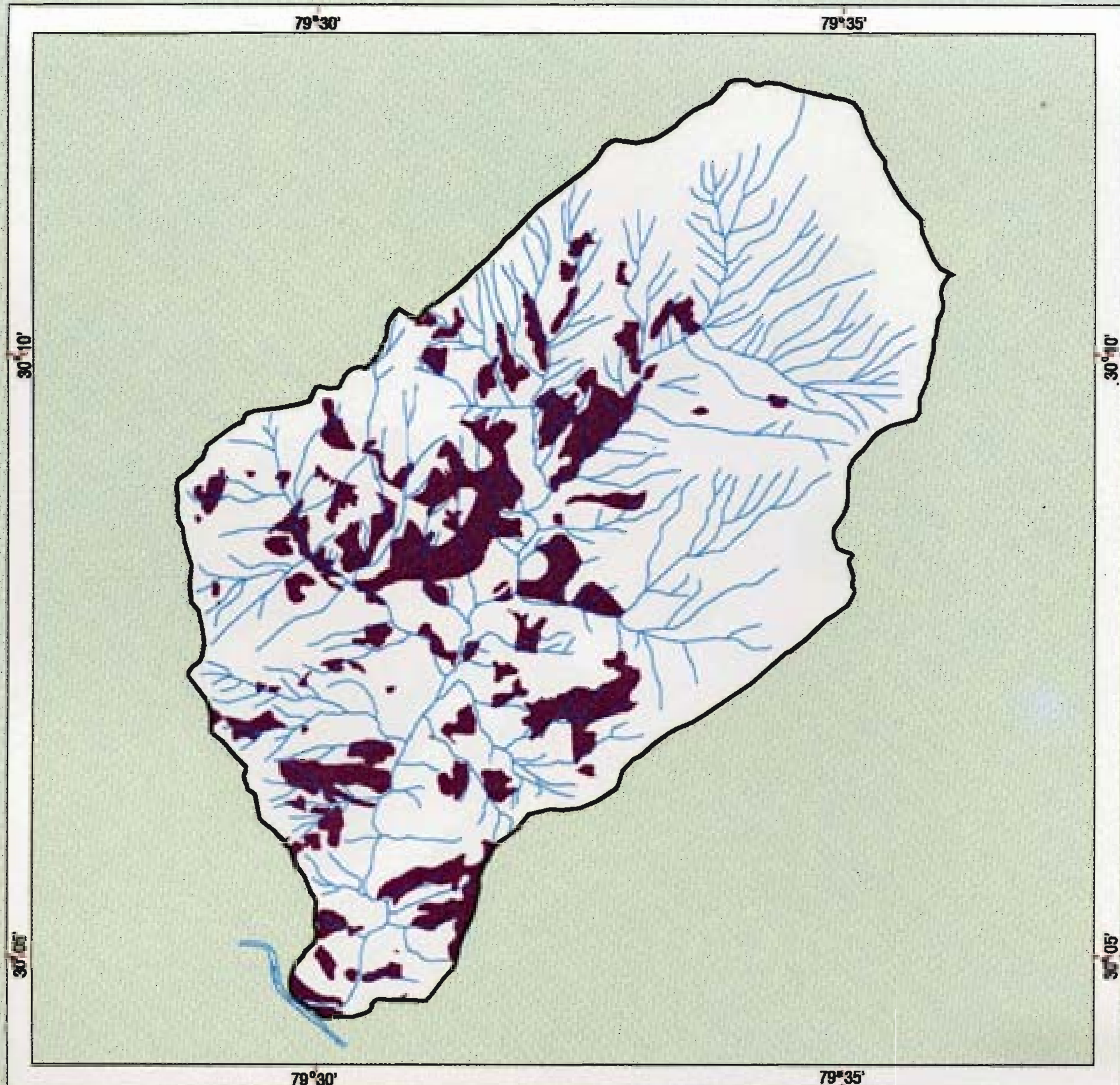
ICIMOD MENRIS '96

GBPIHED

Map 11

Pranmati Watershed
Garhwal Himalayas, India

Land Vulnerable to Accelerated Erosion



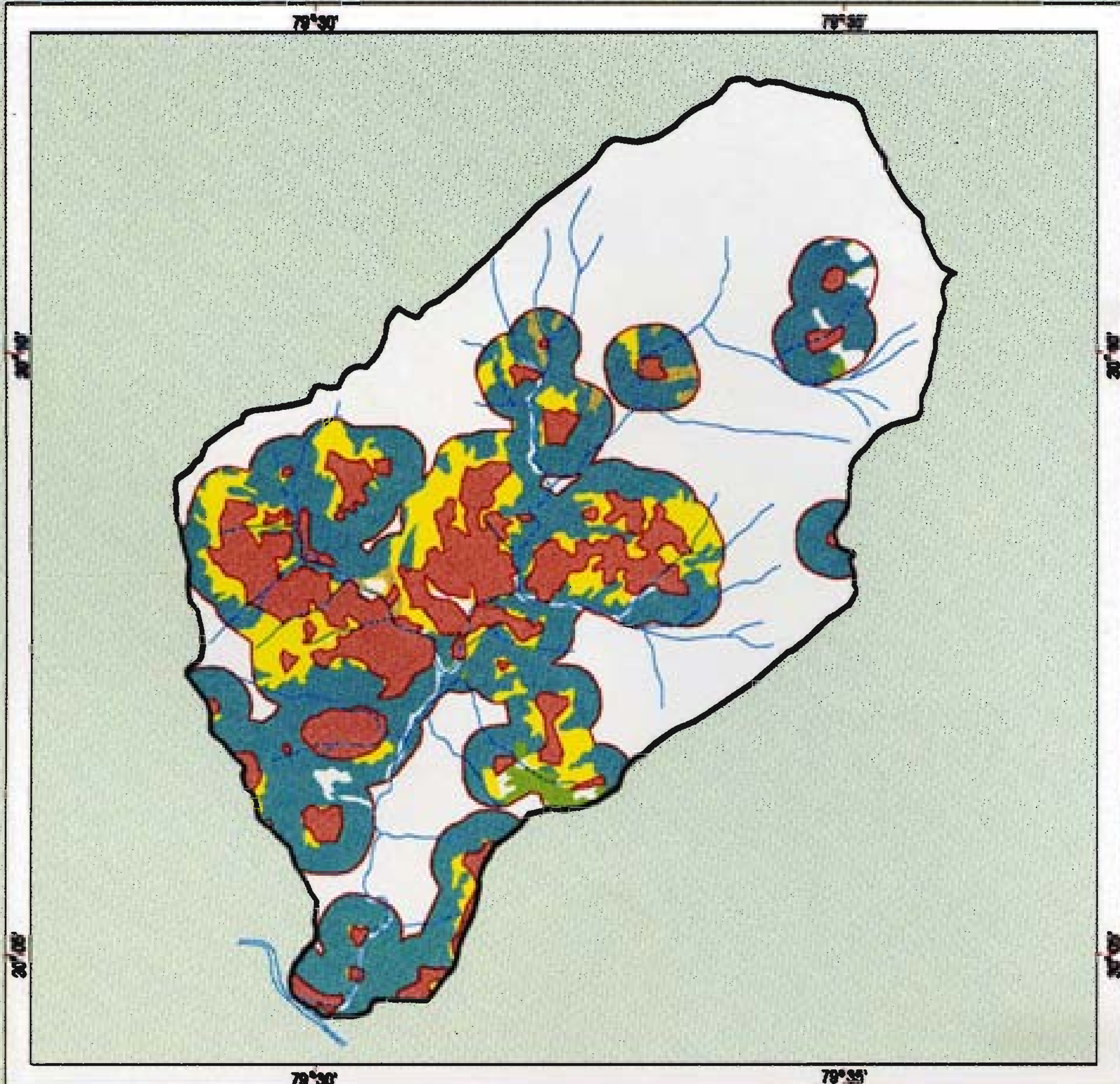
LEGEND

Land vulnerable to erosion due to intense use (e.g., cultivation, grazing, settlement) on steep slopes (>25 degrees average slope).
Land protection measures are necessary in these areas.

1 0.5 0 1 2km.

