PART 3

Agro-ecological Zonation Approaches to Mountain Development

13

AN AGRO-ECOLOGICAL ZONATION APPROACH TO AGRICULTURAL PLANNING IN MOUNTAIN ENVIRONMENTS

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CONTENTS

ABSTRACT

Mountain environments create difficulties for planned development. Heterogeneity, fragility, inaccessibility, and complex socioeconomic settings must be recognized, and developmental issues associated with these problems overcome. In particular, the heterogeneity of agro-climate and soils creates severe constraints when broad-scale agricultural development is programmed for mountain areas. While many international agro-climatic, agro-ecological, and soil classification systems have been developed, none are particularly well suited to the diversity one meets in mountain environments. Agro-ecological zones are presented here as a tool for planning agricultural development in mountainous terrain. The use of a simple, open-ended framework for characterizing land, climate, and associated management on an appropriate scale provides opportunities for improving the efficiency of resource allocation, particularly in the field of agricultural research and extension. With modifications, such a classification system has relevance to mountainous landscapes throughout the world.

INTRODUCTION

Mountain environments offer tremendous challenges to government planners in their attempts to institute rational, efficient programmes for agricultural development. The important mountain characteristics or conditions which separate mountain regions from other areas may be called mountain specificities. They include: (1) inaccessibility, (2) heterogeneity, (3) fragility, (4) marginality, and (5) varied human adaptation mechanisms. These mountain characteristics are interrelated, they have both biophysical and socioeconomic dimensions, and they exhibit considerable variations within the mountain regions.

Because of the above-mentioned factors, mountain regions offer few opportunities for mass development and have a tendency to be economically depressed and environmentally degraded. Concurrently, there is often an unwillingness or inability to learn from the previous development experiences of government and donor-funded projects. Generally, there is no common language to discuss the biophysical factors that affect agricultural development programmes and so the transfer of information is severely hampered. This is particularly critical in a country like Nepal where donor-financed projects are implemented in relative isolation from one another.

In order to overcome these problems, characterization and classification of the agro-ecological pockets become a critical first step in evolving a systematic development plan for mountain areas. The second step involves determining biophysical factors to explain differences in land management within different environments, and, conversely, socioeconomic reasons for management differences within similar regions. This paper presents a biophysical framework, upon which the agro-ecological zones of Nepal are mapped, and also provides a framework for developing agricultural and forestry programmes.

ZONATION APPROACHES TO PLANNING

Planning for the mountainous regions is difficult, and a number of methods to deal with the problems of diversity have been developed, largely by default.

Administrative Units

In general, planners develop programmes for distinct administrative units as they often best reflect political, social, and economic differences within a country. Unfortunately, in mountainous countries such as Nepal, the political boundaries described by Regions, Zones, Districts, and Ilakas have little or no relationship to their biophysical characteristics or associated development potential. Government agricultural and forestry programmes are based largely on the district as the unit of development. Consequently, any given agricultural development programme for a district must cope with the diverse range of climatic, edaphic, and land use conditions that occur.

Administrative zones are often used to define research and extension domains. Integrated Rural Development Projects in Nepal are always defined by district boundaries. Incidental knowledge of a particular agro-ecological zone, applied to a whole district and not to similar agro-ecological zones in other districts, often hinders the efficient allocation of development resources. An extension agent familiar with citrus production in Terathum may be more useful in districts of Western Nepal having the same agro-ecological conditions than in the Tamur Valley two kilometres away. It appears that a simple, systematic land classification system, based on readily available data, is required. Only in this way can we facilitate the efficient distribution of development resources.

Geographic Classification

Many programmes emanating out of central level planning fail to recognize the heterogeneous nature of districts. For example, low-elevation pocket areas in the so-called mountain districts of Nepal receive less attention than they would otherwise receive. The 'mountain' districts of the Eastern Development Region, which include Solukhumbu, Sankhuwasabha, and Taplejung, have agricultural and forestry programmes that are often geared exclusively to high elevation areas. A closer look at these districts reveals that only 25 per cent of the cultivated land in those districts has a cool temperate climate. Agricultural or forestry programmes, based on local knowledge of the Terai, hill, and mountain ecological zones, are, at best, only marginally useful. In most cases, the variability within the ecological zones is at least as great as the variability between the zones. Planning models that suggest movements of seasonally produced goods between the Terai and the mountains, at different times of the year, fail to reflect that the same seasonal movement can occur within distinct agro-ecological pockets of a single isolated watershed, greatly reducing overall transportation cost.

Partial understanding of agro-ecological zones has resulted in failures in research development. Defining altitudinal limits alone, to determine the location of temperate horticultural stations in Nepal, failed to incorporate the overriding importance of total rainfall, length of rainy season, and could cover in viability of production. Although Daman and Kakani are temperature-wise suited to apple production, high humidity strongly restricts the ability to grow economically viable crops.

Historical Production Centres

Grouping of commodity production information is rarely carried out in a framework that identifies agro-ecological differences. Historically, certain areas, by accident or design, have become centres for specialized crop production. Mangoes are said to grow best in Lahan, tobacco in Siraha, sweet oranges in Sindhuli, cauliflower seed in Dolpa, and coffee in Gulmi. In many cases, the administrative boundary, defined by the district, restricts programmes that might be equally or more successful in pocket areas of far removed districts. Many agricultural and forestry specialists wrongly interpret edaphic features (including poor drainage and acidic and drought-prone soils) to reflect regional climatic suitability, whereas they actually represent isolated local soil conditions. Consequently, planners often identify zones of crop suitability that are merely historic production artefacts. Coffee production in Gulmi, a sub-humid tropical to sub-tropical area, has been promoted in spite of the fact that other more humid areas of Nepal are possibly better suited for coffee. A private company is presently developing coffee in Ilam, far from the government-promoted coffee production area in Western Nepal.

National Agro-ecological Classifications

In general, land classifiers are interested in mapping biophysical differences, however minor, to show that they recognize that differences do exist. While this may be useful in the academic sense, it often leaves the planners frustrated in their attempts to work out the significance of 30 to 100 different map units all geographically distinct and more or less incomparable. Information transfer between units is not facilitated. An alternative strategy would be to develop a simplistic framework by which the region of interest is compared using a few pre-chosen characteristics. A uniform classification, investigating rainfall, temperature, and soil characteristics, can provide such a framework. Once these similar areas are recognized across the broad geographical area of interest, the researcher can begin to address the complexities that are important for a particular study. The agro-ecological classification for Nepal developed in this paper has followed this latter strategy.

An International Perspective

The above discussion is based on the difficulties of in-country classification and transfer of information. The problems of communication among countries in the Himalayan Region and beyond are on an even greater scale. Flow of information pertaining to agriculture and forestry is severely restricted not only by language difficulties, direct government interventions, or national pride, but because a common biophysical classification system is lacking. As an example, although there are many similarities between parts of Southern China and Eastern Nepal, how often are the two areas compared? What technologies from similar agro-ecological pockets in China could be introduced into Nepal? To what extent can a general agro-ecological classification system be of use throughout the Himalayan region, or, for that matter, all mountainous regions throughout the world? Obviously, the precipitation and temperature database is a primary requirement. A basic physiographic assessment of geology, geomorphology, and soil characteristics is equally important. The more information available on the existing farming systems, including crops and cropping systems, livestock, local forest management, outside inputs, and productivity, within a defined agro-ecological zone, the greater the likelihood of understanding the system. A properly developed agro-ecological classification permits comparisons of existing farming systems and the extrapolation of potential technologies into areas that might be physically and politically remote.

REQUIREMENTS FOR DEVELOPING AN AGRO-ECOLOGICAL CLASSIFICATION FOR THE MOUNTAINOUS REGIONS OF NEPAL

As previously mentioned, the diversity of climate and landscapes among the mountainous regions of Nepal are not conducive to a generalized planning formula for agricultural development. Climatic differences, normally resulting from thousands of kilometres along any line of longitude, are repeated by diverse altitudinal differences. Tropical and cool temperate crops may flourish less than 15 km apart. The mean annual rainfall of important production areas can range from less than 250 to over 5,000 mm. Infrastructural development varies greatly from one region of Nepal to another. With the exception of the Terai (the plains area), the production of agricultural crops in the mountains occurs in discrete pockets, constrained by climatic zones, soil, and access to supplies and markets.

If agro-ecological maps are too detailed, attempting to portray all possible biophysical differences, no planner can grasp how they can be used. Attempts have been made to develop sophisticated matrices of land characteristics. Without a priority rating of the characteristics significant for agriculture, the results of development actions are impossible to interpret. On the other hand, if classification systems are too general, such as the present Ecological Zones of Nepal, the information may not be suitable for any critical analyses. A proper blending of detail and generalization is required for useful agricultural zonation maps.

A Canadian International Development Agency-funded Land Resources' Mapping Project, carried out between 1980 and 1985, provided an ideal base for land-use planning in Nepal. It combined relatively detailed information on soil, climate, and land use on a scale of 1:50,000, using a standard methodology for the whole country. However, it was difficult, if not impossible, to visualize the total land resource base of Nepal on the 266 individual map sheets. For this reason, 1:250,000 topographic base maps were chosen as the ideal scale for developing the agro-ecological maps of Nepal. Agriculturally significant climatic zones were defined and potential production pockets overlaid on to this base. Current agricultural production areas for a whole development region could be portrayed on a single map sheet and that map sheet could conveniently be used by a planning team.

A number of factors should be considered when developing a framework for an agro-ecological classification system.

- It must reflect all the possible biophysical constraints of importance to agricultural and forestry production.
- It must be simple enough to be readily adopted by the planning arm of the government to focus on development potential.
- It must use existing classification systems, to the extent possible, so as not to further burden planners, politicians, and technical staff.
- The unit of mapping must refer to unchanging edaphic and climatic types rather than the suitability for production of one or two commodities deemed appropriate for development at the time.

- Altitude is the major determinant of the temperature regime in mountainous areas. Consequently, altitudinal zonations must be mapped in units significant to agricultural development. Local variations in temperature, resulting from changes in aspect, slope, and air drainage, are documented but not mapped.
- The agro-ecological classification should have relevance for determining significant research and extension domains for agriculture and agroforestry.
- The classification system must be open-ended, so that new information can be incorporated when made available. This is particularly important when the database is incomplete.

While the data resources in different countries will not be the same, all countries will have some relevant information concerning the above-mentioned factors.

The following inputs were used in the development of the agro-ecological zones of Nepal.

Base Maps (1:250,000 Scale)

Base maps on the scale of 1:250,000 showing topography, rivers, boundaries of development regions, towns, roads, trails, and airports were drafted. All countries should have ready access to this kind of information.

Basic Land Resource/Soil Information

Soil characteristics are critical to plant growth. Soil depth, texture, structure, stability, drainage, macro- and micro-nutrient status, infiltration rate, and permeability are all important when assessing the agricultural potential of a given soil. However, the variability of soils is extreme on any mountain slope and attempting to delineate homogeneous units is a futile exercise—particularly when developing maps on the scale of 1:250,000. For this reason, soil properties by themselves can rarely be used when defining agro-ecological zones in mountainous terrains.

However, within each mapped physiographic region, one finds predictable patterns of bedrock, soil depth, and mineralogy. In this way, map units reflect important soil properties. As an example, Terai soils are universally deep and the high water table is a restricting feature on the lower piedmont, Siwalik soils are very shallow and drought prone, and the middle mountain soils on slopes of less than 30° are sufficiently deep and stable to be terraced. There is a much smaller proportion of gently sloping land (and associated deep soils) as one moves from the Middle Mountains towards the High Himalaya. So, while it is not possible to map the extreme variability associated with a mountain slope on the scale of 1:250,000, it is possible to predict the range of characteristics one might encounter.

Land system maps on the scale of 1:25,000 (LRMP 1985) were reduced to 1:250,000 and the physiographic region boundaries separating Terai, Siwaliks, Middle Mountains, High Mountains, and High Himalaya were transferred to the base map. Soil drainage characteristics significant to agricultural development were extracted from the land system maps for the Terai physiographic region. The boundaries from the land system maps provide important information on soil drainage. A summary of the range of characteristics of individual physiographic regions is provided in Table 13.1.

Table 13.1. Characteristics of physiographic regions of Nepal

Features	Terai	Siwaliks	Middle mountains	High mountains
Geology	Quantenary alluviam	Tertiary sandstone, siltstone, shale and conglomerates	Phyllite, quarzite limestone and islands of granites	Gneiss, quartzite, mica shists
Elevation	100–330 m	200–1500 m	800–2400 m. Relief 1,500 m with isolated peaks to 2,700 m	1,000–4,000 m. High relief 3,000 m from valley floor to ridges
Climate	Tropical	Tropical, sub-tropical	Sub-tropical, warm temperate (but tropical in lower river valleys; cool temperate on high ridges)	Warm to cool temperate, alpine
Moisture regime	Sub-humid in FW + MWDR; humid in W + C and EDR	Sub-humid in most of the area; humid in N-aspect of W+C+EDR and Dun Valley	Humid; perhumid above 2,000 m	Sub-humid to perhumid
Rainfall intensity	High	High	Medium	Low
Vegetation	Sal + mixed hardwoods	Sal + mixed hardwoods + pine forest	Pine forest + mixed hardwood and oak forest	Fir, pine, birch and rhododendron
Soils	Ustochrepts, Haplustolls, Haplaquepts Haplustalfs, Ustifluvents, Ustorthents	Ustochrepts, Haplustolls, Rhodustalfs, Ustorthents, Dystrochrepts, Haplaquepts, Ustifluvents	Ustochrepts, Haplustalfs, Rhodustalfs, Haplumbrepts, Ustorthents, Ustifluvents	Eutrochrepts, Dystrochrepts, Cryumbrepts, Cryorthents, Ustorthents

Crops	Rice, maize, wheat, mustard, sugarcane, cotton, tea	Rice, maize, wheat millet, radish, potato, ginger	Rice, maize, wheat, millet, barley, pulses, sugarcane, radish, potato, ginger, cardamom	Oat, barley, wheat, potato, buckwheat, yams, amaranthus, medicinal herbs
Horticulture	Mango, litchi, pineapple, jackfruit, potato, tomato	Mango, papaya, banana, potato	Mango, papaya, banana, orange, lime, lemon, peach, plum, apricot, potato.	Chestnut, walnut, apple, peach, plum, apricot, potato.
People	Tharus, Brahmins Chetris, Muslims	Tharus (Dun Valley), presently all hill tribes displaced/ immigrated from Middle Mountains	Gurung, Magars, Tamangs, Newars, Brahmins, Chetris, Damals, Sarkis, Sunars, Kumals, Rais, Limbu	Khas Chetris, Tibetan - related groups, Thakalis, Bhotes, Sherpas Tamangs, Ghales
Industry	Match factory, jute factory, cigarette factory, sugar factory, saw-mills, rice & flour mills, soaps, condiment & food processing, furniture, industrial estates.	Saw-mills, rice, flour, & oil mills, industrial estates, cotton factory, cement factory, wildlife camps	Rice, flour & oil mills, cement factory, industrial estates, cottage industry—handicraft, curios, hosiery, metallurgy, furniture, and plastics, hotels & lodges	Cottage industry, carpets, blankets, hand-woven cloth, trekking
Transport	Good road linkage	Good road linkages within Dun Valleys	Road linkages around major centres	Very few road linkages

Source: Carson 1990.

Virtually all countries have some sort of physiographic, geographic, and bioclimatic land system or soil association maps. Any of these could be adopted for the above use.

Land-use Maps

LRMP land-use maps, produced in 1985, were reduced from a scale of 1:125,000 to 1:250,000 scale and major blocks of cultivated land in the Terai, Siwaliks, Middle Mountains, High Mountains, and the High Himalayan regions were delineated. These included all areas of flat or sloping land. Because of the problems of landscape heterogeneity and mapping scale, these cultivated pockets were actually cultivated within the range of 25 to 100 per cent. It can be safely assumed that the uncultivated land in these pockets was heavily used for grazing as well as fodder and firewood collection.

With the advent of high resolution space platforms, this type of information is much more readily available than it was 10 years ago. Isolated pockets having detailed land-use information for representative areas can be used in lieu of country-wide coverage.

Definition of Altitudinal Limits

Altitudinal ranges were defined, based on their effect on temperature. These are summarized in Fig. 13.1. These ranges are significant for food crop production and can help identify and explain differences in forest species, perennial fruit tree cropping patterns, and planting dates. While the upper limits of cultivation are below 3,000 m in the south of the Himalaya, small cultivated pocket areas north of the Himalaya are found to be much higher. These important limits were drafted onto the 1:250,000 base maps. The areas mapped within these contours represented the major climatic zones significant to agriculture. Only existing cultivated areas of the different climatic zones were delineated. These were called the potential production pocket areas. The areas not designated with any pattern on the map represent non-cultivated forest or steep lands.

With major changes in latitude and degree of the continental type of climate, temperature regimes, including diurnal and seasonal ranges, are affected. This is of great significance to an overall classification system of mountain areas and must be considered when geographically remote areas of the earth surface are being compared.

Defining Criteria for Alluvial/Lacustrine Plains

Because of their low relief, a different set of criteria was used to define the potential production pocket areas in the Terai and Dun Valleys. These regions fall exclusively into the tropical zone and are capable of producing a similar range of crops. There are, however, two major, mappable factors of significance to agricultural development. The first is that large areas of land, well suited to agricultural production, are presently under forests that are protected by the government. Although farmers are not legally permitted to clear these forests, in practice many landless hill farmers are felling and clearing this land at an accelerated rate. The other important biophysical differentiation made was based on soils. The active, recent, and sub-recent alluvial plains have imperfectly to poorly drained soils and are well suited for rice cultivation. This is in contrast with the upland soils that are found on erosional landscapes and are well drained.