ICIMOD MENRIS '98

GBPIHED



Map 12

Pranmati Watershed
Garhwal Himalayas, India

Land Use Changes in the Buffer Zones of Settlements (1963-93)

FOCUS: 0.5 KM BUFFER ZONES OF SETTLEMENTS

LEGEND

- Regenerated forest
- Forest area (unchanged) within buffer zone
- New pastures, previously forest land
- New agricultural land
- Settlement area
- No change within buffer zone

1 0.5 0 1 2km.

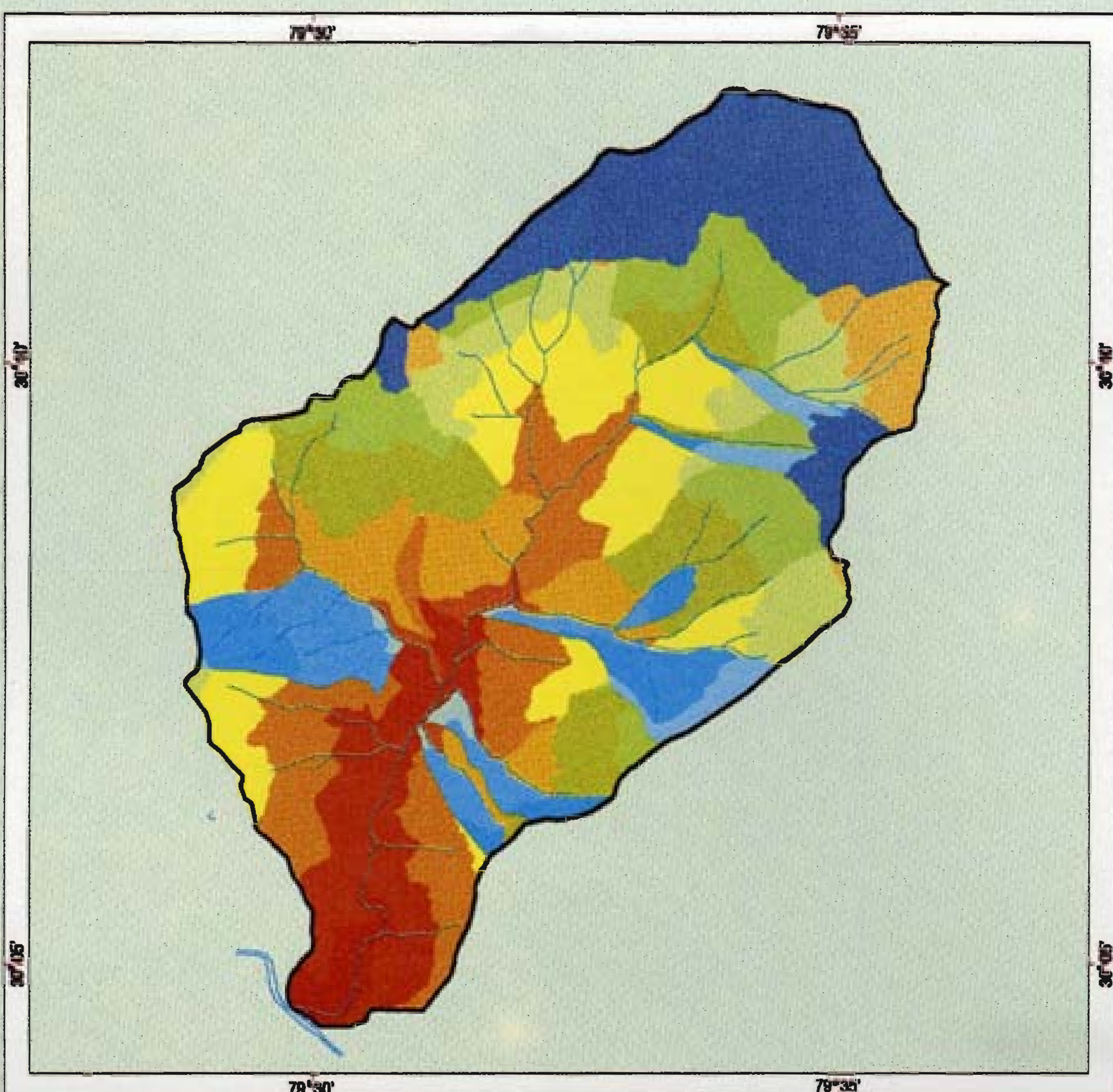
ICIMOD MENRIS '98

GBPIHED

Map 13

Pranmati Watershed
Garhwal Himalayas, India

Biotic Niches



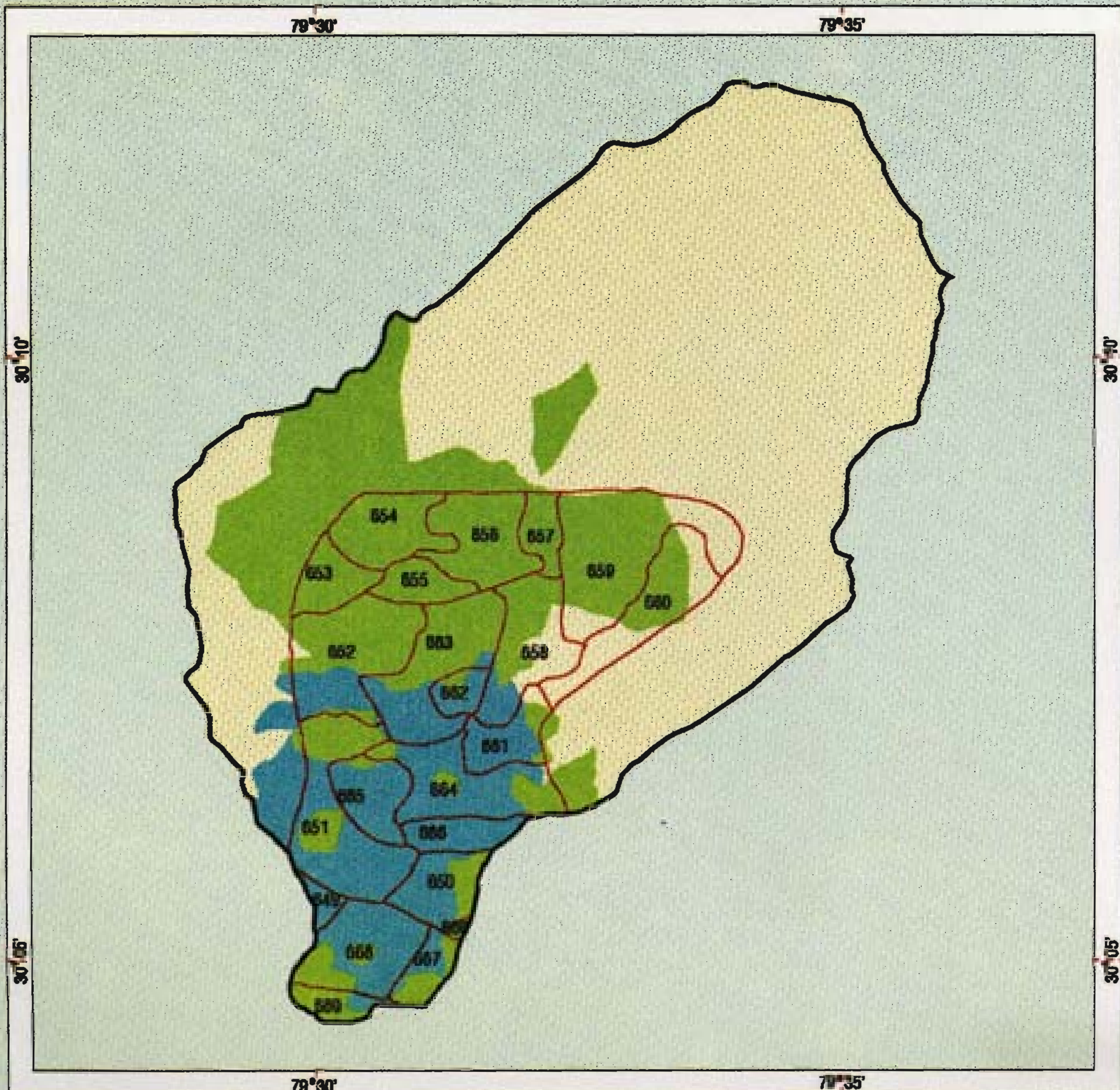
LEGEND

- Cool moist, alpine meadows
- Warm dry, alpine meadows
- Warm moist, alpine meadows
- Cool moist, sub-alpine
- Warm dry, sub-alpine
- Warm moist, sub-alpine
- High elevation, moist cool
- High elevation, warm dry
- High elevation, warm moist
- Mid-elevation moist cool
- Mid-elevation warm dry
- Mid-elevation warm moist
- Low elevation, moist cool
- Low elevation, warm dry
- Low elevation, warm moist
- Warm moist, riverine valley

1 0.5 0 1 2km.

ICIMOD MENRIS '99

GBPIHED



Map 14

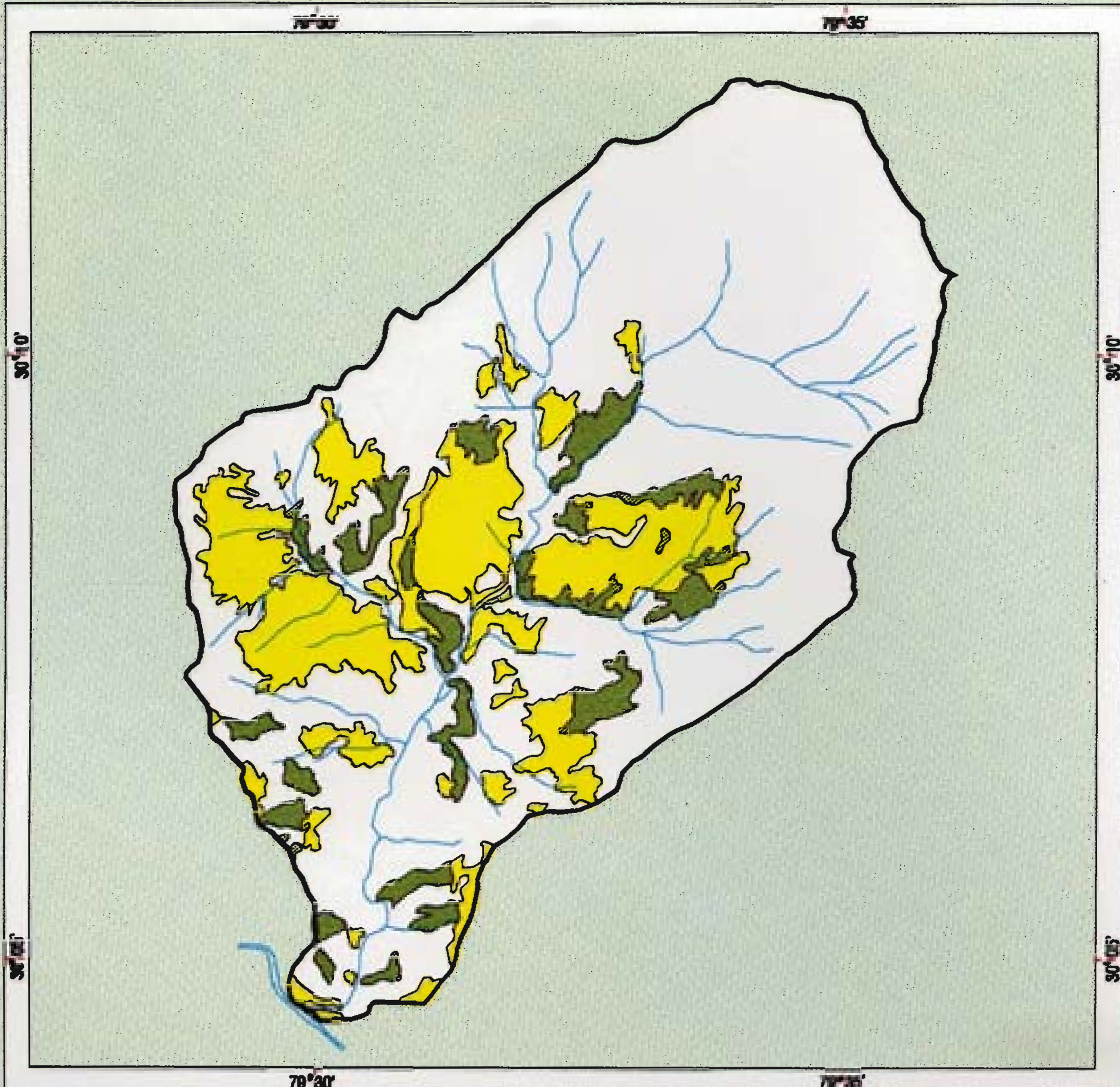
Pranmati Watershed
Garhwal Himalayas, India

Forest Classes

LEGEND

- Protection working circle
- Reserved forests (Chir W.C.)
- Village panchayat forests
- Village boundary (acc. census 1981) with village code number

1 0.5 0 1 2km.



Map 15

Pranmati Watershed
Garhwal Himalayas, India

Degraded Forests

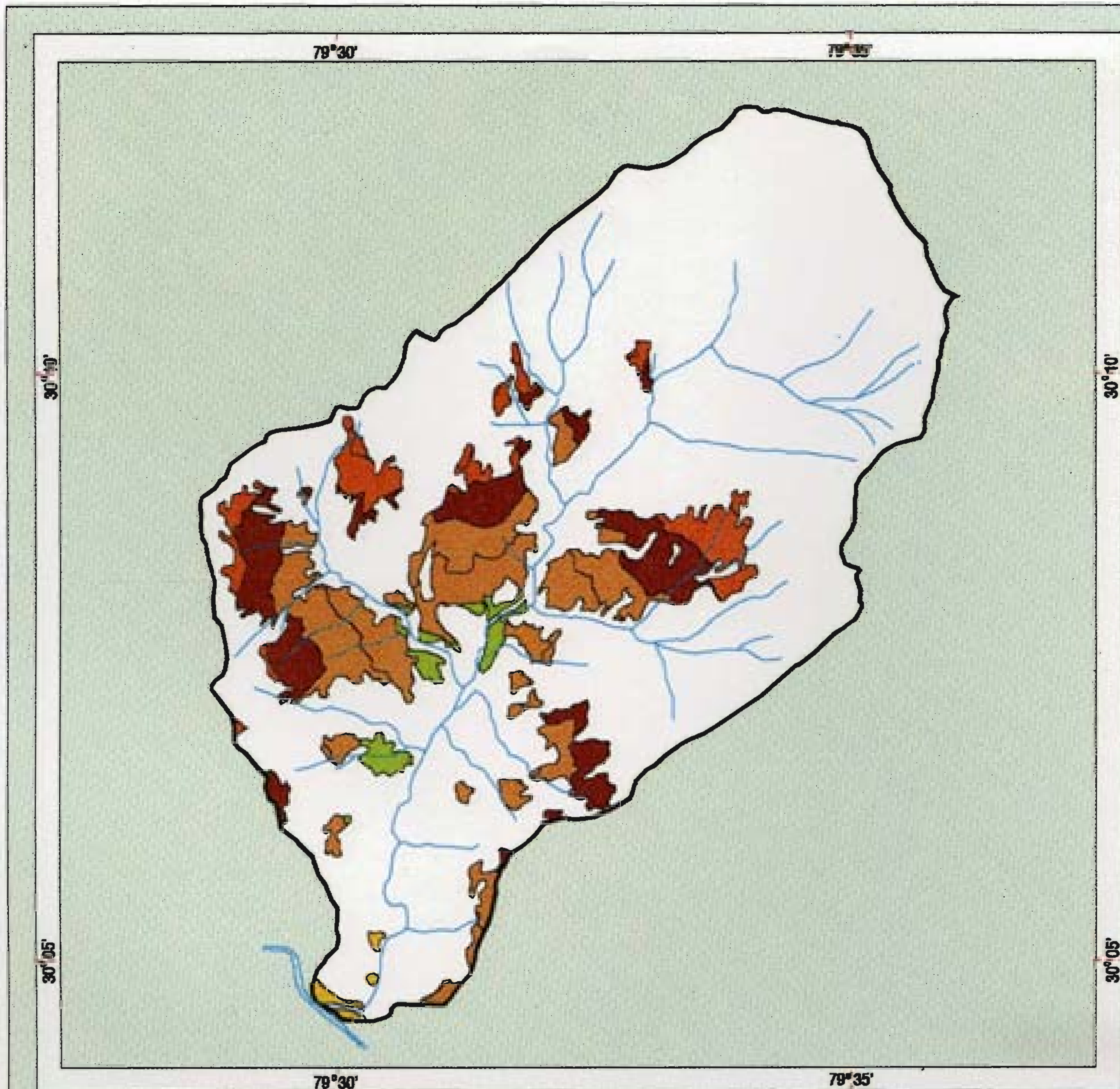
LEGEND

- Degraded forests (< 30% crown cover)
- Agricultural land (including settlements and fallows)

1 0.5 0 1 2km.