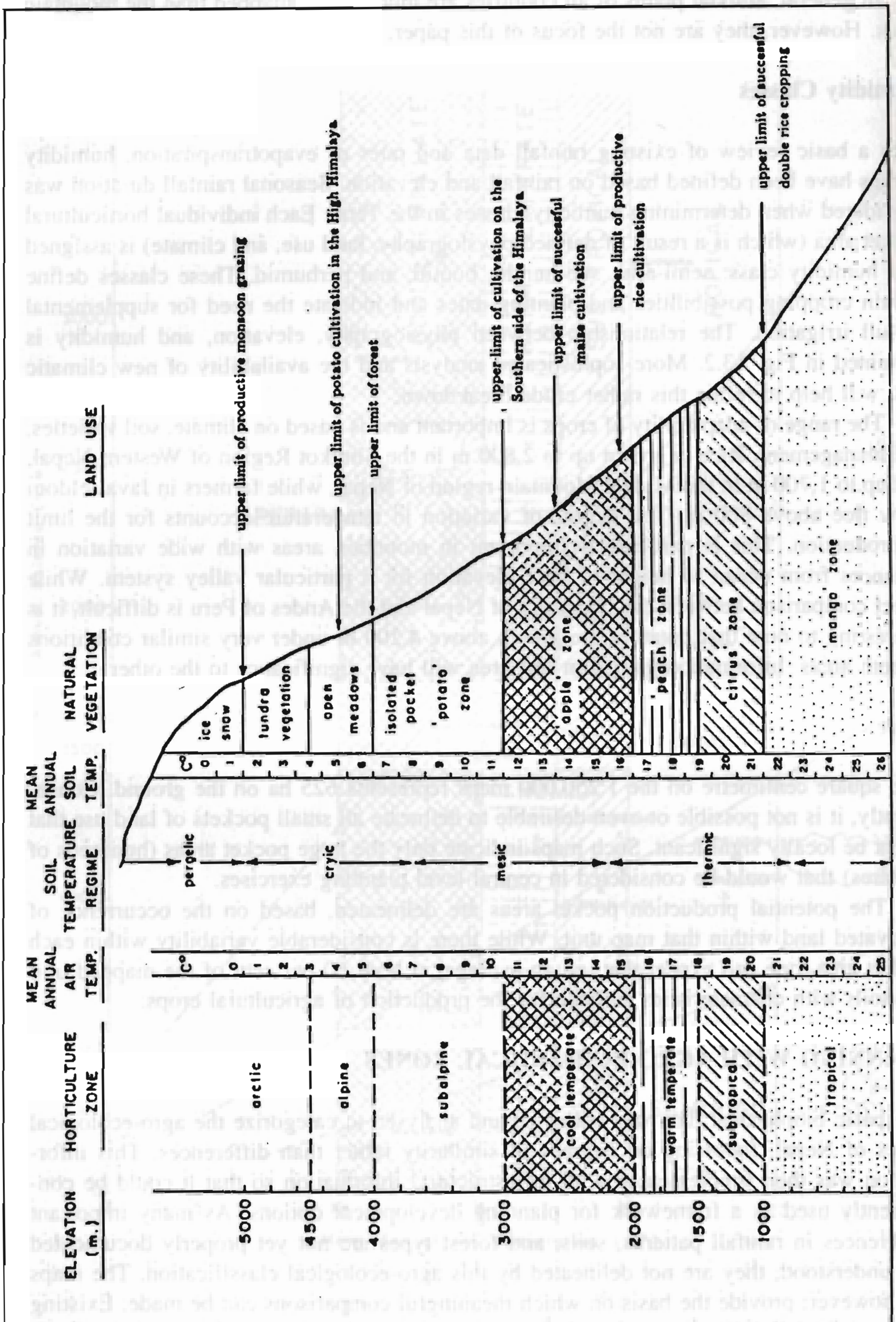

Figure 13.1: Agro-ecological zones of Nepal

In general, alluvial plains of all countries are much better mapped than the mountain areas. However, they are not the focus of this paper.

Humidity Classes

With a basic review of existing rainfall data and rates of evapotranspiration, humidity classes have been defined based on rainfall and elevation. Seasonal rainfall duration was considered when determining humidity classes in the Terai. Each individual horticultural pocket area (which is a result of defined physiography, land use, and climate) is assigned to a humidity class: semi-arid, sub-humid, humid, and perhumid. These classes define certain cropping possibilities and planting dates and indicate the need for supplemental or full irrigation. The relationship between physiography, elevation, and humidity is presented in Fig. 13.2. More sophisticated analysis and the availability of new climatic data will help to refine this rather crude breakdown.

The range of adaptability of crops is important and is based on climate, soil varieties, and management. Rice is grown up to 2,800 m in the Simikot Region of Western Nepal, and up to 1,700 m in the Middle Mountain region of Nepal, while farmers in Java seldom grow rice above 800 m. The degree of variation in temperature accounts for the limit to production. This is particularly important in mountain areas with wide variation in distances from ocean to height of base elevation for a particular valley system. While direct comparison between the Himalaya of Nepal and the Andes of Peru is difficult, it is interesting to note that potatoes are grown above 4,200 m under very similar conditions in both areas. Information gained in one area will have significance to the other.

Scale

One square centimetre on the 1:250,000 maps represents 625 ha on the ground. Consequently, it is not possible or even desirable to delineate all small pockets of land use that might be locally significant. Such maps indicate only the large pocket areas (hundreds of hectares) that would be considered in central-level planning exercises.

The potential production pocket areas are delineated, based on the occurrence of cultivated land within that map unit. While there is considerable variability within each pocket area, one can expect that, on an average, at least 60 per cent of the mapped unit has soils with characteristics suitable for the production of agricultural crops.

PLANNING WITH AGRO-ECOLOGICAL ZONES

The basic biophysical data was collected and analysed to categorize the agro-ecological zones of Nepal, focussing on degrees of similarity rather than differences. This information was then supplemented with infrastructural information so that it could be conveniently used as a framework for planning development options. As many important differences in rainfall patterns, soils, and forest types are not yet properly documented nor understood, they are not delineated by this agro-ecological classification. The maps do, however, provide the basis on which meaningful comparisons can be made. Existing government administrative units of the district and region are superimposed on to the biophysical information and all data are tallied on a district and planning unit basis.

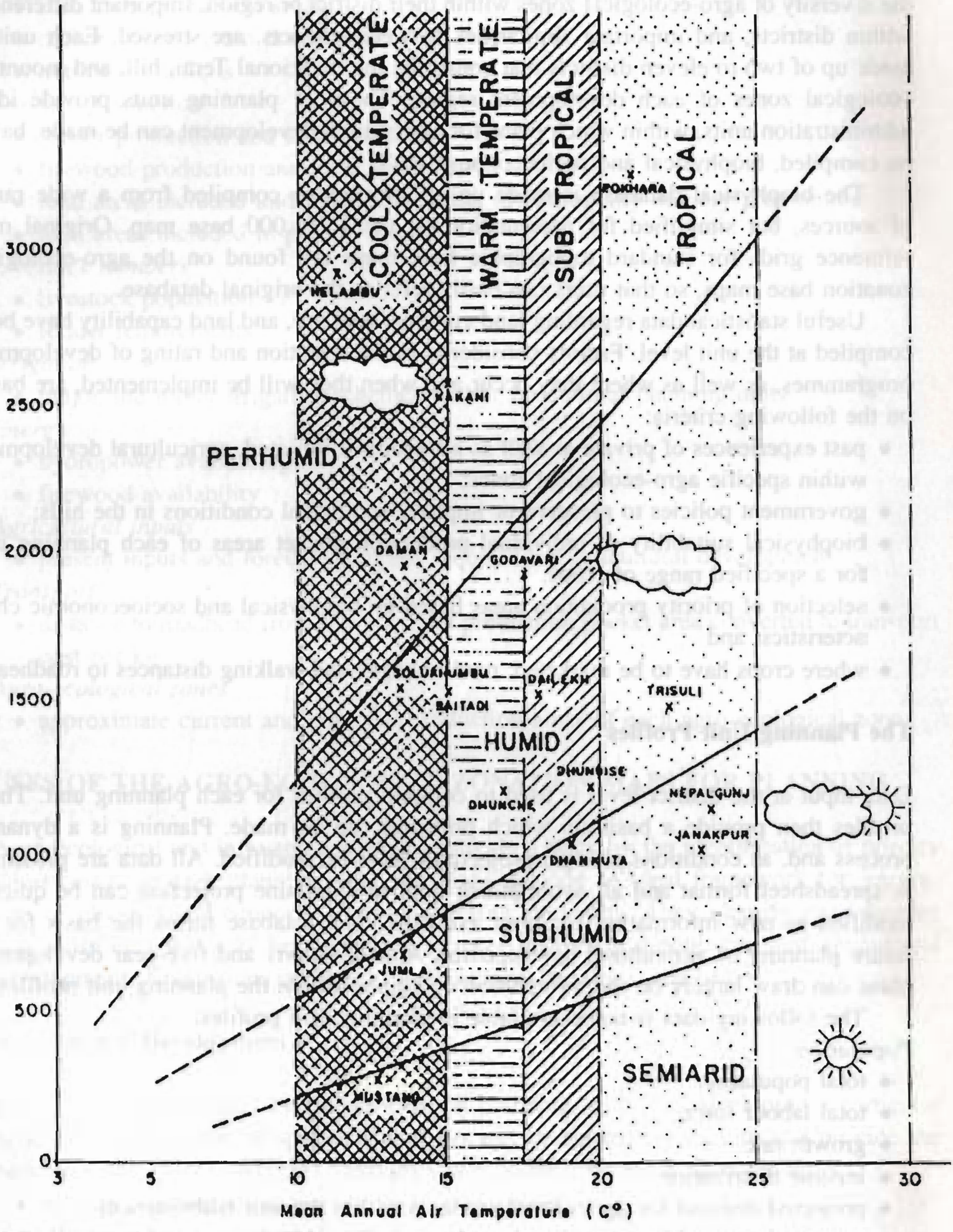

Figure 13.2: Major agro-ecological zones of Nepal

Temperature, rainfall relationships of selected horticulture stations

Agricultural Planning Units

Agricultural planning units have been developed to assist administrators in understanding the diversity of agro-ecological zones within their district or region. Important differences within districts, and important similarities between districts, are stressed. Each unit is made up of two to eleven districts that constitute the traditional Terai, hill, and mountain ecological zones of each development region. These 15 planning units provide ideal administration units, within which plans for agricultural development can be made, based on compiled, biophysical and socioeconomic data.

The biophysical database is made up of information compiled from a wide range of sources, but simplified for presentation on the 1:250,000 base map. Original map reference grids for standard topographic base maps are found on the agro-ecological zonation base maps, so that users can easily refer to the original database.

Useful statistical data regarding land systems, land use, and land capability have been compiled at the unit level. Factors considered in the selection and rating of development programmes, as well as where they occur and when they will be implemented, are based on the following criteria:

- past experiences of private as well as government-initiated, agricultural development within specific agro-ecological zones;
- government policies to preserve or improve ecological conditions in the hills;
- biophysical suitability of individual production pocket areas of each planning unit for a specified range of crops;
- selection of priority production areas based on biophysical and socioeconomic characteristics; and
- where crops have to be marketed, road linkages and walking distances to roadheads.

The Planning Unit Profiles

Data input at the district level is used to compile profiles for each planning unit. These profiles then provide a basis on which priorities can be made. Planning is a dynamic process and, as conditions change, projections must be modified. All data are presented in spreadsheet format and all assumptions used to determine projection can be quickly modified as new information becomes available. The database forms the basis for all future planning of agricultural development. Annual reports and five-year development plans can draw largely on the information contained within the planning unit profiles.

The following data is made available in planning unit profiles.

Population

- total population
- total labour force
- growth rate
- income distribution
- projected demand for agricultural products within the unit (subsistence)
- projected demand for agricultural products, both within the unit and nationally (commercial)

Agricultural production

- total area in rain-fed cultivated land

- total area in irrigated land
- total area of arable land now in forest
- total production of major grain crops
- cash crop production areas
- deficit of food grain production
- nutritional deficits

Forestry production

- fodder production and local needs
- firewood production and local needs
- total areas included under the jurisdiction of community forestry programme
- total areas included in private forests

Livestock numbers

- livestock population
- fodder requirements

Irrigation

- major and minor irrigation schemes within agricultural planning units

Energy

- hydropower availability
- firewood availability

Agricultural inputs

- present inputs and forecasted inputs required for agricultural development

Transport

- distance to roadhead from any potential production pocket area converted to transport cost per kg

Agro-ecological zones

- approximate current and potential production areas of each agro-ecological zone

USES OF THE AGRO-ECOLOGICAL ZONATION MAPS FOR PLANNING

Agro-ecological and infrastructural maps provide a basis for the identification of priority development in each planning unit. The maps provide an ideal framework for integration of physical and economic factors affecting suitability. They identify opportunities and constraints that may be significant in more detailed planning stages of agricultural development. Suggestions on how to use the maps are discussed below.

Agricultural Development

Reliable data is required by the agricultural planning officer in developing a particular agricultural sub-sector. Biophysical analyses can be carried out rapidly and provide the basis for initial area selection. Analyses made possible by the maps include:

- accurate delineation of pocket production areas;
- area of the major potential cropping areas;
- relevance of research work to be extended throughout a given area;
- relative reliance on forest for soil fertility management based on distance from a road-head;

- lower and upper limits of particular cropping patterns and preferred planting dates for individual crops;
- estimation of fertilizer requirements and scheduled arrival dates to different pocket areas to meet different crop needs; and
- initial priorities of different areas for cereal and cash crop expansion.

Many management differences of potential pocket production areas are not yet identified. For instance, winter afternoon humidity seems to be a critical factor differentiating the climate of Eastern Nepal from the Western Region. There is, however, little reliable data on humidity, so, for the time being, inferences must be made. For this reason, extension and research workers should be cautious when making blanket recommendations for individual agro-ecological zones.

Commercial Horticultural Production

Horticultural development is more complex than most agricultural development because commercial markets are required before production can be considered. As an example, by initial supply-demand analyses and estimation of marketing potential, citrus fruits may appear to be a viable crop capable of bringing significant returns to the farmer in a particular planning unit. A cursory inspection of the map will provide initial identification of potential horticultural pocket areas that are close enough to roadheads for farmers to market their produce. Pocket areas requiring a maximum of one day's walk may be considered, but could be considerably less if the economist calculates that three to four years of intercropping of high-value vegetable crops are required to make a viable development package for the small farmers. In Fig. 13.3, a one day walk from roadheads in 1990 encompassed a number of potential horticultural pocket areas. By flagging the subtropical zone pockets within a one-day walk of the roadhead, the land areas most suited for citrus production were then indicated. An initial estimation of potential horticultural land for developing target areas can thus be made.

The planner can then review the original database and come up with more detailed information on crops, cropping intensity, state and condition of forests, and land capability in the block production area. In the majority of cases, both within and in the surroundings of the potential pocket areas, there are considerable areas of forest, scrubland, and marginal forest land that are also well suited to horticultural development. Given the trend to decentralize decision-making processes, the next stage of planning can only come with local involvement and local resource assessment. Rapid rural appraisal by an inter-disciplinary team can quickly identify development opportunities.

Forestry

Forest use in Nepal is often closely related to the demands of adjacent agricultural production areas. The great majority of forest degradation occurs within or immediately adjacent to the major agricultural pockets. Physiographic and climatic characteristics also provide vital information regarding location and significance of forest degradation. Forest degradation in low-elevation forests of the tropics generally results in much more serious soil erosion than the same degree of degradation in cool temperate regions.

Size of production pockets gives an indication of the fodder, litter, and firewood

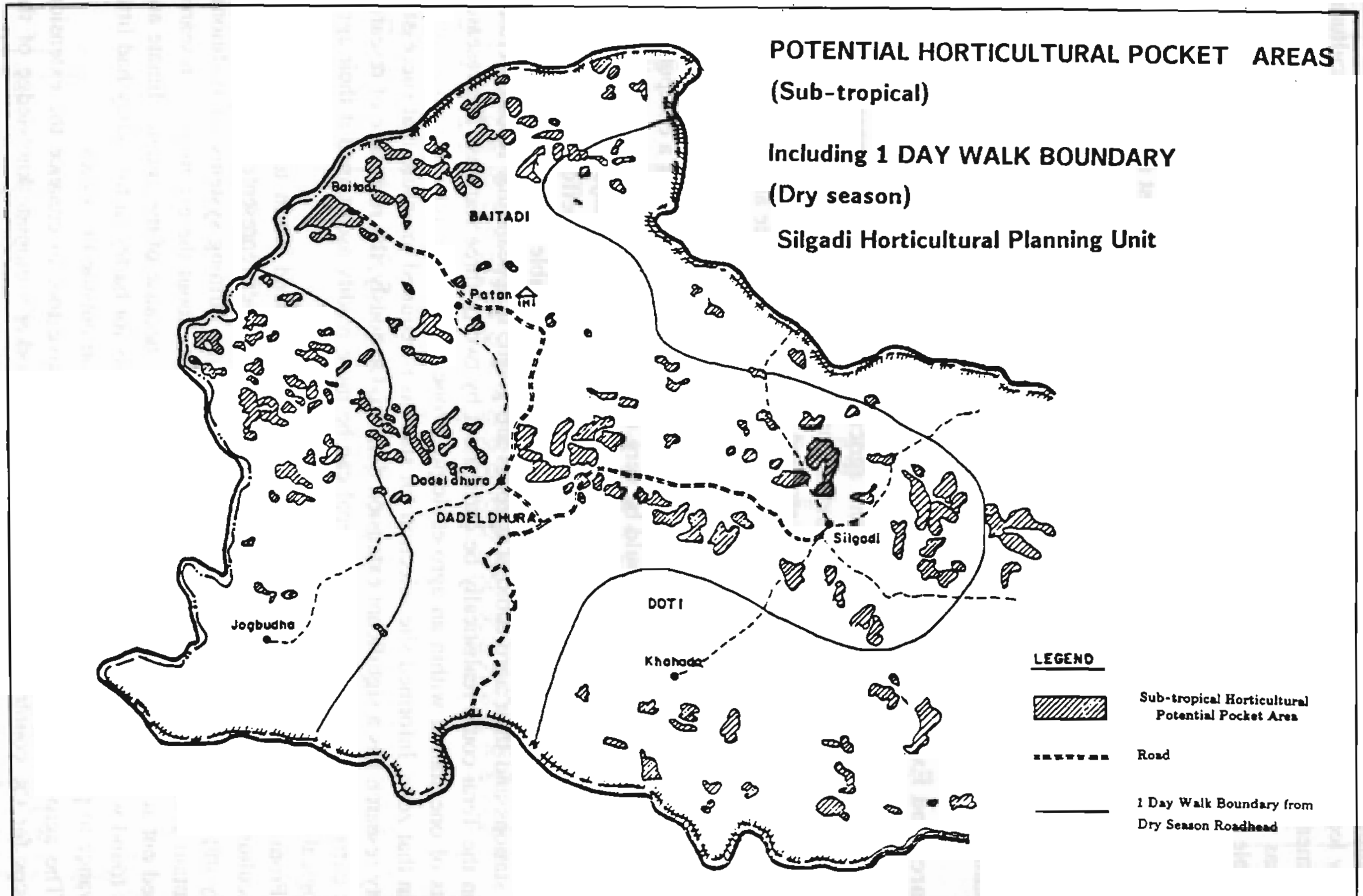

Figure 13.3: Potential horticulture pocket areas (subtropical) including one-day walk boundary (dryseason). Silgadi Horticulture Planning Unit

needs of the village. Specific horticultural crops may require staking and packaging, placing further demands on the forest.