ICIMOD

GBPIHED



Map 16

Pranmati Watershed
Garhwal Himalayas, India

Crop Rotation Zones

LEGEND

(Based on 1993-94 survey: elevation in metres)

- Potatoes (2400-2600 m)
- 'Chua'(& Rajma) and Potato-Wheat/Mustard (2200-2400 m)
- 'Chua-Mandua'('Bhat/Soya)-'Jhangora', and Potato-Wheat/'Owa/Jow'(& Mustard) (1850-2200 m)
- Rice- 'Jhangora'-'Mandua'(Bhat/Soya) and Wheat (& Mustard)/'Owa/Jow' (1600-1850 m)
- 'Mandua'-'Jhangora' and Wheat (below 1600 m)

1 0.5 0 1 2km.

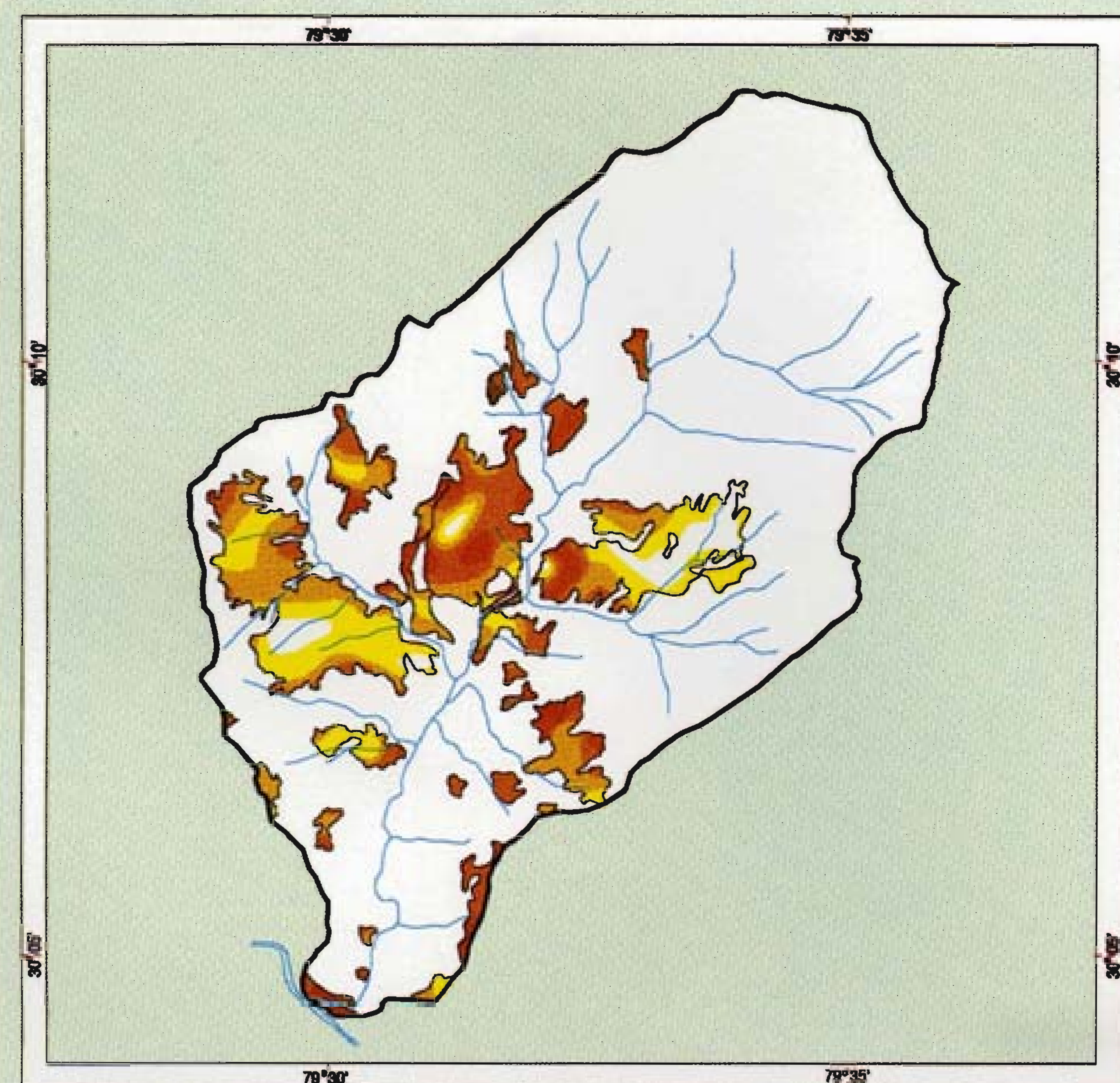
ICIMOD MENRIS '98

GBPIHED

Map 17

Pranmati Watershed
Garhwal Himalayas, India

Agricultural Land in
Different Slope Classes (1993)



LEGEND

- Below 15 (9.6 %)
- 15 - 20 (25.8 %)
- 20 - 25 (29.2 %)
- 25 - 30 (23.3 %)
- 30 - 35 (10.9 %) Unsuitable
- 35 - 40 (0.6 %) Unsuitable
- 40 - 45 (0.4 %) Unsuitable

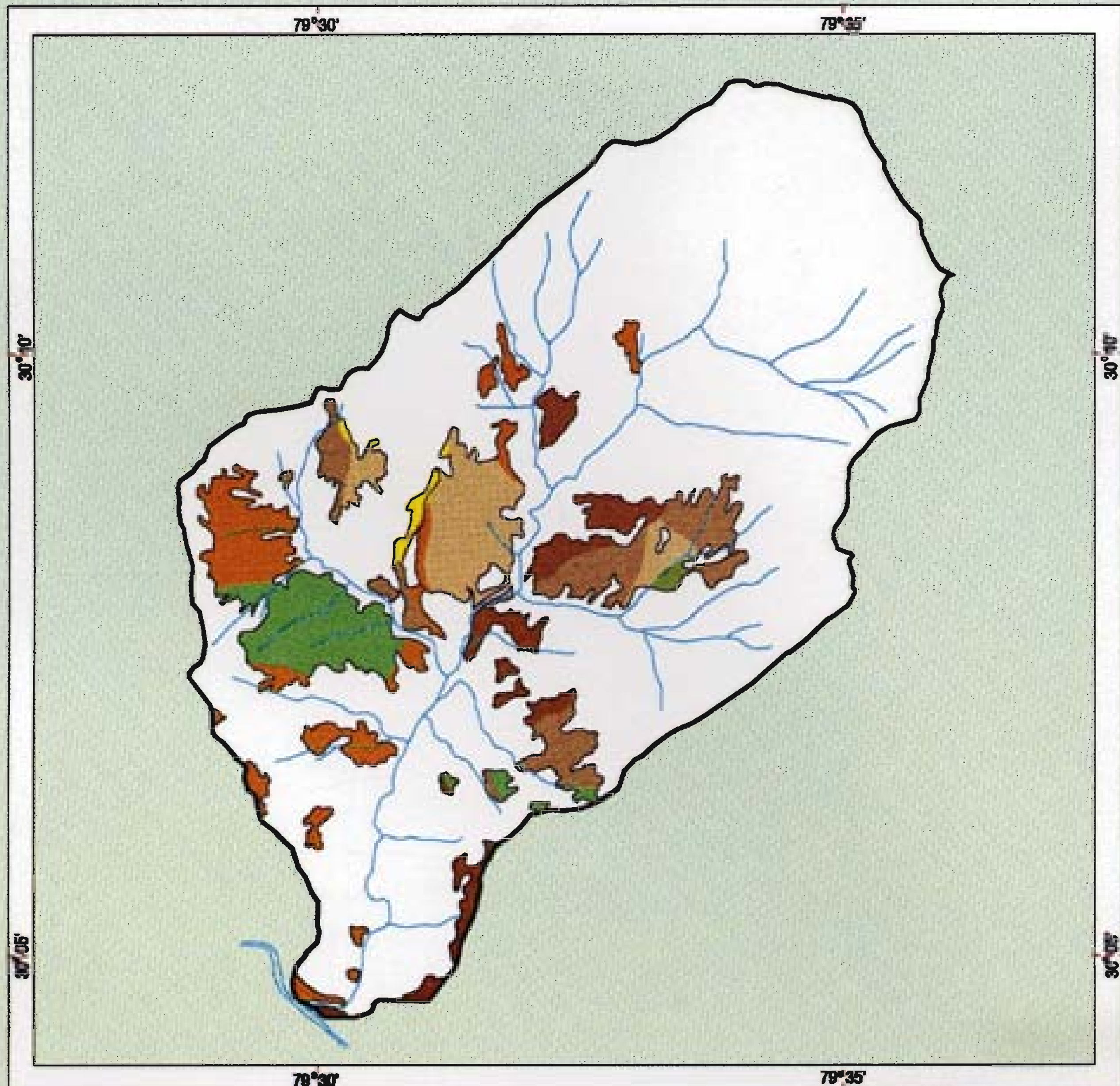
1 0.5 0 1 2km.

ICIMOD
GBPIHED

Map 18

Pranmati Watershed
Garhwal Himalayas, India

Agricultural Land on
Different Slope Aspects (1993)



LEGEND

- North facing (0. 1 %)
- North-west facing (1.0 %)
- North-east facing (18. 0 %)
- East facing (15. 1 %)
- West facing (23. 07 %)
- South-west facing (19. 72 %)
- South-east facing (21. 22 %)
- South facing (1. 72 %)

1 0.5 0 1 2km.

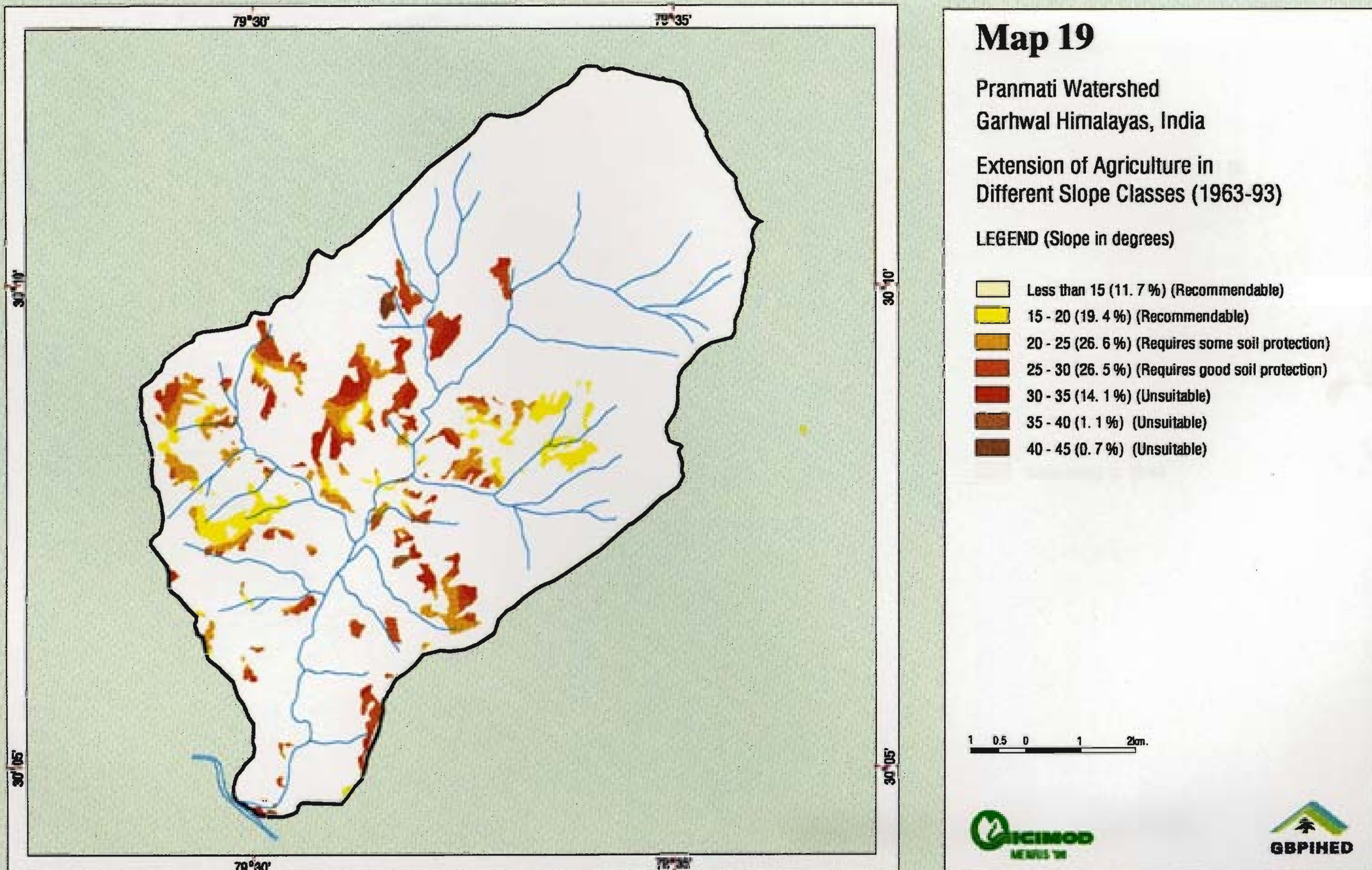
ICIMOD MENRIS '98

GBPIHED

Map 19

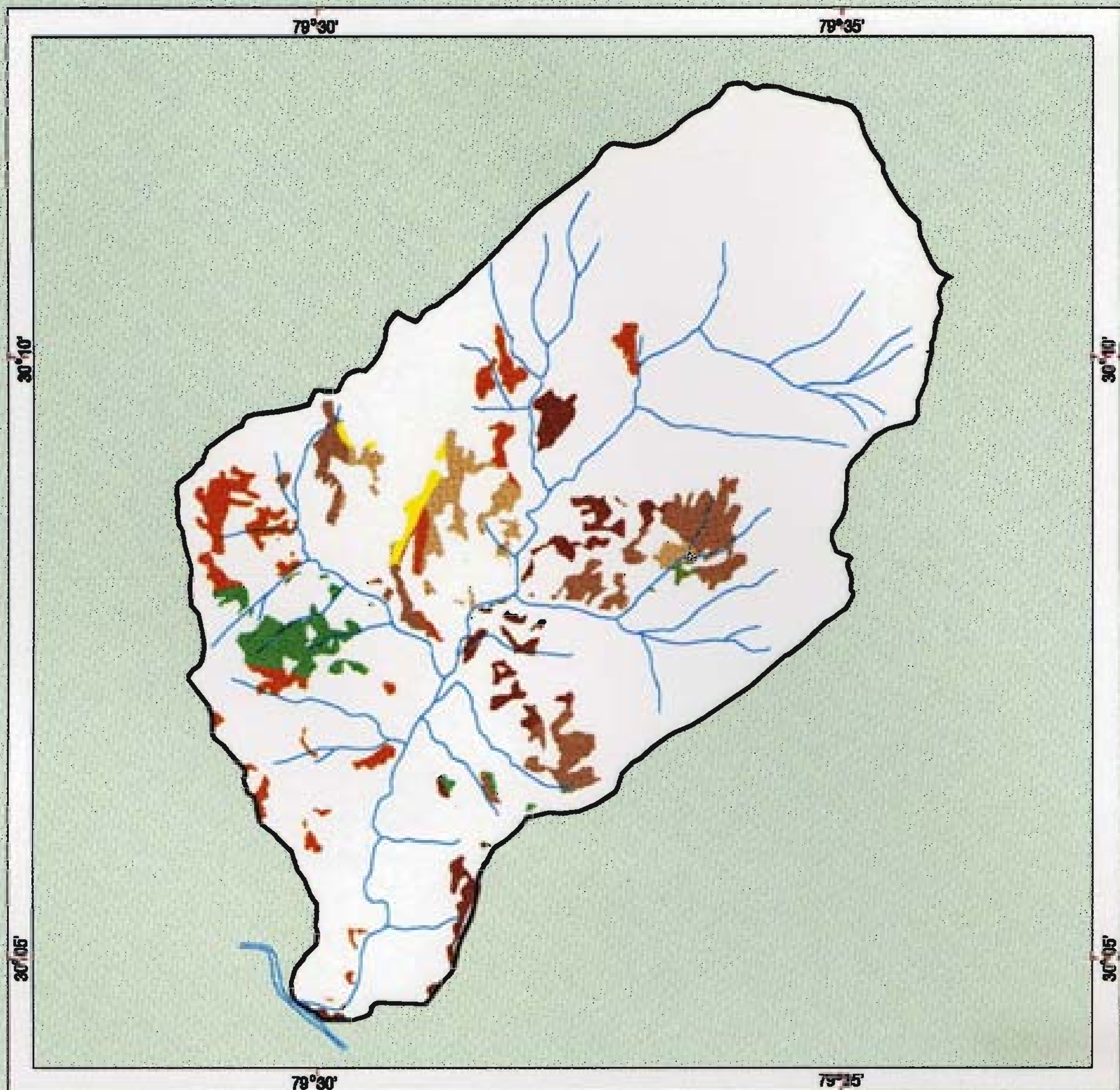
Pranmati Watershed
Garhwal Himalayas, India