Commercial horticultural production in a number of areas of the Himalaya has inadvertently led to increased forest degradation, negating the positive effects of horticultural development.

Areas within or near the agro-ecological production pockets can be assigned a range of suitable agro-forestry species. After initial selection of agro-forestry production pockets, the forest planner can assist the villagers in choosing species appropriate to their needs.

As agriculture and forestry are intricately connected, foresters must acknowledge the needs of the local villagers and become acquainted with village management of forest fringe areas.

To avoid ongoing land degradation in Nepal, the intensive management being carried out on cultivated lands must be extended to forest areas. A common classification for agricultural and forest lands would help planners to facilitate this goal.

Research and Extension Domains

Agro-ecological zonation maps allow the agriculturist to identify and characterize the important agricultural areas of Nepal and to carry out experimentation that will reflect problems and opportunities for a predetermined subset of cultivated land.

The classification is not yet sophisticated enough to differentiate all local biophysical differences, but it lays the groundwork and the methodology. As the database develops, the maps become more detailed. They can then be updated to become increasingly sophisticated. Given the present complexity of the maps, it is apparent that a computerized geographical information system could be very useful.

At the national planning level, the government can identify the major agro-ecological zones of Nepal and, at a glance, match the government's research efforts with requirements of specific agro-ecological zones. As an example, in Table 13.2, selected horticultural stations and their agro-ecological zones are given. It appears that research efforts within the Terai could realistically be carried out by two or three stations. The research results of one station within an agro-ecological zone should have relevance to all areas within that zone. Informed site selection for stations is required to ensure that successful variety research has a significant extension domain. Obviously, the relevance of research work carried out in stations outside Nepal can be more readily ascertained if their agro-ecological character is known.

From Table 13.2 we see that tropical, sub-tropical, and warm temperate, humid horticultural pocket areas on sloping lands appear to be under-represented. This is particularly important considering the need to find alternative farming systems for traditional mountain grain crops farmers. There are serious doubts about the extension of research carried out at Kirtipur to anywhere outside the valley, because of the unique climate and soils found within the Kathmandu valley. Variety trials for barley in the valley had little relevance to production of barley at the same elevation outside the valley.

The agro-ecological approach provides an effective tool to enhance the extension services for the country. It is based on the field worker's intimate knowledge of the land and farming systems of a particular biophysical zone, rather than on specialized

Table 13.2. Horticultural stations of Nepal: Agro-ecological zonations

Horticultural station	Physio-graphic system	Land systems	Elevation (m)	Mean annual precipitation (mm)	Horticultural zone	Humidity class	Crops	Comments
Nepalgunj	T	2	145	1,200	Tropical	Sub-humid	Mango, guava, jackfruit	
Yagapuri	S	5		2,000	Tropical	Humid	Mango, litchi, pineapple	
Trisuli	M	10	600	1,500	Tropical	Sub-humid	Mango, litchi, jackfruit	
Tarahara	T	2	200	1,235	Tropical	Sub-humid		
Sarlahi	T	2	190	2,250	Tropical	Humid		
Parwanipur	T	2	115	1,200	Tropical	Sub-humid		
Janakpur	T	2	100	900	Tropical	Sub-humid	Mango, litchi	
Pokhara	MM	10	850	3,655	Tropical	Sub-humid	Mango, litchi, jackfruit	
Panchkhal	MM	10	850		Tropical	Sub-humid	Mango, citrus, banana	
Palpa (Tansen)	MM	11	1,050	1,200	Sub-tropical	Sub-humid	Banana, mango, pineapple	
Dhunbise	MM	11	1,085	1,200	Sub-tropical	Sub-humid	Citrus	
Dhankuta	MM	11	1,110	1,000	Sub-tropical	Sub-humid	Mango, litchi, lemon, guava	
Kirtipur	MM	10	1,320	1,025	Sub-tropical	Humid	Apple, peach, plum	hail (Mar., Apr.)
Dailekh	MM	11	1,400	1,450	Sub-tropical	Humid	Citrus	
Godavari	MM	10	1,500	1,800	Temperate	Humid	Peach, plum	
Dunche	MM	14(a)	1,950	1,200	Warm	Perhumid	Peach, plum, apple	borderline for apples to humid
Baitadi	MM	11	1,950	1,500	Temperate	Humid	Apple, peach, pear, plum	
Kakani	MM	11	2,000	2,639	Temperate	Perhumid	Apple, apricots, plum	
Jiri	MM	11	2,000	2,213	Temperate	Humid	Apple, plum, pear	
Humla	MM	14 (a)	2,250	625	Cool temperate	Sub-humid	Apple	
Solukhumbu	MM	14 (a)	2,250	1,500	Cool temperate	Humid	Apple, peach, plum	
Jumla	MM	14 (a)	2,300	700	Cool temperate	Sub-humid	Apple, walnut	
Daman	MM	11	2,300	1,900	Cool temperate	Perhumid	Apple, peach, plum	hail, too humid
Mustang	HH	16 bc	2,550	220	Cool temperate	Semi-arid	Apple, grape, apricot	strong winds
Helambu	HM	14 (a)	2,700	3,500	Cool temperate	Perhumid	Apple, walnut	hail (Mar., Apr.)

Source: Carson 1990.

Physiographic regions

T = Terai S = Siwaliks MM = Middle Mountains HM = High Mountains HH = High Himalayas knowledge of a particular commodity or group of commodities. An extension agent who has spent 10 years in the cool temperate, perhumid Helambu area, northeast of Kathmandu, will have considerable difficulty adjusting to agro-climatic characteristics of cool temperate, semi-arid Mustang, even though both stations specialize in cool, temperate fruit crops. On the other hand, he may have a wide range of agronomic experiences valuable in other cool temperate perhumid areas of Nepal.

Agronomic specialists from Northern Canada would not be expected to drive to Southern Mexico to give agricultural advice. However, Nepalese extension agents are often expected to cover such widely different zones. Confusion about the agro-climatic and cropping possibilities along a 2,000 m vertical transect undoubtedly reduces the effectiveness of most junior technicians.

Stressing farming systems within the distinct agro-ecological zones provides for a more efficient use of scarce human resources. Farming systems researches, in particular, should be more in tune with the agro-ecological zones in which they are working.

CONCLUSIONS AND RECOMMENDATIONS

Agro-ecological classifications and maps based on those classifications can be useful tools for planning agricultural development. While most nations already have classifications focussing on regional differences, the classifications considered here concentrate on production pocket similarities. In this way, degrees of similarity between widely separated geographic production pockets can be assessed and appropriate farming systems research be effectively communicated. The ability to group similar climatic and land characteristics is extremely important for district, national, or even international communication concerning the agricultural development of mountainous regions.

Most, if not all, nations have enough basic data on climate, soils, and farming systems to develop a meaningful international agro-ecological classification system for the diverse mountain landscapes. Mean annual, seasonal, and diurnal variations in temperature as well as total and monthly distribution of precipitation and soil characteristics would form the basis for identifying distinct agro-ecological pocket areas. Ongoing military restrictions for maps and aerial photographs in third world countries are ludicrous in this age of sophisticated remote sensing from space platforms. The lack of educational background to understand and effectively use map products is, possibly, the most serious limitation to developing effective agro-ecological classification systems. Major gains in this field will require pressure from scientists on politicians to declassify information and introduce it into the educational network.

It is recommended that an international agency interested in mountain development take the lead in developing a more appropriate agro-ecological classification to deal with heterogeneity.

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14

COMPARATIVE METHODS FOR CHARACTERIZING MOUNTAIN AGRO-ECOSYSTEMS

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CONTENTS

INTRODUCTION

This paper was invited to address issues related to resource characterization and zonation in mountain areas and to present a workable procedure for initiating an internally usable information system for mountain agro-ecosystems. This request has rekindled my interest in methods and concepts with which I had worked during the late 1970s, but had neglected during a decade of administering rural development programmes. For this reason, the empirical evidence needed to completely support the proposals made below is only now being gathered. It is hoped the arguments put forward, and the preliminary examples shown, will generate support for this approach from other workers in the field.

Researchers and planners face formidable difficulties in accurately characterizing the variation of phenomena which can be observed in mountain agro-ecosystems. Because of the inherent complexity of mountain agro-ecosystems, information systems designed for planning purposes are often based upon the definition of geographically discrete zones or regions. The boundaries of these zones are usually characterized by the core conditions of a set of observed variables. Each zone in the system is assumed to be composed of a set of conditions which distinguishes it from adjacent units. These units can vary greatly in size and complexity, depending upon the variables selected and the methods of analysis employed.

The establishment of a zonation system is a time-honoured means of dealing with the complexity of environmental and cultural phenomena. It can be argued, however, that mappable zones are a conceptual construct which can mask the reality of continuous gradients in environmental and other variables. The concept of a graded continuum of variation is particularly important in mountain environments. Rather than focus research efforts on establishing a hierarchy of generalized regions, this paper argues that a use of comparative analysis techniques will lead to a more complete understanding of the complex interactions which shape mountain agro-ecosystems. Better knowledge of these interactions can have a tremendous effect on the success or failure of development programmes.

One of the requirements for any information system suitable for international use is that data of comparable type be available from a large number of locations. The uneven terrain of mountain areas makes areal averages of most phenomena difficult to calculate and the comparatively low agricultural productivity means that fewer data collection points are maintained than is generally the case for lowland areas (White and Perry 1989). Therefore, I propose that we begin our work by using a simplified database that will enable us to establish a set of preliminary clusters of mountain locations. The key to this initial grouping should be the characteristics of mountain locations which can be derived from the most common climatic data; namely monthly mean values for temperature and precipitation. By this I do not mean to imply that climate is the only significant factor for determining the characteristics of mountain agro-ecosystems. I have chosen climate because substantial amounts of data and analytical methods are readily available for comparative analysis. Subsequent additions of other data will allow for better correlation of agro-ecological system properties along environmental, socioeconomic, and other gradients.

I was also asked to discuss the utility of such an information system in support of a decentralized approach to development planning. Decentralization of development planning means that decision-making authority is pushed down to increasingly lower levels and away from central control. I argue that the extreme diversity of mountain environments demands that development planning follow a decentralized approach. A crucial point in this paper rests on the assumption that technical knowledge systems can only provide some of the answers required for designing and maintaining sustainable development programmes. Therefore, one key to increasing the utility of development information systems is first to identify the interactions among the variables of an agroecosystem which are important for local decision-making. This obviously requires the intimate involvement of the people who operate those systems.

Agro-ecological systems can be characterized using data on physical factors, cropping systems, culture, technology, market options, and information linkages. However, it is clear that the actions of farmers and peasants are not determined solely by external influences and we must recognize that most existing agro-ecosystems represent an adaptive management strategy designed to minimize the risk of failure. These strategies are based upon farmers' analyses of the available data, usually in the form of an intimate knowledge of the history of successes or failures of particular management practices. By linking technical advice to existing management systems we can have the advantage of both knowledge systems integrated into one. This leads logically to a development planning process that first assesses local needs and priorities, then provides farmers with a range of potential choices, and, finally, assists the farmer himself to initiate experiments that can enable him to know definitively what is the best arrangement of his particular space at a particular point in time.

ANALYSES SUITED TO A DECENTRALIZED APPROACH TO RURAL DEVELOPMENT

Comparative Methods

Government and donor agency planners often demand information that typifies regions of large size in order to facilitate easy programming of development budgets. The zones and regions, which are thus defined, support a centralized approach to planning. The alleged homogeneity of these regions often disguises factors that are critical to programme success or failure. An unfortunate outcome of programmes so designed is that blanket prescriptions are made for an entire region without any reference to the internal variation. The results of the past 40 years of centrally planned development throughout much of the Third World provide ample evidence for an argument against this approach.

There are other considerations that should also temper our enthusiasm for zonal classifications. On strictly technical grounds, a report by the American Association for the Advancement of Science (Conant et al. 1983) argues that a zonal classification must be structured so as to be understandable in the map legend, regardless of the complexity of phenomena being mapped. Although the report also suggests that land use can be used as a frame for interpreting the changes in a landscape that are important to humans, it notes that the establishment of international soil evaluation classification systems has been less than successful because, in each region, there is always a different combination of factors that needs to be taken into account. Further, it should be obvious that many variables that are critical to understanding development problems simply cannot be mapped.

However, despite these limitations, we must derive a method of synthesizing the disaggregated information which is available. Site conditions must be made comparable and the information must be shared in order to increase our ability to support positive change in utilization in mountain environments. We are, therefore, faced with the choice of developing a plethora of detailed classification systems which are based upon locally significant information or we can design a system that has as its basis a comparison of the inherent similarities in man/environmental relations that are found in different mountain locations.

In comparative methods, localized information remains paramount at all times. Larger groupings are merely clusters of individual sites. In this way we never lose sight of the disaggregated information and yet we are able to build a system for sharing information about different agro-ecosystems. A comparative approach to site analysis will reveal more about the interactions of variables in mountain systems than can be shown by focussing attention on the distinctions required in zonal classification systems. It also allows us to visualize similarities among geographically distant locations which might not otherwise be apparent. In addition, initial work for such an analysis would not immediately require new field research. Considerable information can be brought together simply by carefully compiling (and critically evaluating) the secondary data available.

The idea for suggesting this approach arose from an examination of an example of this method presented by Brookfield (1962) for the New Guinea Highlands. The 26 factors which he considered for his comparative analysis of indigenous highland farming systems (Table 14.1), were used to cluster 31 locations stretching across the entire length of the central cordillera of the Island of New Guinea. At first glance, this list appears to be a daunting array of factors representing very time consuming field data collection from extremely inaccessible locations. However, the vast majority of the data used in this analysis were obtained from secondary sources. The conclusions he drew from a comparative analysis of the data pointed to 'a series of cores showing gradations outward', rather than the discrete regions he had initially postulated. Brookfield illustrated how the comparison of data from a number of locations may be used both to provide local detail and to approach an understanding of the interrelationships of unlike phenomena.

Table 14.1. Primary and derived characteristics used in a local study and comparative methods of the New Guinea Highlands' farming systems

Staple crop	Altitude
Other major crops	Terrain
Tree crops	Main soil parent material
Hunting significance	Rainfall
Pigs	Climatic index (Schmidt-Ferguson quotient)
Enclosure	Coefficient of seasonal variation
Dominant fallow cover	Frost occurrence
Method of clearing	Crop maturation time
Ground preparation	Cultivation factor
Erosion control	Garden area per capita
Water control	Approximate population density of cultivated land
Mulching and fertilization	Occupation density
Inter-cropping	Technical elaboration

Source: Brookfield 1962:244–245.

Brookfield was searching for information leading to an understanding of the origin and evolution of existing systems. Development researchers, on the other hand, seek information to help guide the alteration and, hopefully, improvement of existing systems. Given that distinction, the 'core' areas of development-related analyses might best be represented by locations having the most complete databases. Gradations from these cores could then be described in terms of loss of detail as well as in terms of changes in the character of the agro-ecosystem elements. In a decentralized planning system, that loss of technical detail would be made up by accessing the indigenous knowledge of the existing systems.

Gradient Analysis and Classification

Sharp disagreements often occur among researchers over determining the boundaries of particular units of any given classification system. One means of avoiding those often pointless arguments is to begin by determining the entire range of variation to be found in the factors under investigation. This method of analysing a continuum of information is known as gradient analysis. A secondary advantage of initiating comparative analysis of agro-ecosystems through gradient methods is that detailed maps are not immediately necessary because the analysis relates locations along a continuum that is not tied to physical space. Ultimately, studies of agro-ecosystem properties are not only meaningful when presented in relation to well-defined geographic areas, but an initial goal of the investigation should be to understand the range of differentiation and the similarities apparent among widely separated mountain locations.