Extension of Agriculture in
Different Slope Classes (1963-93)



ICIMOD

GBPIHED



Map 20

Pranmati Watershed
Garhwal Himalayas, India

Extension of Agriculture on to Different Slope Aspects (1963-93)

LEGEND

- North facing (0. 1 %)
- North-west facing (1.0 %)
- North-east facing (18. 0 %)
- East facing (15. 1 %)
- West facing (23. 07 %)
- South-west facing (19. 72 %)
- South-east facing (21. 22 %)
- South facing (1. 72 %)

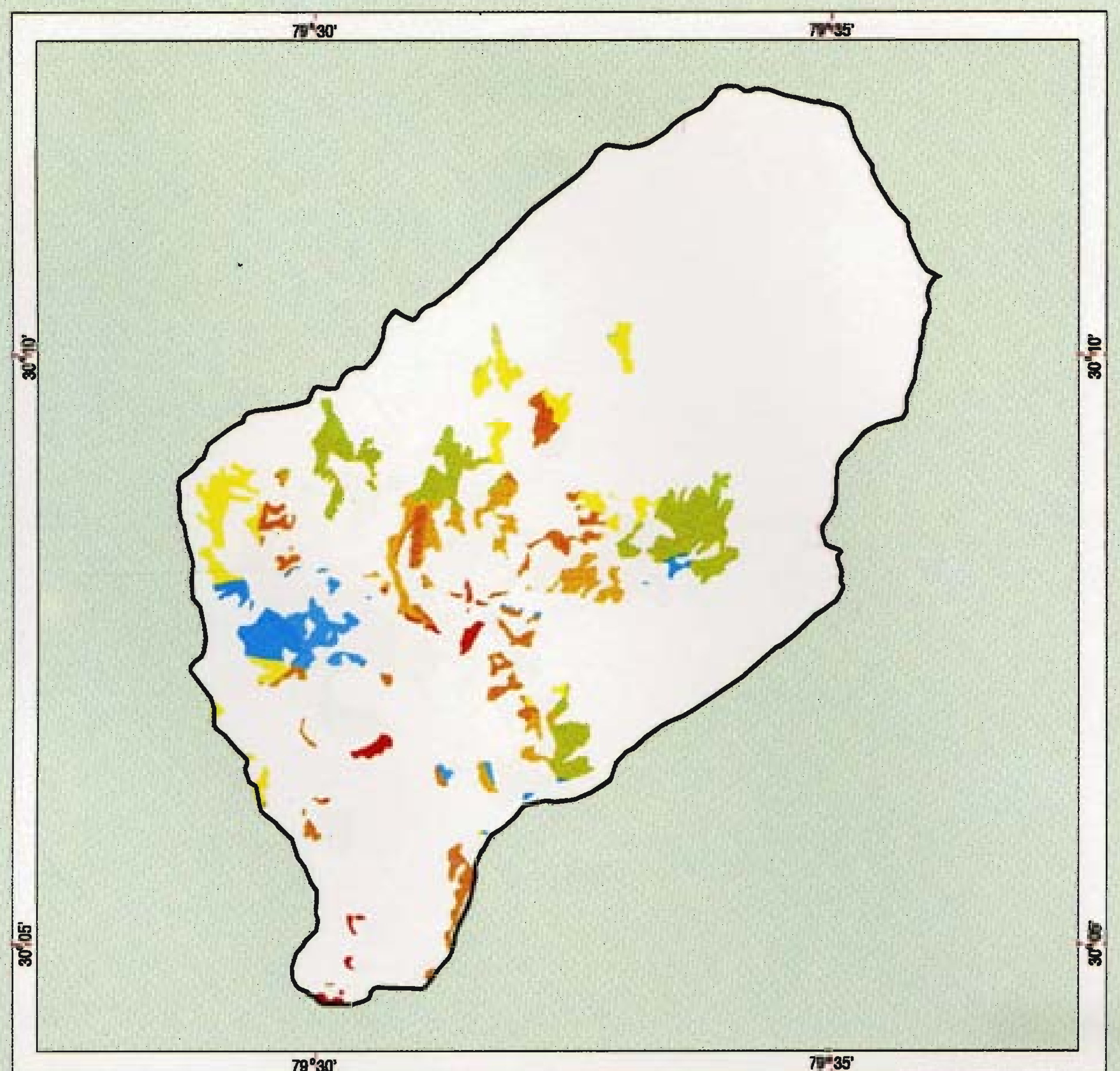
1 0.5 0 1 2km.

ICIMOD
GBPIHED

Map 21

Pranmati Watershed
Garhwal Himalayas, India

Agricultural extension in different Bioclimatic Zones (1963-93)



LEGEND

- Cool moist, alpine meadows
- Warm dry, alpine meadows
- Warm moist, alpine meadows
- Cool moist, sub-alpine
- Warm dry, sub-alpine
- Warm moist, sub-alpine
- High elevation, moist cool
- High elevation, warm dry
- High elevation, warm moist
- Mid-elevation moist cool
- Mid-elevation warm dry
- Mid-elevation warm moist
- Low elevation, moist cool
- Low elevation, warm dry
- Low elevation, warm moist
- Warm moist, riverine valley

1 0.5 0 1 2km.

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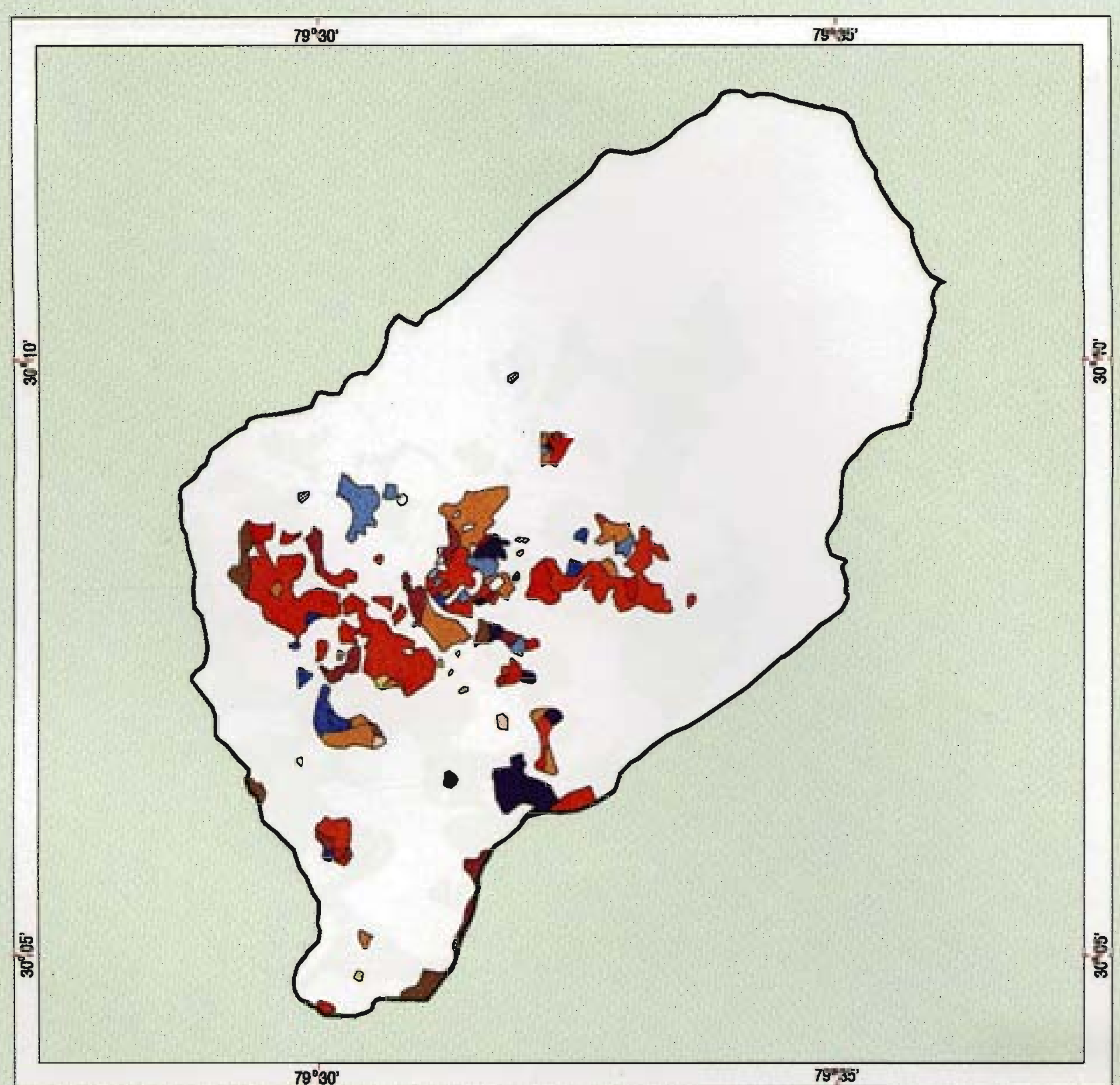
Map 22