Gradient analysis is defined as: 'an arrangement of units in a uni- or multi-dimensional order' (Mueller-Dombois and Ellenberg 1974). The resulting arrangement is known as ordination. The emphasis is on the arrangement of sample units by individual values rather than by generalized group (or regional) values. An arrangement by postulated group values, or by placing a site within a range of values, could result in a classification that may contain distinctions that do not really exist in nature and, therefore, the establishment of boundaries in this way is always the result of personal choice. In contrast, an ordination of units simply exposes the relative continuity or discontinuity among individual sites.

Ecologists have provided evidence over the past several decades that species are distributed individually over environmental gradients. Whittaker (1970) drew two conclusions concerning this phenomenon.

Each species is distributed in its own way, according to its own genetic, physiological, and life-cycle characteristics and its way of relating to both physical environment and interactions with other species; hence no two species are alike in distribution.

The broad overlap and scattered centres of species' populations along a gradient imply that most communities intergrade continuously along environmental gradients, rather than forming distinct, clearly separated zones (except where environmental discontinuities or disturbance by man have an effect).

It can be argued that a parallel can be drawn between the distribution of species and the variations found in farmers' fields in the world's mountain areas. However, the farmers' situation is even more complex as these farming systems result from conscious decisions made by humans when interacting with the natural environment. The individual choices which represent themselves to farmers in the selection of crops, trees, animals, and cultivation techniques are influenced by a variety of factors. A careful analysis of a wide range of sites will reveal that the composition of mountain agro-ecosystems varies over gradients composed of environmental, economic, cultural, and informational factors.

It is precisely because of this variation of influences that the ingenuity of individual farmers and groups of farmers remains a decisive factor in devising the means to overcome limitations to development. The concept of the gradient in rural development is crucial to the ideal that effective decentralized planning must involve farmers together with technical workers. No two farmers' opportunities are exactly like. Farmers must be provided with opportunities to experiment and choose a range of choices and not be limited by a technocrat's preconceived notions of general conditions.

Cluster Analysis and Classification

Planners face difficult problems when trying to classify particular agro-ecosystems in relation to others. We have discussed that rural development potential can be represented as a continuum along a gradient which is variously affected by environmental, economic, and cultural/historical factors. Before we can proceed, we need a means of synthesizing this information. The important question to be determined is what are the relatively greater or lesser differences among individual locations that make it possible to recognise significant groups for further analysis ? Cluster analysis is one technique which may assist in organising this disparate information.

In contrast to gradient analysis, locations assessed under cluster analysis are not shown as individual points in geometric space but as clusters of pairs linked together to certain levels of similarity. The clusters of pairs are further combined into more inclusive or generalized clusters that form a hierarchical arrangement (Mueller-Dombois and Ellenberg 1974). For us to proceed with developing a classification through cluster analysis of mountain agro-ecosystems, we will have to establish agreed upon 'Indexes of Similarity' that can be used to compare different locations. An example is presented below in the next section to illustrate the utility of certain climatic variables for initiating such work.

Recent work on classifying the climates of England and Wales (White and Perry 1989) used multivariate cluster analysis. In this work, principal component analysis was used to determine the factors that provided the most critical distinctions between stations. Then six different methods of cluster analysis were carried out on the component scores. They found that the cluster analysis methods of 'furthest neighbour' and 'minimum variance' provided the greatest definition of classes in all parts of the country.

The success of a sophisticated technique in a developed country does not necessarily point to its utility in less developed regions. This paper does not advocate an immediate move to use sophisticated multivariate analyses to generate agro-ecological classifications for mountain environments. However, any agreed upon information system which is established should be set up in such a manner that this type of analysis could be included at a later stage, if warranted. It is strongly argued, however, that agglomerative methods (such as gradient and cluster analysis) be used whether or not classification is desired as a necessary end result of a comparative analysis of locations.

Formally, agglomerative classification may be defined as 'the grouping of objects into classes on the basis of some similarity in either properties, or in the relationships between the objects' (Grigg 1967:479–480). Agglomerative classification proceeds from the detailed to the more general level of inclusiveness. These classifications are based usually on the relationships of several characters simultaneously. Few *a priori* assumptions need to be made on the nature of the objects under study. In contrast, hierarchical classification systems, usually employed for defining regions or zones, assume profound *a priori* knowledge of the subject and are usually divisive. This means they proceed by postulating highly generalized regions and then subdividing these into less complex units. The distinction between levels of a divisive hierarchical classification usually involves a dichotomous decision regarding one single character (Hutchinson 1978).

R.G. Bailey (1978) notes that 'as a general rule, taxonomies are based on aggregation and regionalisations are based on subdivisions'. Brookfield (1973) states that the distinction between divisive and agglomerative classification can be equated to the distinction between explanation and understanding. Explanation implies the 'specification of causal relationships and a process of logical deduction while the role of understanding is to ensure that the premises and explanations themselves have meaning'. Brookfield also points out that while agglomerative systems can provide the means to generalize and produce theories on the nature of human use of mountain areas, divisive methods can never be used to give details on individual sites.

The issue of scale is also important in this debate on classification systems. A classification system devised for addressing problems on one scale will not necessarily be useful on other scales. Because of this, we should focus our attention on data collection for comparative analysis rather than for establishing a fixed classification system. Thus, data can be stored in such a way that it can be available for creating individual classifications which meet the needs of a particular planning job (Conant et al. 1983). Brookfield (1973) illustrates this with an example about coffee. He argues that the task of assessing the total coffee production in Central New Guinea is a macro-level problem, but the effects of the coffee innovation, and the reasons for farmers' personal responses to economic incentives, involve micro-level issues. Both of these problems could be adequately addressed if the necessary database was built from the bottom up rather than by sub-dividing generalized characterization from the top down.

Level of Relevance to the Local Population

No matter how refined a system of zonation used for planning purposes may be, the end result is usually the imposition of technocratic decisions on the lives of rural farmers.[1] Through the use of gradient and cluster analysis we can provide planners, researchers, and decision makers, at all levels, with the understanding that a range of choices is necessary for successful development. Chambers (1983) has discussed the inherent experimental

[1] Not all zonations are devised to support top-down planning. Carson (HMG 1990) decided not to make his horticultural zones more detailed because he argued that the central government should only attempt to guide the development process in general terms ('to create a climate for development, not to control the weather'). He felt that individual farmers should be left to make their own decisions based on their intimate knowledge of the details. While this philosophy is laudable, I would argue that simply by producing a set of mapped zones one has provided the government with all the information it needs to impose technological solutions on farmers.

nature of rural people's knowledge about their environment. He points out, quite rightly, that thousands of years of farmer experimentation led to the development of most of the common domestic crops and animals found on farms today. There is obviously great variation to be found in the willingness of the farmers of a particular place to experiment with new crops or techniques. The point is that the farmer's involvement in decision-making is crucial to successful diffusion of innovation.

A classic case of farmer-based technological innovation is that of the sweet potato agro-ecosystems found in the highlands of New Guinea (Yen 1974). The sweet potato was introduced in the lowlands of New Guinea four hundred years ago by Spanish and Portuguese explorers whose colonial organizations had obtained the root in the American tropical highlands. The sweet potato was traded widely among the indigenous people of New Guinea and eventually supplanted traditional root crops as the staple of the highland diet. The result was a complete overturning of the existing agricultural and related social systems. No scientific analysis of environmental similarities between the two highland areas was used during the introduction. Until the middle of this century, modern science did not know the sweet potato had been adopted in the New Guinea highlands, or even that there were people living there. No controlled greenhouse experiments were used to determine the most productive cultivars for particular micro-environments, although recent research has distinguished 55 cultivars in the Baliem Valley alone (Achmady 1986). Sweet potato cultivation practices differ considerably between the Dani, who are the highland valley swamp cultivators of New Guinea, and the Quechua who are hill slope cultivators in Peru, but the crop exists in both places because basic climatic parameters are sufficiently similar to allow normal physiological action to take place, and farmers are innovative enough to recognize opportunity when it presents itself.

Does the assertion that prehistoric farmers have been responsible for the development of the world's major food crops mean that technical analysis of mountain resources is a superfluous activity? I think the obvious answer is no. The timespan that was required to create the indigenous selections of food crop and domestic livestock varieties was considerable. The issues of decreasing productivity, increasing population, and degradation of the mountain resource base clearly point to the need for technical assistance to modern farmers in order to improve their ability to survive and to advance. A comparative analysis of mountain resources provides opportunities to support this linkage. During the assessment of these resources, a characterization of the successful options which have been employed in similar agro-ecosystems can also be made. In this way, the analysis will not only compare the existing resource base but will also compare the differing approaches of farmers to the use of those resources.

THE USE OF BIOCLIMATIC VARIABLES FOR AGRO-ECOSYSTEM COMPARISON

Carson (in his paper presented at this conference) has suggested that temperature, precipitation, and soils are critical factors which can form the basis for an international information system on mountain agro-ecosystems. I have argued above that such an information system must use indexes of similarity, in order to properly compare the variables that form these systems. In the section below, I have presented a summary of the salient features of a method that uses rigorous indexes for comparing climatic characteristics on a global basis. It is hoped that similar work on soils and human-related factors can be done in order to facilitate the accurate comparison of different agro-ecosystems. Climate variables lend themselves more readily to quantification than do many of the other variables that make up mountain agro-ecosystems. However, it can be argued that a judicious use of quantitative analysis, where possible, and narrative analysis, where necessary, will enable us to progress towards a more complete understanding of these systems.

The methods described were all developed by the late Harry P. Bailey, a geographer from the University of California. The methods and the resulting bioclimatic[2] class terms are the result of 30 years of empirical analysis of worldwide climatic data. Bailey himself concentrated his published efforts on methodology (1958, 1960, 1964b, 1966, 1972) coastal environments (1960, 1976) individually. However, significant advances in his methodology came about through collaboration with botanists interested in determining the climatic ranges of mountain flora (Axelrod and Bailey 1976). It should be pointed out that Bailey himself never employed the term 'Bailey's Bioclimatic Analysis'. This is a convention I have employed solely as an expedient.

First Principles

Physical Basis of Similarities in Climatic Distributions

The basic facts of the physical geography of the earth (involving size, shape, orbit, and rotation period) account for the apparent similarities in the earth's climate. The influx of solar energy on a daily and seasonal basis creates a zonal pattern that is similar in both directions from the equator. Seasonal differences also increase polewards and particularly in the northern hemisphere, with altitude. Therefore, opportunities for identifying similar climatic influences on a global basis depend greatly upon the comparable data of a combination of latitude, continental location, and altitude of particular stations (Bailey 1977). In mountainous areas, three additional topographic situations are critical in creating significant differences in local climate: ridge top, slope, and valley bottom (Barry 1981).

The latitudinal patterns of climatic similarity are not necessarily repeated in altitudinal zones in mountain areas. Troll (1959) explains that although it is often stated that 'the temperature zones found beltwise in succession from the equator to the pole are found in layers atop one another in the mountains', this is contradicted by comparing the climatic conditions of the tropical mountains with the northern latitudes. The basic difference between the temperate and frigid latitudes of the northern hemisphere and the temperate and frigid mountain regions of the tropics is that the former have a thermal regime, characterized by seasonal variation, while the latter are characterized by daily fluctuations. Troll also pointed to significant similarities between the three-dimensional distribution of climate and vegetation from the Pamir Highlands along the Himalaya to Burma on the one hand and the distributions found in the range from Northern Arizona through Mexico to Guatemala on the other. The similarities shared by the Andean, African, and Austronesian highlands have also been extensively documented. It has been postulated, but remains to

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2 'Climatic data' usually refers to unweighted instrumental data, in this case monthly and annual means of temperature and precipitation, while 'bioclimatic information' refers to a process by which these data 'have been used to calculate summary terms that agree better than unweighted data with selected characteristics of plant behaviour and distribution' (Bailey 1979).

be proven, that a significant exchange of information can be accomplished between the Andean and Himalayan highlands. It is hoped that further use of the bioclimatic analysis described below will enable us to ascertain whether meaningful similarities do exist.

Correlation of Bioclimatic Factors with Agriculture

The importance of temperature and moisture to the physiology of plants is well known. The duration of warmth and the extreme of temperature are both critical factors in the environmental suitability of a location for particular plant species. Plants that do not have ready access to significant groundwater are dependent upon precipitation for their moisture needs. Evaporation is directly related to precipitation and has been shown to be related exponentially to temperature. Precipitation is probably not continuous in any location on earth. Therefore, the length of alternating wet and dry periods is critical for agricultural planning.

White and Perry's (1989) principal component analysis of English climates indicated that there were only two important independent sources of variation in the data. These were maximum summer soil moisture and effective transpiration. These two factors accounted for 90 per cent of the variance in 16 variables over 62 stations. Further, they have shown that the warmth and duration of the growing season is significantly correlated to soil moisture deficit in the summer season. Effective transpiration was also significantly correlated to January precipitation. Both of these factors are integral components of the Bailey Bioclimatic Analysis described below.

Demonstrating the usefulness of comparing the climatic similarity of different agro-ecosystems would be simple if there was an exact correlation between climate and agricultural activities. However, owing to man's ingenuity, different cultures have adopted different means of coping with similar climatic regimes. In addition, genetic advances have made possible the introduction of improved varieties of common crops into environmental ranges where previously this would have been impossible. This difficulty in analysis forces us to realize that agro-ecosystemic characterizations cannot be made on the basis of natural resource factors alone. The only meaningful characterizations must involve an understanding of the ways in which man has chosen to use those resources to enhance his chances of success.

Bailey devoted his primary attention to the relationships between climate and natural vegetation. The lack of data illustrating the correlation of bioclimatic indexes with actual crop distributions is a major limitation in this paper. I have only begun to establish a database of bioclimatic factors for Nepal and have not yet had the opportunity to build a database on the distribution of existing cropping patterns in relation to those factors. This is proposed as a crucial step in establishing a useful agro-ecological information system. Numerous researchers have left an immense assortment of detailed information relating to agricultural practices in Nepal. One of the earliest examples is the work of Kawakita (1956), which provides considerable information on crop ranges along thermal gradients.

Use of Classifying Terminology

Despite the arguments above regarding the utility of zonal classification schemes, it is obvious that a common terminology is necessary if geographically disjunct locations are to be meaningfully compared. To be useful both on an international scale and for local decision-making, an information system describing mountain agro-ecological properties must use terms that are objective and do not rely upon the reader's association with certain vegetation types or geographic regions. Examples of this type of 'circular reasoning' are common. The oft quoted classification schemes of Thornthwaite use ambiguous terms such as tropical, mesothermal, microthermal, taiga, tundra, and frost to define global climatic zones. Koeppen (Thrower 1970) relied on vegetation types to define climatic zones and then circled back to define vegetation patterns in terms of climate. In addition, the vegetation types used by Koeppen have almost no meaning for mountain classifications. The Land Resources' Mapping Project (LRMP 1985) resource classification of Nepal uses terms that perhaps reflect the North American origin of the classifiers (sub-alpine, alpine, arctic).

The class terms employed by Bailey (1979) have been retained in the example in this paper (see Annex 1). Bailey uses common terms which are readily translatable into local languages with no loss of meaning. These terms are also used because they have resulted from the comparison of thousands of individual data stations. It is understood that the classification employed, while useful for a global range of bioclimatic characteristics, will require refinement when used exclusively in mountain environments.

Bailey's Bioclimatic Analysis (BBA)

Conventional climatic data have been employed in thousands of studies and climatic classification is not a new subject. This method is significant because of its ease of use in comparative analysis and its potential for providing a wide range of information from simple data. Length of growing season, thermal extremes, and a moisture index which accounts for temperature-related evaporation loss have been derived from conventional climatic data by equations and nomograms[3] published by Bailey (1958, 1960, 1964b, 1966).

The basic inputs of the system are monthly mean temperature, mean annual range of temperature, and monthly mean precipitation. The indexes that are explained below are all derived from the empirical comparison of temperature and precipitation data of several thousand climate stations worldwide.

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[3] Bailey has devised three nomograms which are useful for rapid comparison of stations using only data available in monthly form. Each of the bioclimatic terms referred to in this paper can be derived from these nomograms. Fig. 14.2 uses a nomogram devised by Bailey for illustrating the thermal relations among geographically dispersed stations. This nomogram is also available in a Fahrenheit model. The use of the nomogram in judging climatic similarities offers certain attractions and opportunities. Because the nomogram requires only the annual mean and the standard deviation of the annual range of monthly means of temperature, data are rapidly entered and compared. The construction of the thermal nomogram is oriented in the fourth quadrant in order to best represent the actual bioclimatic conditions in mountain areas. Stations of higher elevation will, on average, have lower mean annual temperature.

The nomogram was devised at a time before ready access to personal computers. All the thermal factors that can be derived from this nomogram, except the calculation of frost frequency, can easily be derived through the use of a simple spreadsheet programme. The majority of the calculations and graphs prepared for this paper were performed on *Lotus 123*. However, the nomogram remains of significant use in locations without ready access to computers and its unique structure provides a means of visual multivariate analysis unavailable elsewhere. Readers interested in copies of Bailey's nomograms are advised to write to the author.