Pranmati Watershed
Garhwal Himalayas, India

Soil Types in Agricultural Land



LEGEND (Soil Depth-Texture)

VERY HIGH DEPTH SOIL TYPES (>80 cm)
- Clayey Loam
- Sandy Clay Loam
- Sandy Loam to Loamy Sand

HIGH DEPTH SOIL TYPES (50-80 cm)
- Clayey Loam
- Sandy Clay Loam
- Sandy Loam to Loamy Sand
- Sandy Soil

MEDIUM DEPTH SOIL TYPES (20-50 cm)
- Clayey Loam
- Sandy Clay Loam
- Sandy Loam to Loamy Sand
- Sandy Soil

SHALLOW DEPTH SOIL TYPES (<20 cm)
- Clayey Loam
- Sandy Loam to Loamy Sand

1 0.5 0 1 2km.

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Map 23

Pranmati Watershed

Garhwal Himalayas, India

Areas Viable to Agricultural Extension

LEGEND

- Currently under dense forest (should be safeguarded against encroachment)
- Currently under degraded forest (should be kept under strict surveyance to prevent encroachment and misuse)
- Currently not under Forest (fallow or pasture land that may be cultivated depending on soil conditions)

1 0.5 0 1 2km.

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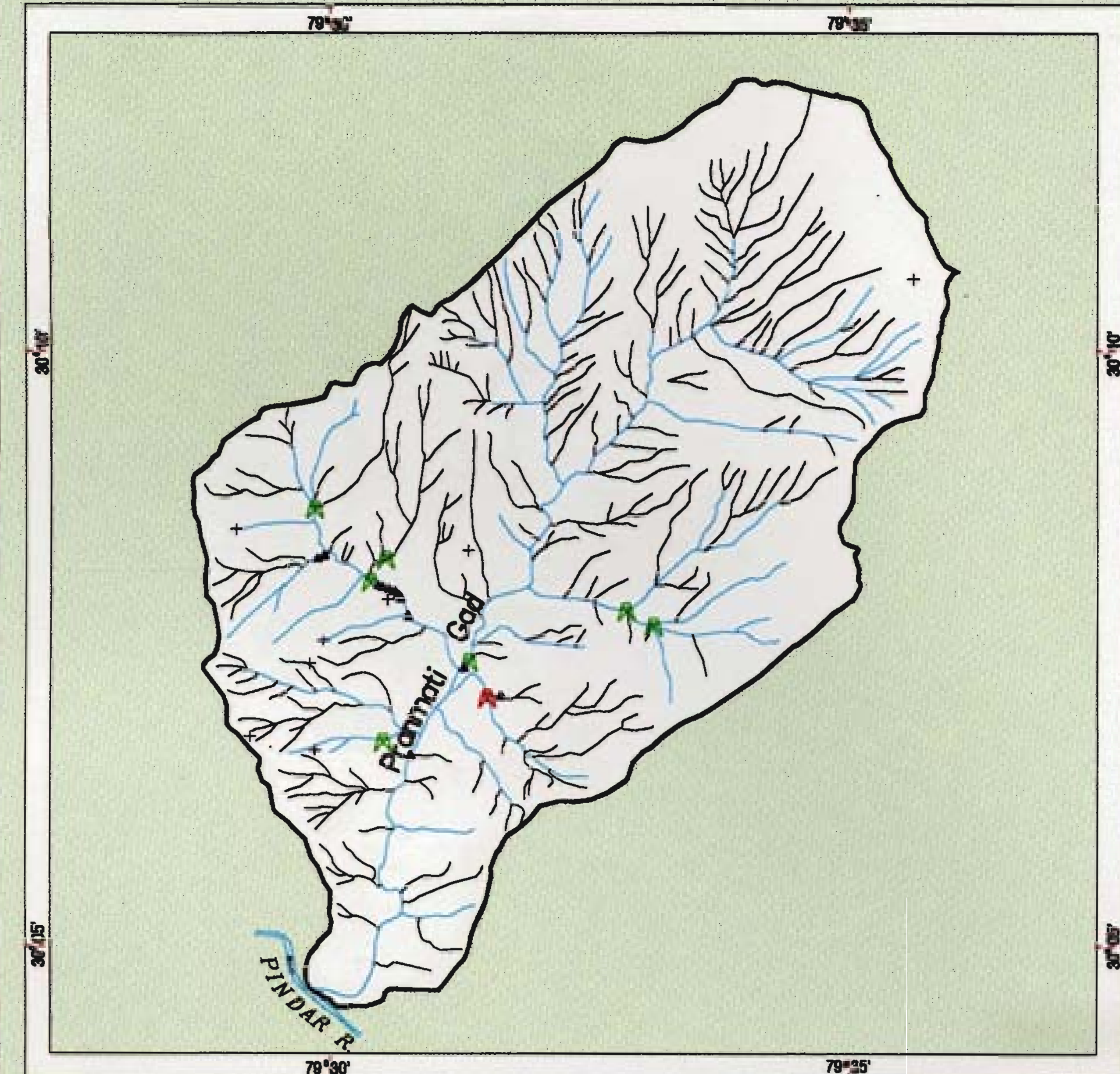
Map 24

Pranmati Watershed
Garhwal Himalayas, India

Proposed and Operational
Micro Hydels & Water Mills



LEGEND

- Operating Micro hydel
- Proposed Micro hydel
- Water mills (traditional)
- Springs
- Perennial streams
- Seasonal streams

1 0.5 0 1 2km.