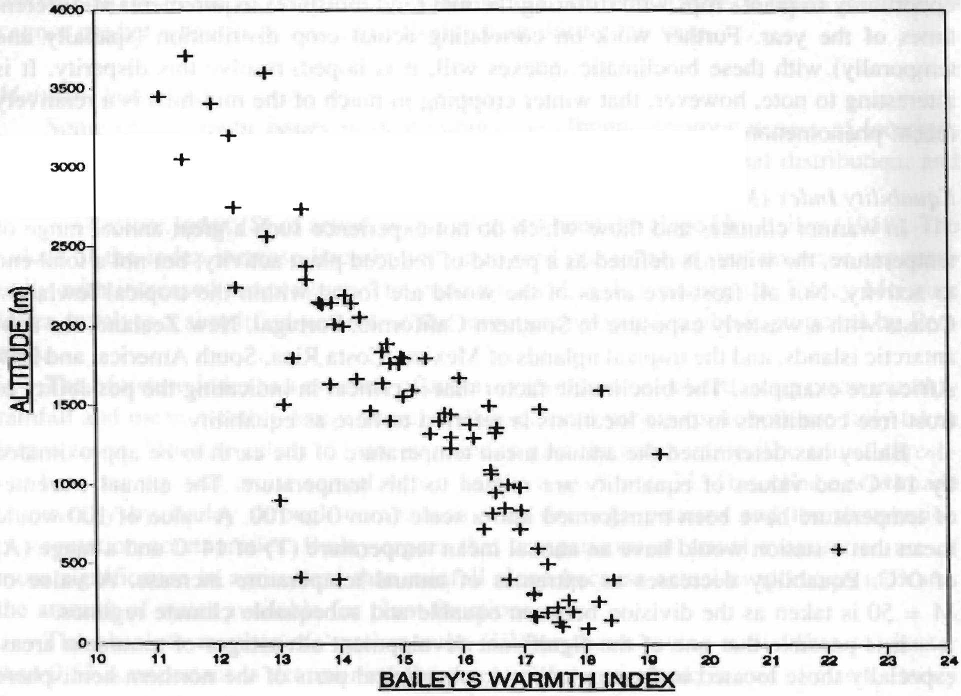

Figure 14.1: Ordination of all stations by altitude and Warmth (W) Index
Source: Data from LRMP, 1985 & Jackson, 1987; Analytical Methods from Railey, 1979.

Warmth Index (W)

The Warmth Index is determined from the mean annual temperature (T) and the standard deviation of the range of the individual monthly means (A). It is measured by a scale that specifies temperature at the beginning and end of a warm period and the duration of that period. Therefore, this index describes seasonal rather than annual warmth for all locations between the cool limit of tropical (no winter) conditions (W = 18) and the warm limit of polar conditions (W = 10). A Warmth Index of W > 10 is necessary to support tree growth and most forms of agriculture.

The number of days of the year that are expected to have a mean temperature higher than a computed W value for a given station is referred to as the potential growing season (Td) of that station. A value of W = 18 will have 365 Td while a value of W = 10 will have 0 Td. In other words, warmth is a temperature specified at the beginning and ending of summer and Td denotes its length. Where the annual range is greater than 18°C, short period fluctuations are so great that warmth is equivalent to the duration of the total combined frost-free period. This aspect of continentality is most apparent in the mountain areas of northern latitudes in the middle of the North American and Asian continents.

One significant limitation on the utility of the BBA for use in Nepal is that many parts of the mid-hills have year-round agricultural activity, despite the fact that the method only predicts an average of a little more than 200 days of potential growing season. This disparity occurs because the thermal extremes are mild enough to afford farmers the opportunity to plant crops with differing thermal (and moisture) requirements at different times of the year. Further work on correlating actual crop distribution (spatially and temporally) with these bioclimatic indexes will, it is hoped, resolve this disparity. It is interesting to note, however, that winter cropping in much of the mid-hills is a relatively recent phenomenon.

Equability Index (M)[4]

In warmer climates and those which do not experience such a great annual range of temperature, the winter is defined as a period of reduced plant activity, but not a total end to activity. Not all frost-free areas of the world are found within the tropical lowlands. Coasts with a westerly exposure in Southern California, Portugal, New Zealand, the sub-antarctic islands, and the tropical uplands of Mexico, Costa Rica, South America, and East Africa are examples. The bioclimatic factor that is critical in indicating the possibility of frost-free conditions in these locations is referred to here as equability.

Bailey has determined the annual mean temperature of the earth to be approximated by 14°C and values of equability are related to this temperature. The annual extremes of temperature have been transformed into a scale from 0 to 100. A value of 100 would mean that a station would have an annual mean temperature (T) of 14°C and a range (A) of 0°C. Equability decreases as extremes of annual temperature increase. A value of M = 50 is taken as the division between equable and subequable climate regimes.

It is possible that one of the significant development advantages of mountain areas, especially those located in the tropical and sub-tropical parts of the northern hemisphere and almost the entire southern hemisphere, is the increased equability of climate. A high value in the Equability Index indicates a reduction in thermal extremes. This increased equability should allow a significantly greater range of agricultural and agroforestry products to be cultivated in a single location. Thus the range of opportunities which can be presented to a farmer, given an appropriate moisture regime and market potentials, is potentially greater than what usually is possible in lowland areas. This hypothesis will be tested as more data is collected which correlates crop distributions in Nepal with these bioclimatic indexes. It should be noted that this potential in agricultural diversity, resulting from increased equability, is not the same as natural biological diversity which results from an increase in the complexity of natural ecosystems.

Frost Frequency (%)

Frequency of hourly temperatures below freezing can be most easily derived directly from the thermal nomogram. Bailey (1966) has shown that the use of the sine wave as a model for annual temperature variation is sufficiently accurate to predict the potential frequency of freezing temperatures on an annual basis. The sine wave is useful both as a model for the annual range in temperature and for the gradient of temperature between the two poles. This method is useful in areas that experience either seasonal or diurnal frost occurrence. However, in areas experiencing diurnal frost, the result can only predict

[4] It should be noted that Bailey changed his use of the term 'Equability' to 'Temperateness' in his later papers. I returned to the original term in order to avoid confusion with the term 'Temperate' which is generally understood to refer to a thermal regime normally associated with climates in the mid-latitudes.

the percentage of the total number of hours of the year which will be below freezing. It cannot predict when these will most likely occur during the year.

Moisture Index (S)

Some of the major issues in determining the climatic appropriateness of locations for certain crops include: (1) total amount of rainfall, (2) its seasonal distribution, and (3) the differing amounts which go into evaporation and runoff.

A Moisture Index (S) of actual evaporation has been developed by Bailey (1958). The values of the index increase linearly with increased precipitation, but decrease exponentially with increased temperature. The equation used in determining the Bailey Moisture Index involves a simplified version of the more sophisticated methods proposed by Penman.

The Moisture Index is a measure of actual evaporation calculated using mean monthly rainfall and mean monthly temperature so that seasonal variations in both are fully taken into account. Monthly values (Si) are summed to give the index value. The annual threshold between dry and moist annual values is given as $S = 6.37$. This choice was made empirically by Bailey through comparison with drainage patterns and the distribution of vegetation communities. Bailey argues that comparisons of actual evaporation are of more significance in agriculture than rainfall alone because actual evaporation indicates the amount of water available for plant functions.

The absolute number of 'wet' months (F3) or those having a Si value of greater than 0.53 is important in determining the potential for agriculture in arid climates. Bailey found no example where grain cultivation is possible without irrigation when less than three months are classed as 'wet'. This monthly classification can be further refined into dry ($Si < 0.53$), neutral ($Si > 0.53$ and $Si < 0.81$), and wet ($Si > 0.81$) months depending upon the needs of the analyst. In this instance, F3 is the sum of neutral and wet months. By making this distinction, this method places equal emphasis on dry seasons and over-wet periods.

The Bailey Moisture Index is a simplistic calculation of moisture balance which can be used as an index for comparison of geographically dispersed stations. Errors in the Bailey Moisture Index are most common in areas where permafrost occurs ($T < -3°C$), on warm, marine coasts, and in extremely dry climates. Bailey (1979) states that the index should not be used as a substitute for soil moisture budget calculations. For specific site calculations, researchers should refer to the Penman Method of determining potential evapotranspiration. However, the Penman Method requires knowledge of incoming solar radiation (hours of sunshine and day length), air temperatue, vapour pressure (from relative humidity), and wind speed (Jackson 1987). These data are available from only a limited sample of climate stations around the world. Therefore, the Bailey Moisture Index is presented as a reasonable alternative to initate work on comparison of mountain envoironments.

Winter Rain (R)

The percentage of rain which falls during the 'winter' half of the year is of particular importance in certain climatic regimes. This factor is most useful in semi-arid and arid regions with a high warmth value, because more rain falling in the cooler part of the year will be available as moisture for plants rather than evaporating. The Koeppen classification term 'Mediterranean' is distinguished primarily by the predominance of precipitation falling in the cooler half of the year.

A PRELIMINARY BIOCLIMATIC ANALYSIS OF NEPAL

Database

A set of 59 climatic stations from Nepal was used as the primary data for illustrating the utility of the BBA for agro-ecological research in mountain environments. An additional 23 arbitrarily selected locations have been used to provide a preliminary comparison of similarity and diversity among a range of mountain enviornments. These selections were based primarily on the data readily accessible in Kathmandu. Stations were included from cool, northern highland zones, tropical highlands of South America and Africa, and adjacent locations in the Western Himalaya and associated ranges. The Nepali station numbers are those assigned by the meteorological service, while those of other stations have been assigned exclusively for this paper.

Results

Figure 14.1 shows the graph of all 82 stations plotted according to altitude and Bailey's Warmth Index for each station. This clearly shows the strong relationship between altitude and warmth, as would be expected. It also indicates those stations that do not conform to the general trend. By initiating the investigation by comparing individual station values, it is then possible to assess their particular conditions to understand the reasons for deviation.

All of the stations plotted in Fig. 14.1 are listed in Table 14.2 according to their individual warmth (W) value (sorted from low to high to approximate position in a mountain range). By sorting the stations according to a single value (W), the table represents an example of a unidimensional ordination of the stations. The reader can also note all of the other bioclimatic index values which can be derived from the same mean monthly temperature and precipitation data for each station.

This ordination is also useful for examining the argument that altitude can be used alone as a basis for highland zonation. Throughout this table we can find several stations with higher warmth values than others located at similar or lower elevations. Due to the inclusion of many non-Nepali stations in the data set, we can see that latitude also plays a meaningful role, as one might expect, when comparing stations internationally. However, a comparison of the stations of Lhasa, The People's Republic of China, and Lomantang, Nepal, clearly illustrates other factors that must be taken into consideration. These stations are found within 100 m elevation and within one degree of latitude of each other and they are both located on the northern side of the High Himalaya, yet they have considerably different thermal and precipitation regimes. The lower potential for freezing temperatures in Lhasa can be explained by its more equable thermal conditions (the annual mean temperature (T) is twice as high and the annual temperature range (A) is less by one-third). The increased precipitation at Lhasa may be partially responsible for ameliorating the temperature extremes.

When we compare the Nepali stations alone, we can also find several cases of higher

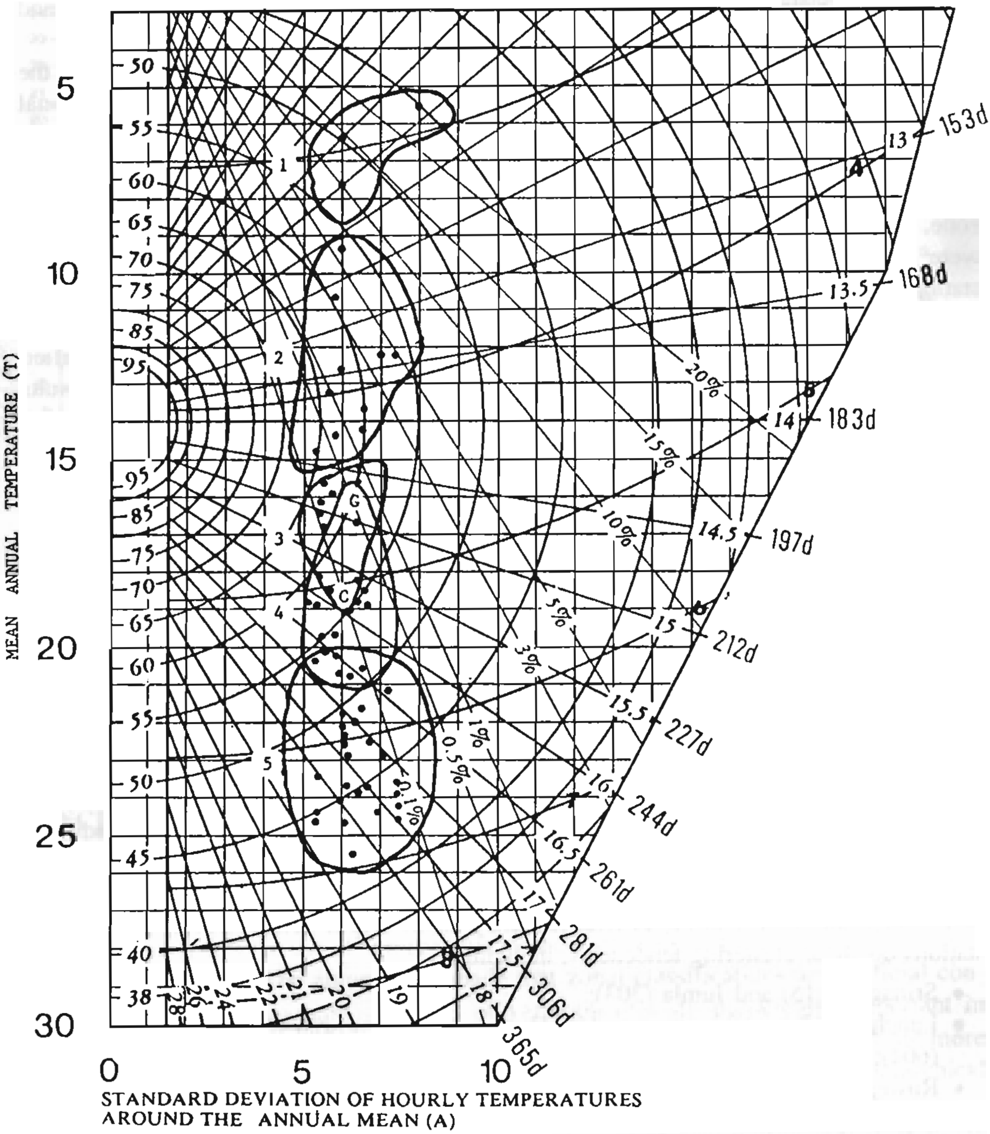

Figure 14.2: Bailey thermal nomogram illustrating Nepali stations clustered by LRMP (1985) altitude classes

Class	Values				
1	> 3,000 m	4	1,000–1,500 m	000–1,500 m	C—Chaa
2	2,000–3,000 m	5	0–1,000 m	C—Chaautara 1,676 m	
3	1,500–2,000 m				

Source: LRMP 1985.

than expected warmth values. Note the relative positions of Chautara, Kathmandu, and Godavari in the table. Although Chautara sits at the highest elevation of the three, and Godavari at the lowest, their correspondingly reversed order according to warmth value indicates the important role local topographic position plays in mountain micro-climates.

Chautara is located on a ridge top, Kathmandu is in the centre of a large valley, and Godavari is located at the bottom of the mountains ringing the Kathmandu Valley.

The LRMP (1985) reports and maps and the HMG (1990) horticultural plan used the same set of altitudinal classes for differentiating thermal zones in Nepal. One additional test was carried out on the Nepali data set to determine if the chosen altitude classes were justified. The test consisted simply of plotting the stations on the original Bailey Thermal Nomogram and grouping the individual stations according to the corresponding altitude zone. The test (Fig. 14.2) showed, for the stations chosen, that the higher altitudinal zones were internally consistent, but there were serious overlaps in the zonal boundaries for stations located from 1,600 m to 700 m. The major factor in the mid-hill region, which appears to account for the discrepancies, is topographic position. The stations that are classified as being 'too warm' are found on ridge tops (e.g., Chautara) and those classified as 'too cool' are found at the bases of hills in valley bottoms (e.g., Godavari). The results of this test illustrate the basic utility of such an altitudinal model for differentiating similar temperature regimes. It also points out the difficulties that a planner faces when he is required to make decisions based upon a classification that forces a location to fit group conditions rather than characterizing the location individually.

Figure 14.3 presents an example of bi-dimensional ordination by relating the Warmth Index value of individual stations with its corresponding Moisture Index (S) value. Purposive selection was made of the available Nepali stations to reduce the number of stations which had exactly the same Warmth Index value. The stations with extreme index value were eliminated from both the Nepali and the global set. As this exercise was carried out as an example of a methodology, both of these selections were done expressly to make the figures more easily readable.

This graph compares readily with the usual ordination done by using raw data for mean annual temperature and mean annual rainfall. It is argued that the use of these bioclimatic indexes provides us with a more accurate characterization of the site conditions than can be determined by using the raw data alone. This comparison shows, at a glance, that the arbitrary set of global stations (station numbers below 100) selected tends to be both cooler and drier than the general tendency of the Nepali set. However, a few of the stations do show clustering tendencies, including:

- Srinaghar (15) and Jumla (303);
- Lanchow, China (3), Ankara (18), Denver (23), Jomosom (601), and Thakmarpha (604); and
- Ruwegura, Burundi (9), Khanchikot (715), Godavari (1022), Okhaldunga (1206), and Taplejung (1405).

Additional bi-dimensional ordinations can be performed. Especially useful graphs can be made by comparing stations according to their Moisture Index and Equability Index and also their Warmth Index and Equability Index separately. The utility of these additional ordinations is to provide a finer differentiation in the clusters noted on Fig. 14.3. The employment of a three dimensional graphing technique allows us to show the relationships among these three indexes simultaneously. Formal cluster analysis will enable us to perform this type of discrimination more accurately using a much larger set of variables when the data base is more complete. For now, this simple technique can be useful in establishing initial groupings of widely separated mountain locations having certain bioclimatic properties in common.