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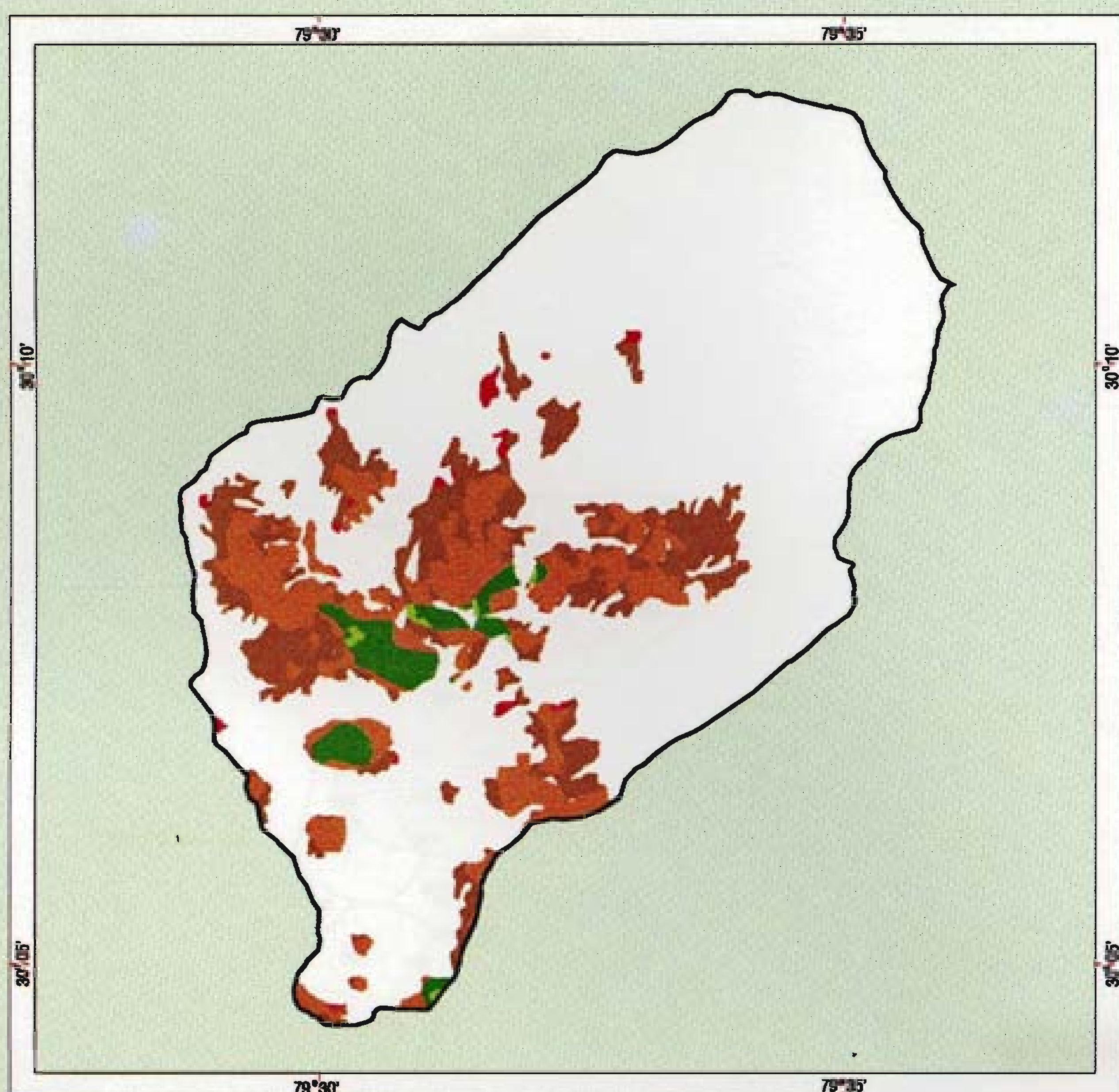
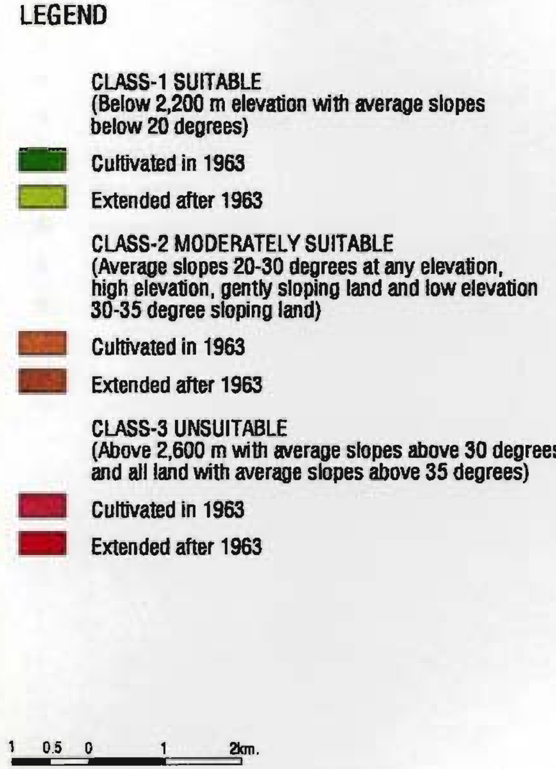


Map 25

Pranmati Watershed

Garhwal Himalayas, India

Suitability Classes of Agricultural Land



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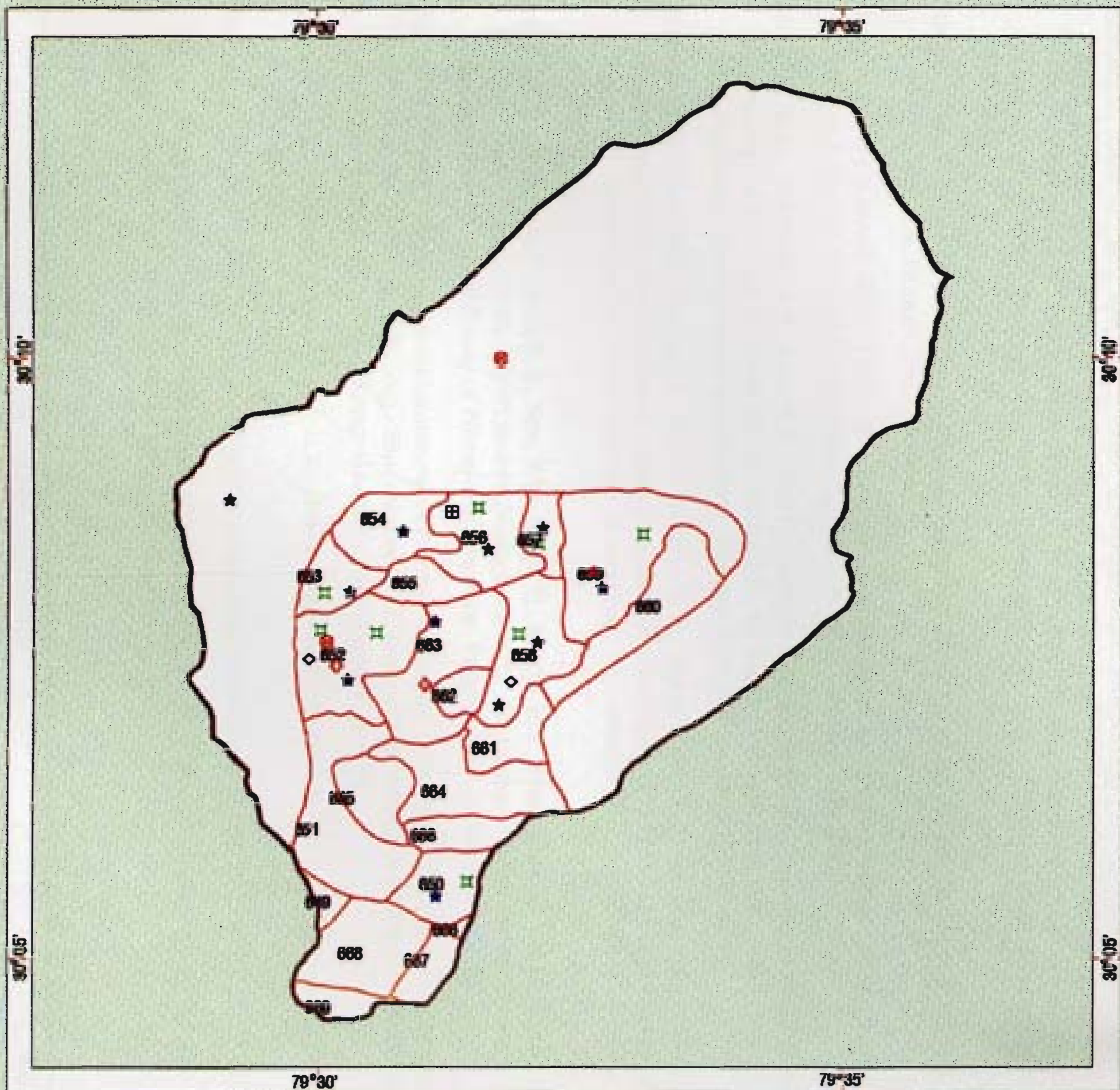

Map 26

Pranmati Watershed
Garhwal Himalayas, India

Schools & Hospitals (1993)

LEGEND

- ★ Primary school
- ◇ Modern primary school
- ▲ Junior high school
- High school
- ⊞ Intermediate college
- Anganbari
- Hospital

1 0.5 0 1 2km.

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Participating Countries of the Hindu Kush-Himalayan Region

- Afghanistan
- Bhutan
- India
- Nepal
- Bangladesh
- China
- Myanmar
- Pakistan

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