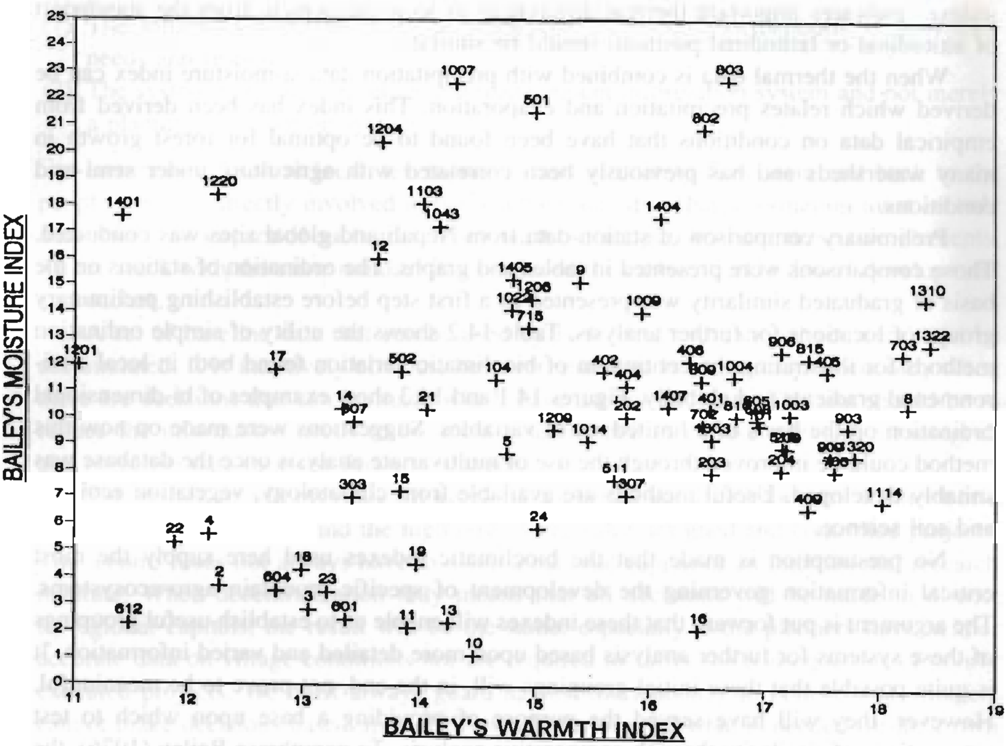

Figure 14.3: Ordination of stations by Moisture (S) and Warmth (W) Index

Source: Data from LRMP, 1985 & Jackson, 1987; Analytical Methods from Bailey, 1979.

CONCLUSIONS AND RECOMMENDATIONS

Implications for International Mountain Research

This paper advocates the use of comparative methods of analysis for characterizing mountain agro-ecosystems. The argument is made that zonal classifications are artificial constructs which mask important gradients of variation that are particularly important in mountain areas. It is further argued that agglomerative methods of classification are more compatible with a decentralized approach to development planning than are hierarchical systems. This is because local detail is an inherent part of agglomerative databases.

The introduction to bioclimatic analysis presented the physical principles that lead to similarities in the climates of disjunct locations on the earth. An illustration of a simple method of comparing mountain localities (Bailey Bioclimatic Analysis) was described. The analysis then proceeded to a preliminary examination of the bioclimatic attributes of selected mountain locations.

The use of this methodology indicates that useful analysis of mountain environmental conditions is possible from climatic data consisting of only monthly and annual means of temperature and precipitation. From the basic thermal data, information can be supplied on the warmth and duration of a potential growing season, the percentage of annual hours below freezing, and the level of equability for a given station. The use of these indexes indicates important thermal differences in locations which, from the standpoint of altitudinal or latitudinal position, should be similar.

When the thermal data is combined with precipitation data, a moisture index can be derived which relates precipitation and evaporation. This index has been derived from empirical data on conditions that have been found to be optimal for forest growth in many watersheds and has previously been correlated with agriculture under semi-arid conditions.

Preliminary comparison of station data from Nepali and global sites was conducted. Those comparisons were presented in tables and graphs. The ordination of stations on the basis of graduated similarity was presented as a first step before establishing preliminary groups of locations for further analysis. Table 14.2 shows the utility of simple ordination methods for illustrating the continuum of bioclimatic variation found both in local environmental gradients and globally. Figures 14.1 and 14.3 show examples of bi-dimensional ordination on the basis of a limited set of variables. Suggestions were made on how this method could be improved through the use of multivariate analysis once the database was suitably developed. Useful methods are available from climatology, vegetation ecology, and soil science.

No presumption is made that the bioclimatic indexes used here supply the most critical information governing the development of specific mountain agro-ecosystems. The argument is put forward that these indexes will enable us to establish useful groupings of these systems for further analysis based upon more detailed and varied information. It is quite possible that these initial groupings will, in the end, not prove to be meaningful. However, they will have served the purpose of providing a base upon which to test assumptions of similarity through comparative analysis. To paraphrase Bailey (1976), the most significant statement which can be made about this method is that it does not try to prescribe what farming system should be developed in a given climatic regime, but rather describes the range of climatic data in the area currently occupied by existing agricultural systems and provides a basis for comparing these locations globally.

Implications for Decentralised Rural Development

A comparative analysis of mountain locations provides opportunities to build a link between farmers and researchers. A characterization of the successful options which have been employed in similar agro-ecosystems can be made. In this way, the analysis would not end at comparing the existing resource base but would also extend to comparing farmers' differing approaches to the use of those resources. The results could be used to formulate local development options.

Providing information to local planners on options that have been successfully tried in other areas does not necessarily need to end up in a 'blueprint' planning process. What is advocated here is the provision of a range of choices for local planners coupled with relevant data to back up the potential suitability of the offered choices. Local institutions at different levels (down to farmers' groups) could then begin their own adaptive research, with technical assistance, to understand the possibilities that are most appropriate for their local system.

The key issues involved in the preparation of a useful information system are as follows.

(1) The information system must be supportive of people's perceptions of their own needs and resources.
(2) The system must be a development management information system and not merely a planning information system.

Information used in local development must ultimately flow from and back to the people who are directly involved in the resultant activity. That information must include data about the impact of such an activity on those people. Without these two elements, we are stuck with the same mindset that produced the earlier 'trickle-down' development approaches.

A set of baseline data that can be used by both local and national planners must be accumulated. It is intuitively obvious, however, that data become information only when there are decisions that can be made which have use for that data. The aim should be to reduce the information needs to the most essential and to choose relevant, meaningful, and objective data to assist decision makers.

The results of the previous 40 years of concerted rural development in the world illustrates the limitations and the high cost of centrally designed and controlled projects. The 'centre' does not always have to mean a national capital or an international research institute. When decentralization only means that all decisions will be made in district or regional capitals, the result will be the same; especially if the planners have neither accurate data on village conditions nor are required to suffer the consequences of poorly executed projects. We must always guard against the tendency to believe that villagers cannot make decisions based upon their own knowledge of what is needed for their own development.

Recommendations for Future Action

(1) An action plan for the development of an agro-ecological information system should be drawn up.
(2) The initial emphasis for data collection should be on the climatic variables mentioned in this paper. The preliminary climatic data would be analysed as described above.
(3) Once initial grouping based upon bioclimatic variables is accomplished, additional information such as elevation, topographic position, dominant slope and aspect, and major soil type can be added to the analysis. This will further refine the clusters and provide more meaningful ordination gradients. Economic and sociological data should be added when suitable indexes have been established.
(4) Work should be initiated on establishing the range of limits of particular crops, agroforestry products, and livestock along observed environmental gradients. This can be facilitated by using methods such as those proposed separately by Nayava (1980) and Axelrod and Bailey (1976) for determining the temperature regimes of locations distant from climate stations in mountain areas. Computer simulation models can also be developed for estimating the distribution of rainfall within given environmental parameters when this has been proven useful.
(5) Multivariate analysis could be undertaken once a sufficient set of comparable data has been gathered and a review of appropriate methods has been undertaken. Suitable methods are available from climatology, vegetation ecology, and soil science. How-

Table 14.2. Preliminary bioclimatic ordination of selected stations of Nepal with global comparison (Warmth (W) sort)

Country	Station	#	ALT	lat	long	T	W	Td	W CLASS	%f	f CLASS	A	M	M CLASS	RAIN (mm)	S	F3	S CLASS	R	R CLASS
Nepal	Namche Bazar	1201	3450	27 49N	86 46E	6.5	11.0	86	v.cool	14.0	mod	12.3	50.1	equable	1010	11.9	6	humid	19	Strong summer
Nepal	Olanochung	1401	3048	27 41N	87 41E	7.4	11.4	101	v.cool	10.0	mod	12.3	52.1	equable	1558	17.5	9	perhumid	16	Strong summer
Nepal	Lomantang	612	3705	29 11N	83 58E	5.8	11.5	103	v.cool	>20	severe	18.0	45.4	subequable	184	2.2	0	arid	22	Summer
Boliv	La Paz	22	3400	16 00S	68 00W	10.0	11.9	118	cool	1.0	rare	7.2	63.4	equable	484	5.2	3	dry sub-humid	17	Strong summer
PRC	Changtu	4	3200	31 11N	96 59E	8.0	12.2	127	cool	16.0	mod	18.2	48.8	subequable	553	5.6	5	dry sub-humid	9	Strong summer
Nepal	Chialsa	1200	2750	27 31N	86 37E	9.5	12.2	130	cool	5.5	mod	12.4	56.6	equable	1857	18.4	8	perhumid	9	Strong summer
PRC	Hsining	2	2244	36 35N	101 55E	6.9	12.3	131	cool	>20	server	24.7	42.9	subequable	377	3.7	3	semi-arid	11	Strong summer
PRC	Lhasa	17	3600	29 57N	91 08E	10.4	12.8	146	cool	7.0	mod	12.8	55.4	equable	1303	11.8	5	humid	5	Strong summer
Nepal	Thakmarpha	604	2566	28 45N	83 42E	10.9	12.8	146	cool	3.0	light	12.1	59.6	equable	340	3.5	0	semi-arid	31	Summer
Turk	Ankara	18	900	40 00N	33 00E	10.4	13.0	153	cool	13.0	mod	20.6	49.8	subequable	320	4.3	4	arid	62	Winter
PRC	Lanchow	3	1507	36 01N	103 59E	9.6	13.0	155	cool	>20	server	29.3	42.2	subequable	338	2.8	1	semi-arid	11	Strong summer
USA	Denver	23	1800	40 00N	105 00W	10.9	13.2	159	cool	14.0	mod	22.8	48.3	subequable	324	3.5	1	arid	31	Summer
Japan	Naguru	14	418	36 40N	138 12E	11.1	13.3	163	cool	16	mod	26.2	45.5	subequable	996	10.4	12	humid	61	Winter
Nepal	Jomosom	601	2744	28 47N	83 43E	12.2	13.4	164	cool	4.0	mod	15.0	57.6	equable	249	2.4	0	arid	36	Summer
Nepal	Jumla	303	2300	29 17N	82 10E	12.3	13.4	166	cool	4.5	mod	15.8	56.7	equable	769	7.0	6	moist sub-humid	22	Summer
Nepal	Lete	607	2384	28 38N	83 36E	12.5	13.4	166	cool	3.5	mod	12.5	61.4	equable	1051	9.9	9	humid	23	Summer
Pak	Murree	12	2155	33 55N	73 24E	12.8	13.6	172	mild	6.0	mod	18.5	53.8	equable	1639	16.0	10	humid	31	Summer
Nepal	Aisealukharkh	1204	2143	27 21N	86 45E	13.2	13.7	173	mild	1.0	light	11.9	62.9	equable	2373	20.4	7	perhumid	8	Strong summer
India	Srinagar	15	1637	34 06N	74 49E	13.3	13.8	177	mild	9.9	mod	23.5	48.8	subequable	663	7.2	5	moist sub-humid	47	Even
Nepal	Shera Gaun	502	2152	28 35N	82 49E	13.6	13.8	178	mild	2.0	light	13.4	60.7	equable	1375	11.8	6	humid	14	Strong summer
Pak	Kalam	11	2015	25 58N	64 36E	13.6	13.9	179	mild	7.0	mod	21.5	50.8	equable	232	2.1	1	arid	69	Winter
USSR	Tashkent	19	400	41 00N	66 00E	13.8	14.0	182	mild	12.0	mod	27.8	45.1	subequable	342	4.5	5	semi-arid	72	Winter
Nepal	Jiri	1103	2003	27 38N	86 14E	14.1	14.0	183	mild	1.5	light	13.7	60.3	equable	2255	18.1	7	perhumid	8	Strong summer
Equad	Quito	21	2200	1 00S	79 00W	14.0	14.1	184	mild	<0.1	rare	0.7	95.1	superequable	1071	10.4	9	humid	40	Summer
Nepal	Nagarkot	1043	2150	21 45N	85 31E	14.4	14.2	187	mild	0.6	light	11.8	63.2	equable	2099	17.2	6	perhumid	9	Strong summer
Pak	Quetta	13	1672	30 12N	67 01E	15.0	14.3	190	mild	6.0	mod	23.0	49.2	subequable	196	2.4	2	arid	78	Winter
Nepal	Kakani	1007	2064	27 48N	85 15E	14.7	14.3	191	mild	0.4	rare	10.7	64.9	equable	2741	22.6	6	perhumid	8	Strong summer

Pak	Gilgit	10	1467	35	54N	74	18E	15.8	14.5	196	mild	6.0	mod	23.5	48.4	subequable	138	1.1	0	arid	25	Summer
Nepal	Dadeldhura	104	1837	29	18N	80	35E	15.7	14.7	202	mild	0.7	light	13.2	60.1	equable	1420	11.5	7	humid	19	Strong summer
Nepal	Lumle	814	1642	28	18N	83	48E	15.6	14.7	202	mild	0.3	rare	11.2	63.3	equable	5167	40.2	7	perhumid	8	Strong summer
PRC	Kunming	5	1893	25	02N	102	43E	15.7	14.7	204	mild	0.1	rare	10.6	64.1	equable	1095	8.7	6	humid	16	Strong summer
Nepal	Godavari	1022	1400	27	35N	85	24E	16.0	14.8	206	mild	0.5	rare	12.7	60.4	equable	1876	14.1	6	humid	8	Strong summer
Nepal	Taplejung	1405	1768	27	21N	87	40E	16.0	14.8	206	mild	0.4	rare	61.3	61.3	equable	1995	15.3	7	humid	10	Strong summer
Nepal	Khanchikot	715	1760	27	56N	83	09E	16.2	14.9	210	mild	0.2	rare	11.0	62.7	equable	1681	13.4	6	humid	11	Strong summer
Nepal	Okhaldhunga	1206	1810	27	19N	86	30E	16.3	15.0	211	mild	0.2	rare	11.1	62.3	equable	1911	14.5	7	humid	9	Strong summer
Nepal	Rumumkot	501	1560	28	36N	82	38E	16.6	15.0	212	mild	0.4	rare	13.0	59.2	equable	2798	21.5	7	perhumid	11	Strong summer
Mexico	Mexico City	24	1800	25	00N	105	00E	15.5	15.0	213	mild	<0.1	rare	3.9	78.3	v.equable	659	5.9	4	dry sub-humid	15	Strong summer
Nepal	Bhojpur	1209	1595	27	11N	87	03E	16.8	15.2	217	mild	<0.1	rare	11.3	61.2	equable	1268	9.6	6	humid	14	Strong summer
Bur	Rwegura	9	1800	3	00S	30	00E	15.6	15.4	224	mild	<0.1	rare	1.3	85.0	superequable	1684	15.2	9	humid	36	Summer
Nepal	Kathmandu	1014	1324	27	44N	85	20E	18.1	15.5	226	mild	0.3	rare	14.3	55.4	equable	1364	9.2	5	humid	9	Strong summer
Nepal	Dailekh	402	1402	28	41N	81	43E	18.3	15.6	230	warm	0.3	rare	13.4	55.9	equable	1696	11.8	4	humid	11	Strong summer
Nepal	Salyan	511	1457	28	23N	82	10E	18.5	15.7	233	warm	0.2	rare	13.2	55.7	equable	1078	7.7	4	moist sub-humid	17	Strong summer
Nepal	Chainpur (W)	202	1304	29	33N	81	43E	18.8	15.8	237	warm	0.2	rare	13.2	55.2	equable	1452	10.1	7	humid	18	Strong summer
Nepal	Dhankuta	1307	1445	26	59N	87	21E	18.3	15.8	237	warm	<0.1	rare	11.3	58.0	equable	1006	7.2	5	moist sub-humid	13	Strong summer
Nepal	Jajarkot	404	1231	28	42N	82	12E	18.9	15.8	237	warm	0.2	rare	13.6	54.6	equable	1673	11.3	4	humid	11	Strong summer
Nepal	Chautara	1009	1676	27	47N	85	43E	18.7	15.9	241	warm	<0.1	rare	11.6	56.8	equable	2056	14.1	5	humid	7	Strong summer
Nepal	Taplethok	1404	1383	27	29N	87	47E	18.8	16.1	247	warm	0.1	rare	10.4	57.8	equable	1544	17.6	8	perhumid	11	Strong summer
Nepal	Ilam Tea	1407	1300	26	55N	87	54E	18.9	16.2	249	warm	<0.1	rare	10.1	57.9	equable	1520	10.5	6	humid	9	Strong summer
Nepal	Surkhet	406	720	28	36N	81	37E	21.1	16.3	255	warm	<0.1	rare	16.2	48.4	subequable	2064	12.2	4	humid	10	Strong summer
Namib	Windhoek	16	1500	23	S	17	E	19.4	16.4	258	warm	<0.1	rare	10.0	56.6	equable	315	2.1	0	arid	82	Strong Winter
Nepal	Gorkha	809	1097	28	00N	84	37E	20.1	16.5	259	warm	<0.1	rare	11.9	53.5	equable	1776	11.5	5	humid	9	Strong summer
Nepal	Tansen	702	1067	27	52N	83	32E	19.8	16.5	260	warm	<0.1	rare	10.7	55.2	equable	1494	9.8	4	humid	9	Strong summer
Nepal	Khudi Bazar	802	823	28	17N	84	22E	20.2	16.5	260	warm	<0.1	rare	12.1	53.1	equable	3308	20.9	7	perhumid	8	Strong summer
Nepal	Pusma Camp	401	950	28	53N	81	15E	20.7	16.5	262	warm	<0.1	rare	13.2	51.2	equable	1632	10.4	4	humid	11	Strong summer
Nepal	Chainpur (E)	1303	1329	27	17N	87	20E	19.9	16.5	263	warm	<0.1	rare	10.6	55.0	equable	1399	9.3	7	humid	12	Strong summer
Nepal	Silghadi	203	1360	29	16N	80	59E	20.8	16.5	263	warm	<0.1	rare	13.3	51.0	equable	1236	8.0	4	moist sub-humid	19	Strong summer
Nepal	Pokhara	803	850	28	13N	84	00E	20.8	16.7	268	warm	<0.1	rare	12.3	51.6	equable	3710	22.7	7	perhumid	10	Strong summer
Nepal	Nuwakot	1004	1003	27	55N	85	10E	20.5	16.7	270	warm	<0.1	rare	10.9	53.4	equable	1819	11.7	5	humid	8	Strong summer

(Contd.)

Table 14.2. Contd.

Country	Station	#	ALT	lat	long	T	W	Td	W CLASS	%f	f CLASS	A	M	M CLASS	RAIN (mm)	S	F3	S CLASS	R	R CLASS
Nepal	Chapkot	810	400	27 53N	83 49E	21.7	16.8	271	warm	<0.1	rare	14.5	48.3	subequable	1730	10.1	6	humid	11	Strong summer
Nepal	Baglung	605	984	28 16N	83 36E	21.6	16.9	278	warm	<0.1	rare	12.8	49.6	subequable	1748	10.3	6	humid	10	Strong summer
Nepal	Tulsipur	508	725	28 08N	82 18E	22.1	16.9	278	warm	<0.1	rare	14.0	47.9	subequable	1706	10.0	4	humid	9	Strong summer
Nepal	Kakerpakha	101	842	29 39N	80 30E	22.0	17.0	279	warm	<0.1	rare	13.6	48.4	subequable	1637	9.8	4	humid	13	Strong summer
Nepal	Hetauda	906	303	27 25N	85 03E	22.2	17.1	288	warm	<0.1	rare	13.0	48.2	subequable	2211	12.6	6	humid	8	Strong summer
Nepal	Mahendranagar	204	176	29 02N	80 13E	23.6	17.1	288	warm	0.1	rare	16.5	43.8	subequable	1547	8.2	4	perhumid	9	Strong summer
Nepal	Koilbas	510	320	27 42N	82 32E	23.1	17.2	288	warm	<0.1	rare	15.0	45.6	subequable	1644	9.0	4	moist sub-humid	7	Strong summer
Nepal	Dhanghadi	209	167	23 41N	80 36E	23.7	17.2	290	warm	<0.1	rare	16.4	43.7	subequable	1725	9.0	4	humid	9	Strong summer
Nepal	Trisuli	1003	595	27 55N	85 09E	22.3	17.1	291	warm	<0.1	rare	12.6	48.3	subequable	1767	10.2	6	humid	10	Strong summer
Phili	Baguio	1	1482	16 25N	120 36E	18.2	17.3	293	warm	<0.1	rare	2.3	68.3	v.equable	4177	33.5	8	prehumid	16	Strong summer
Nepal	Nepalganj	409	190	28 06N	81 34E	24.1	17.4	299	warm	<0.1	rare	16.1	43.1	subequable	1285	6.7	4	moist sub-humid	9	Strong summer
Nepal	Khairini	815	500	28 02N	84 06E	22.9	17.4	300	warm	<0.1	rare	13.1	46.8	subequable	2214	12.4	5	humid	9	Strong summer
Nepal	Chisopani	405	225	28 39N	81 16E	24.6	17.5	308	warm	<0.1	rare	16.0	42.4	subequable	2260	11.9	4	humid	7	Strong summer
Nepal	Simra	909	137	27 10N	84 59E	23.9	17.6	311	warm	<0.1	rare	14.2	44.4	subequable	1632	8.6	6	moist sub-humid	10	Strong summer
Nepal	Bhairawa	705	110	27 31N	83 28E	24.4	17.6	314	warm	<0.1	rare	15.1	43.1	subequable	1525	8.1	4	moist sub-humid	7	Strong summer
Nepal	Jhawani	903	270	37 35N	84 32E	23.9	17.7	322	warm	<0.1	rare	13.3	44.8	subequable	1817	9.8	4	humid	8	Strong summer
Nepal	Tarahara	1320	200	26 42N	87 16E	23.8	17.8	328	warm	<0.1	rare	12.7	45.3	subequable	1628	8.7	6	humid	10	Strong summer
Nepal	Hardinath	1114	93	26 48N	85 59E	24.5	18.0	365	warm	<0.1	rare	12.8	43.9	subequable	1332	7.0	4	dry sub-humid	9	Strong summer
Nepal	Butwal	703	263	27 42N	83 28E	25.4	18.2	365	v.warm	<0.1	rare	13.7	42.0	subequable	2452	12.5	5	humid	7	Strong summer
Bur	Busiga	8	1600	3 S	30 E	18.9	18.3	365	warm	<0.1	rare	1.3	65.5	v.equable	1345	10.5	9	humid	36	Summer
Nepal	Barahkshetra	1310	146	26 52N	87 10E	24.6	18.4	365	v.warm	<0.1	rare	11.3	44.2	subequable	2688	14.6	6	humid	8	Strong summer
Nepal	Dharan	1322	400	26 49N	87 17E	24.6	18.4	365	v.warm	<0.1	rare	11.1	44.4	subequable	2401	12.9	6	humid	11	Strong summer

Bur	Musasa	7	1200	3	S	30	E	21.4	19.2	365	hot	<0.1	rare	3.4	55.2	equable	1227	8.5	8	moist sub-humid	29 Summer
Bur	Bujumbura	6	600	3	S	30	E	23.9	22.2	365	hot	<0.1	rare	1.7	48.7	subequable	871	5.5	6	dry sub-humid	29 Summer

List of abbreviations used in Table 14.2.

Turk	TURKEY
Phili	PHILIPPINE ISLANDS
Bur	BURUNDI
PRC	PEOPLES' REPUBLIC OF CHINA
Pak	PAKISTAN
Boliv	BOLIVIA
Mex	MEXICO
Equad	EQUADOR
Namib	NAMIBIA
#	Station number
ALT	Altitude in metres
lat	latitude
long	longitude
T	Mean annual temperature, Celcius
W	Warmth index (0–35)
Td	Length of potential growing period in days (0–365)
%f	Percentage of annual hours below freezing (0–>20)
A	Mean annual range of temperature, Celcius
M	Equability Index (0–100)
RAIN	Mean annual total precipitation in millimetres
S	Moisture index (0–40)
R	Percentage of precipitation falling in cooler half year

Note: See Annex 1 for full explanation of all values and class boundaries ever, at no time should sophisticated technology eliminate the need for interaction with people at the farm level.

(6) For certain areas this use of sophisticated, multivariate analysis and simulation techniques may be warranted. However, for the majority of the highland areas, an impressive wealth of information has been shown to be available through tapping the indigenous knowledge of local agro-ecosystems. The combination of the technical and farmer information can be used to produce simple maps of localized gradients of variation found in the observed variables. This information is also critical for assessing the reasons for observed differences in human use patterns found in similar environments. This knowledge can be attained more easily through comparative analysis than through zonation. It is this understanding which is most crucial in designing sustainable rural development programmes.

(7) Adjustment of the database and determining the resulting typologies should advance through a continual process of revision. Preliminary results should be published and distributed as widely as possible to obtain critical review of the system's utility for both international communication and local development planning.

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ANNEX 1

DEFINITION OF TERMS OF EQUATIONS FOR THE BAILEY BIOCLIMATIC ANALYSIS

A. Temperature terms

1. The Warmth Index (W) is defined as:
   $W(°C) = (2.93T + 14s_1 - 20.4)/(1.47 + s_1)$
   $s_1 = 1.46 - .366A$

where W is the mean daily temperature at the onset and exit of summer, T is mean annual temperature, A is the mean annual range of temperature (the difference between the warmest and coldest monthly means), and s_1 is the standard deviation of all hourly temperatures around the annual mean.

2. The duration of summer is defined as:
   $Td(\text{days}) = 182.5 + 2.028 \text{ arc } \sin[(W - 14)/4]$,
   where Td is the duration of summer in days (interval in which daily means exceed W). The equation applies only if W is within the limits of 10 and 18.
3. The classification of summer warmth is:

W			Class
0	to	7.5	Glacial
7.6	to	8.6	Very cold
8.7	to	10.0	Cold
10.1	to	11.6	Very cold
11.7	to	13.4	Cool
13.5	to	15.5	Mild
15.6	to	18.0	Warm
18.1	to	20.8	Very warm
20.9	to	24.1	Hot
		>24.1	Torrid

4. The Equability Index (M) is defined as:
   $M = 109 - 30\log[(14 - T)^2 + (1.46 + 0.366A)^2]$
   where M is an indication of the range of temperature extremes of a local climate.
5. The classification of equability is:

M			Class
0	to	20	Extreme
21	to	35	Inequable
36	to	50	Subequable
51	to	65	Equable
66	to	80	Very equable
		>80	Superequable

6. The frequency of annual hours below freezing as a percentage of all hours of the year is given by the normal probability integral, summed from $-\infty$ to $+\infty$, entered by:

$x/\sigma = -T/(1.46 + 0.366A)$.

This measure is best derived directly from the Baily Thermal Nomogram.

7. The classification of frost frequency is:

%			Class
0	to	0.5	Rare
0.6	to	3.0	Light
3.1	to	20.0	Moderate
20.1	to	50.0	Severe
50.1	to	100.0	Permafrost

B. Precipitation terms

8. Moisture Index (S) is defined as the sum of 12 monthly moisture values (Si)
$Si = 0.18p/1.045^t$
where p is mean monthly precipitation in CM, and
t is mean monthly temperature in °C
9. $F3$ is the number of wet months, where a wet month has a moisture index $S_i > 0.53$.
10. The classification of the annual moisture index (S) is:

Annual moisture			Moisture province	Moisture realm
			Arid	
2.5	to	20	Extreme	Dry
4.7	to	35	Inequable	
6.37				
			Moisture sub-humid	
8.7	to	80	Humid	Wet
16.7			Perhumid	

11. Winter concentration of precipitation (R) is defined as:

$$R = 100 \times \frac{\text{Sum of winter half-year precipitation}}{\text{total annual precipitation}}$$

where the winter half-year is October–March in the northern hemisphere, and April–September in the southern hemisphere.

12. The classification of the seasonal distribution of precipitation.

(R)%			Class
0	to	20	Strong summer
21	to	40	Summer
41	to	60	Even
61	to	80	Winter
81	to	100	Strong winter

Note: All equations and classes are taken from Bailey (1979) with modifications to provide for the use of the standard deviation (s_1) of hourly temperatures around the annual mean.

15

GEOGRAPHIC INFORMATION SYSTEMS TECHNOLOGY APPLICATION IN AGRO-ECOLOGICAL ZONATION OF MOUNTAIN ENVIRONMENTS

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Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, India.

CONTENTS

Maps

INTRODUCTION

Mountain agricultural development requires, as a major effort, the planning of land-use activities in the most appropriate way, apart from several other institutional and policy programme initiatives. This would mean selecting ways of land-use that are most suited for specific mountain areas and that best serve the interest of those concerned and involved in making a living from the land area. The zonal planning approach for mountain areas arises because most of the climates in the mountains are condensed into small geographic areas, resulting in a variable mosaic of specialized areas, capable of supporting varied natural ecological systems (Troll 1988). Implications are that the agricultural systems of these specialized mountain micro-environments also vary in order to fully utilize the potentials existing within each micro-environment.

ICIMOD (Jodha 1990) developed mountain perspective framework helps systematically classify the factors that create these micro-environmental conditions and different agricultural systems within mountain areas. It groups the influencing factors into six main categories called mountain specificities. These specificities take into account not only the physical environment but also the whole ecosystem, including mountain communities and their activities. The imperatives of these mountain specificities dictate that no single technological solution or agricultural development approach can be successfully applied in these diverse mountain environments.

As a result, agricultural development planning in mountain areas is increasingly being based on agro-ecological zones. In this process agroclimatic zoning has become very popular (Verma and Partap, Chapter 26, ARPU 1989, Carson, Chapter 13, Beg et al. 1985). The approach is used to categorize agroclimatically uniform geographical areas for agricultural development planning and other interventions. However, it was the FAO (1976) that first conceptualized a framework for agro-ecological zoning describing concepts, methods, and procedures (FAO 1983, 1989). The agroclimatic zoning, adopted later by regional and national institutions in mountain areas, was mainly based on this framework. The initial focus of the FAO agro-ecological zoning system was to assess the suitability of different types of land for selected land uses. Use of several biophysical factors was recommended as a methodology for this type of agroclimatic (agro-ecological) zoning. The useful contributions of this approach relate to three aspects.

(1) It looks at the potentials of land use, for example, potentials for the production of certain crops. It is an important starting point for land-use planning.
(2) These potentials are based on an evaluation of physical resources, especially land and water, and their possible uses, coupled with an evaluation of economic and social opportunities and constraints. It therefore links biophysical disciplines to socioeconomic ones.
(3) It has a strong geographical orientation. On the required scale it maps present land-use, properties, and potentials for certain land-use types. This provides land-use planning with an overview of the whole region in question.

Of late, workers in the agro-ecological zoning field (Carson, Chapter 13, FAO 1990, ARPU 1989, and Tapia, Chapter 4) are stressing the incorporation of more information about farming systems, socioeconomic structure, and existing land- use patterns into each agro-ecological zone. There is a strong plea for integrating all this information into one comprehensive system that would provide a better database for regional and zonal resource use and management planning. Building such a sound information base for each agro-ecological zone or region is favoured for the following reason. It diagnoses the present situation with regard to farming and land use by categorizing, describing, and analysing farming systems components. It would indicate and analyse the linkages of farming systems with aspects of higher-level systems that impose constraints on farm-level performance. When farming systems information is combined with zoning, land-use types can be matched properly with farming systems and they will be more in tune with the existing systems.

Farming systems and socioeconomic information would help acquire insights into necessary improvements in existing methods of farming.

NEW TOOLS FOR INTEGRATING AGRO-ECOLOGICAL ZONING AND ZONAL RESOURCES INFORMATION

The above suggested integration of zoning and zonal resources information builds on the methods developed for evaluating each of the aspects. The possibility of using digital techniques for information storage, processing, and retrieval is seen as a promising way to use this process. The advantages of using this technique are that information does not need to be aggregated and classified *a priori*, which leads to appreciable loss of information. Instead it can be stored as basic data without losing any details in the analysis. Retrieval of data is possible any time and at any level as required.

It is important because of the multi-stage character of the comprehensive approach to agro-ecological zoning. In the past, a large amount of agroecological data could not be handled easily, and aggregation was required at an early stage in the analysis. This led to the loss of information on spatial variability. On a digital database, information can be stored and retrieved as required. The data can be classified and aggregated for any number of planning exercises, thus making them more efficient to use. The software farm analysis package developed by FAO (1986) and other relational database programmes are providing promising techniques in the whole process of land-use planning.

THE USE OF RELATIONAL DATABASES AND GEOGRAPHIC INFORMATION SYSTEMS

A geographic information system (GIS) is a computerized database management system capable of handling entities of which the location is known (x, y, z coordinates). In a GIS, data can be collected from maps and be stored, manipulated, and represented as maps. Geo-information systems use software for computer graphics, in most cases combined with software for alphanumerical data handling. In a GIS, the relationships among the entities in the database can be established by map manipulation, alphanumeric (table) operations, or combinations of these two. Most GISs have, therefore, the characteristics of relational database management systems. The structure of such a geo-database can be designed with normal (alphanumeric) database design procedures. A land-related data set is useful to support planning procedures and to develop agro-ecological zoning and zonal resource use. To identify which interventions are necessary and most appropriate within an agro-ecological zone, and to judge the consequences of such interventions, data on natural resources (land, climate, etc.) and data on farming systems (farm-household data, cropping patterns, and agricultural practices) would be required.

Agro-ecological zoning tries to find suitable classifications of geographic units, presented on a map. On the other hand, information on mountain farming systems can be presented as textual and numerical information without much geo-referencing. As a consequence, information on land units cannot be combined or linked with information at the farm level. It is, however, possible to overcome these disadvantages through applying GISs (Burrough 1989, Aronoff 1989). The system is capable of containing all data required to solve resource management problems. So far, the available information indicates the wide use of technology for a variety of related purposes (Loveland and Johnson 1983). Special interest applications include the land management model (Johnston 1987), special crop site modelling and watershed monitoring (Smith and Blackwell 1980).

To demonstrate the potentials of the tool for the kind of work under discussion, there is a sufficient body of knowledge (Ripple 1986) which proves its capabilities; these include regional natural resource inventories and management, land-use suitability mapping, agricultural land evaluation and site assessment systems, local resource-use planning, land records information system, erosion control potentials, rangeland management, forest management, desertification hazards and management, and global resources information database.

Inputs to the GIS

The major requirements of computerized GIS for an activity like agro-ecological zoning and zonal resources information of mountain areas are topographic maps, land resource maps, and contour maps. These maps, containing physiographic, geographic, and bioclimatic information, form primary inputs. The scale of the maps is decided upon the basis of need and the technology is capable of handling maps up to very large dimensions. Reductions and enlargements would also be possible. Therefore, the more detailed the information, the better it is. The system also facilitates the enlargement of a particular geographic pocket to render more details on retrieval. After collecting basic data on zonal resource information, the data can be manipulated to create relevant profiles of applied use that can be retrieved on demand. A zonal database can also be fed non-geographic information, such as socioeconomic data, that is relevant for making decisions on development priority interventions about the sustainable management of zonal resources.

The Mountain Perspective as a Source of GIS Data for Agro-ecological Zoning and Zonal Resources Information

The mountain perspective concept advocates consideration of the important conditions that characterize mountain areas and separate mountain habitats from other areas. Jodha (1990) explained that while the mountain specificites, namely, diversity, fragility, marginality, and inaccessibility, are first order specificities, natural suitability or 'niche' for some activities and products, in which mountains have a comparative advantage over the plains, and human adaptation mechanisms in mountain habitats are the two second order specificities. Geographic factors (Table 15.1) such as slope, altitude, terrain conditions, and spatial seasonal hazards collectively contribute to inaccessibility. Similarly, altitude and slope, in association with geologic, edaphic, and biotic factors, contribute to the fragility of the physical land surface, bioresources, and the economic life-support systems of mountain communities. The basic factors that contribute to the marginality of any area are remoteness, physical isolation, and low productivity. The diversity of mountain areas is a function of interactions among different factors such as elevation, climate, edaphic factors, geologic factors, mountain orientations, and relief (Table 15.1). Biological adaptations and socioeconomic responses, such as agricultural patterns, add other dimensions to diversity. Owing to their specific environmental and resource-related features, mountains provide a 'niche' for specific activities or products (Table 15.1).

The imperatives of these mountain specificities for zoning exercises imply that their specific factors can be used in building zonal databases for resource management. This is supported by the fact that among the several implications of the mountain specificities, a resource-centered development strategy is one of the key imperatives (Jodha 1990). Here, resource characteristics, such as fragility, heterogeneity, and 'niche', determine the choice and pattern of resource use for different mountain areas or zones.

Using mountain specificities in agro-ecological zoning would mean selecting factors that are good for the main zoning process, and then segregating those to form a constraints filter, and to identify the potentials of habitats. The geographic considerations further divide them into the following two categories: geographic factors containing spatial information (Table 15.1) and factors with non-spatial information.

Whereas factors related to the physical and biological nature of mountain specificities can be actually used in the zoning process and in building up resource information, the socioeconomic factors may be considered separately as an inventory for each zone without necessarily involving them in the actual zoning process, because of their dynamic character. Also, they can be considered on the level of building a socioeconomic database for each zone.

Making use of all these data variables, one may come up with several wider geographic units or recommendation domains (FAO 1990) with information on the state of their physical and biological resource bases and the status of human interventions. The information on zones can also play a crucial role in deciding the effectiveness of sharing knowledge and resources among the zones.

The Case Study

A study was conducted to demonstrate the use of GIS as a tool for agro-ecological zoning with a mountain perspective. The study also included experimentation on building zonal information using mountain specificities factors. The objective of the study was also to see how socioeconomic data can be incorporated as a part of the zoning scheme. The socioeconomic data were used in this study to test methods of identifying agricultural and resource management priorities. While doing so, a conceptual approach for reaching sustainability through unsustainability (Jodha 1990) was used to determine issues of priority for development. The concept is based on the thinking that for the identification and operationalization of sustainability components for a given system, one needs to examine the unsustainability phenomenon first and then proceed backwards to understand the factors and processes contributing to it. Indicators of unsustainability become the focal point of research, apart from looking into the how and why behind them.

Table 15.1. A sample of GIS factors/data variables for agro-ecological zoning and zonal resources information derived from mountain specificities

Mountain specificities	Implications	GIS factors/data variables
Physical dimension		
Physical diversity	Creation of agroclimatic zones. Many micro-climates.	Climatic factors, i.e., temperature, precipitation, moisture. Soils and geological features. Elevation.
Physical marginality	Unfavourable conditions of soil. Low productivity, reduced growth periods. Higher costs of maintenance. Less carrying capacity.	Soil depth and fertility status, slope angles, areas with water limits and limits of radiation. Wind affected areas for temperature and moisture constraints.
Physical fragility	Environmental degradation Ecological destabilisation of a habitat, limited opportunities for economic use.	Steep slope areas creating vulnerability and enhancing chances of destabilization. Typical geological features causing or contributing to destabilization, shallow soils, temperature, and precipitation as causative factors inducing fragility in areas
Physical inaccessibility	Isolation of mountain communities, higher costs of development activities. Difficulties in moving goods.	Distance, natural barriers, contribution of elevation, climate-imposed inaccessibility. Status of roads and transport.
Physical 'niche' (C.A.)	Areas with special advantages for mountain agriculture.	Areas with beneficial potentials of elevation, wind, water resources, irrigation. Hydropower, climatic variability, wide temperature variations over short distance, i.e., valley floors to mountain tops. Micro-climates, etc.
Physical adaptation experiences	Areas with specialized information on managing mountain agricultural lands. Soil erosion control through traditional systems, etc.	Useful locations with traditional land-based practices which help adapt to prevailing environmental conditions or using land in an efficient manner
Biological dimensions		
Biological diversity	Areas with diverse mountain farming systems and their components indicating specific resource management.	Areas with diverse ecosystems or agro-ecosystems of an area, types of forest and grassland ecosystems, species. Diversity with respect to agricultural and horticultural crops, economic plants. Crop seasons. Diversity of components of farming systems and their dominant status. Genepools of indigenous species and their population, diversity.

Mountain specificities	Implications	GIS factors/data variables
Biological marginality	Habitats of underdeveloped subsistent agriculture waiting for upgradation to commercial farming. Potential species for development and harnessing	Agro-ecosystems or agricultural systems with low productivity affecting food and fodder needs. Marginal or neglected biological resources such as mountain crops, high mountain animals (yak). Under-exploited biological resources of mountain areas. Kinds of degraded ecosystems and their status.
Biological fragility	Habitats with species requiring immediate conservation management.	Gene pool areas of species threatened with extinction. Agro-ecosystems or ecosystems threatened with habitat destruction or transformation. Indigenous agricultural systems with valuable germplasm and needing conservation as a matter of global efforts on bioresources conservation
Biological inaccessibility	New resources, ecosystems for exploration and harnessing.	Unexplored bioresources and mountain agricultural systems with high potentials for development, if any.
Biological 'niche'	Development of mountain farming systems which are self-sufficient or produce exclusive products from locally adapted bio-resources. Comparative advantages of the trade of such items is a focus.	Areas with comparative advantage offered by biological resources of the habitat, as species, populations or system. Areas for horticulture, mountain floral resources, mushrooms, medicinal and aromatic plants. Climate-specific crops. Local animals with low productivity but showing adaptation to degraded range lands of low nutrition. Harsh mountain climates and their adapted animals.
Biological adaptation experiences	Knowledge of levels of resource use and management. Indicators of degree of resource scarcity. Assessment of impacts of introductions.	Habitats with specific adaptations of plant and animal resources. Introductions of biological materials into habitats.
Socioeconomic dimensions		
Socioeconomic diversity	Indicators of complexity and quality of human life.	Areas showing kinds of mountain communities, political organsations. Human settlement patterns. Demographic attributes of areas with respect to diversity of culture, lifestyles, and economic activity, etc. Inequalities of resource-sharing and development between areas.
Socioeconomic marginality	Indicators of degree of unsustainability	The state of marginalization of the mountain farming communities in the areas. Marginal farming classes, areas with respect to land holdings,

Contd.

Table 15.1. Contd.

Mountain specificities	Implications	GIS factors/data variables
		economy, and farming practices. Trends and impacts of marginality on economy and resource use in different areas. Deficits of food production. Nutritional deficiency status.
Socioeconomic fragility	Indicators of underdevelopment and unsustainability of zones. Dimensions of inequity within and between zones.	The state of socially and economically backward mountain communities of the zone, e.g., tribal peoples Their food situation, undernutrition malnutrition, and economy. Degree of subsistence and reasons.
Socioeconomic inaccessibility	Indicators of underdevelopment and unsustainability of zones. Knowledge of state of farming systems existing within zones	Areas with mountain communities having little access to resources, information, technology, and opportunities to improve quality of life. The attribute could be dominating a whole area or a class of people within a zone.

Source: Authors.

Data Source

Sindhupalchowk District of Nepal was used as a representative mountain area in this study and relevant data were acquired from various sources. For more details on the area see Partap et al. (1990). Details on the computer hardware and software used in the study are given in the same report.

The Zoning Process

Three different aspects for zoning and information building for zones were considered as follows:

(1) The main zoning process to delineate agro-climatically homogeneous geographic areas—the agro-climatic zones.
(2) Preparation of inventories of the resources and the mountain specificities of the zones.
(3) Identification of agricultural and resource management priorities of the areas.

The basic data for the study were made available by UNEP-GRID, Geneva, in the form of 1:125,000 scale digitized maps. Besides this, numerical data, mostly of a socioeconomic nature, were acquired from the district profile of Sindhupalchok (Kansakar et al. 1989).

Phase A. The Main Zoning Process to Delineate Agro-ecological Zones

The aim was to classify the area into suitable agroclimatic zones. Influence on the macro-climate and the stability factor are two of the criteria that were considered in the selection of climatic factors for this zoning exercise.

Stable factors falling within the spectrum of physical diversity (Table 15.2) are most

Table 15.2. GIS factors used in the study

Mountain specificities	Physical dimension	Biological dimension	Socioeconomic dimension
Diversity	Temperature zones, rainfall zones, moisture zones, soils-geology classes. > Agro-climatic zones.	Land cover/land in ACZs, cropping system in the zones and degree of components of farming, forestry, grazing land, etc.	Human population size and distribution pattern.
Marginility	Marginal areas mapping. Degree of marginality as a compound factor of activities and conditions.	Areas of low or declining productivity: 1. wastelands 2. abandoned fields 3. shrubland 4. agricultural lands without irrigation 5. areas of mountain crops	Farming conditions leading to economic marginality. Land holdings.
Fragility	Fragile zone mapping. Degree of fragility as a compound factor of activities and conditions.	Fragility of organism-habitat relationship 1. genepool diversity, areas of red panda and Larix trees. (threatened because of habitat limitations) 2. Fragility of component linkages. Forestry-farming relationship impact areas.	Food security and subsequent impacts on economy.
'Niche' comparative advantage	Limitations of roads, service, and market centres. River water resources for irrigation potential, combined with slopes.	Distance from conservation zones	Biological resources for development. Potentials, imperatives documented.
Human adaptation experiences	Terracing in the Himalaya. Abandoned agricultural fields.	Relay cropping Nomadic pastoralism.	Community forestry.

appropriate for this exercise. Selection of a particular factor or number of factors was mainly guided by data availability.

The main objective of agroclimatic zoning was to understand the paths to follow. The limited number of factors, i.e., rainfall and temperature, were selected to generate agroclimatic zones in this study. Temperature was considered to functionally represent altitude and latitude.

Agroclimatic zones were further overlayed (unionized) with land use to identify the ecosystemic types of the zones. Figure 15.1 describes the process followed for agroclimatic zoning.

Phase B. Inventories of Resources and Mountain Specificities of the Zones

The efforts here were directed towards building comprehensive inventories of the resources and mountain specificities of each zone. The aim was to develop two kinds of thematic maps. Category one maps were prepared from the GIS factors listed in Table 15.2. The standard assumption was that each theme, covered by a thematic map in category one, is expected to be exercising direct or indirect impact in varying degrees on the functioning of the agro-ecosystems of the agro-climatic zones.

A composite map (database) of the category one thematic maps was prepared by using the GIS overlay technique. The composite map was intended to serve as an inventory for storage, retrieval, and analysis for other information that is needed about the zones. Thus, a multivariate composite, updated database was created as a first step in developing zonal resources information. The thematic maps were either obtained from the digitized base maps or from reclassification, extracting, and overlaying scattered information. Exercises were exclusively designed to identify erosion-prone areas and biologically fragile areas, and to locate the medium-scale irrigation potentials of the area. Important examples of pathways followed to develop these maps are given in Figs. 15.2, 15.3, 15.4, 15.5 and 15.6).

Phase C. Using Information Contained in the Socioeconomic Dimension of Mountain Specificities

Socioeconomic factors and variables were used to assess the unsustainability status of agriculture in different zones of Sindhupalchok. Because the socioeconomic information was available on a politico-development area basis, the data processing was conducted in the same pattern. The score points were classified into three classes and computed to produce an unsustainability status map (Fig. 15.7). Table 15.3 lists the indicators of unsustainability used in the study.

RESULTS OF THE STUDY

A list of the maps prepared by using GIS is given in Table 15.4.

Sindhupalchok was broadly categorized into six agroclimatic zones (Map 1). The nomenclature of the zones is based on the FAO classification of agro-ecological zones (1980). It states that temperate regimes do not exist in Asia. However, regionally 'temperate' word has been frequently used in mountain zoning to equate general climatic conditions. The names of zones given in brackets are regionally or nationally recognized equivalent names for these agroclimates. Zone I is a natural water reservoir in the form of snow and ice and feeds several river systems. Zone II is a forest and grassland ecosystem (Table 15.5). The other zones, III, IV, V and VI, are agroclimatically suitable for agricultural activities (Table 15.5). Temperature is a limiting factor for farming in

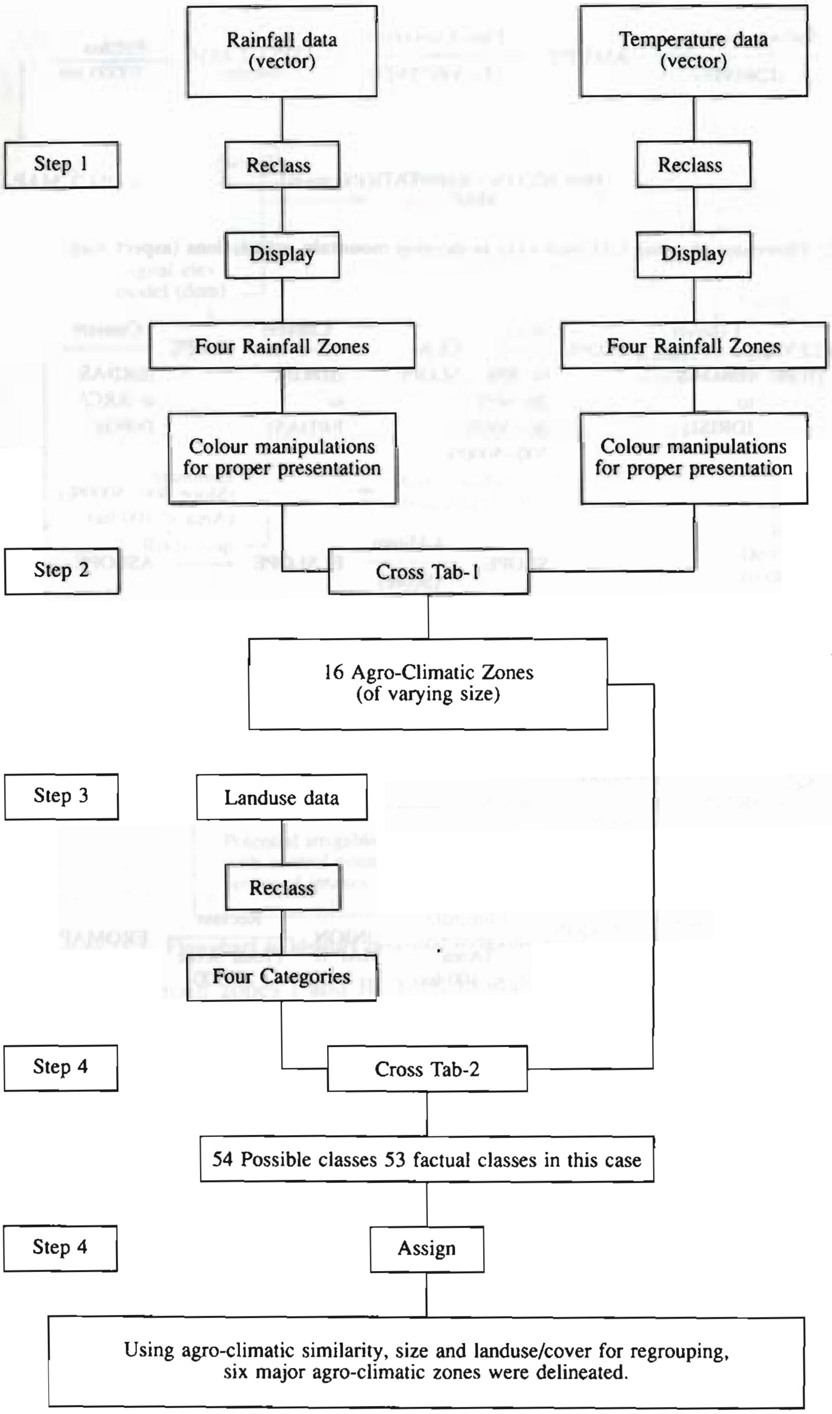


Figure 15.1: Flowchart diagram of the IDRISI system used in agro-climatic zoning

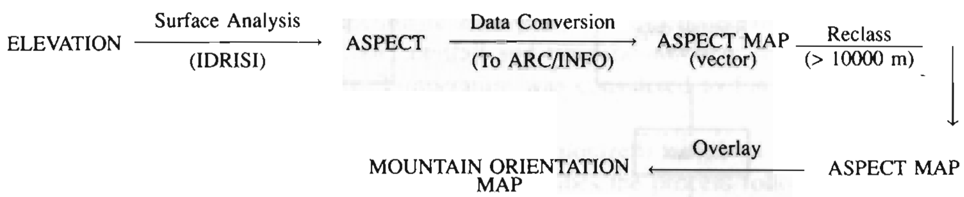


Figure 15.2: Flowchart showing GIS pathways to develop mountain orientations (aspect map)

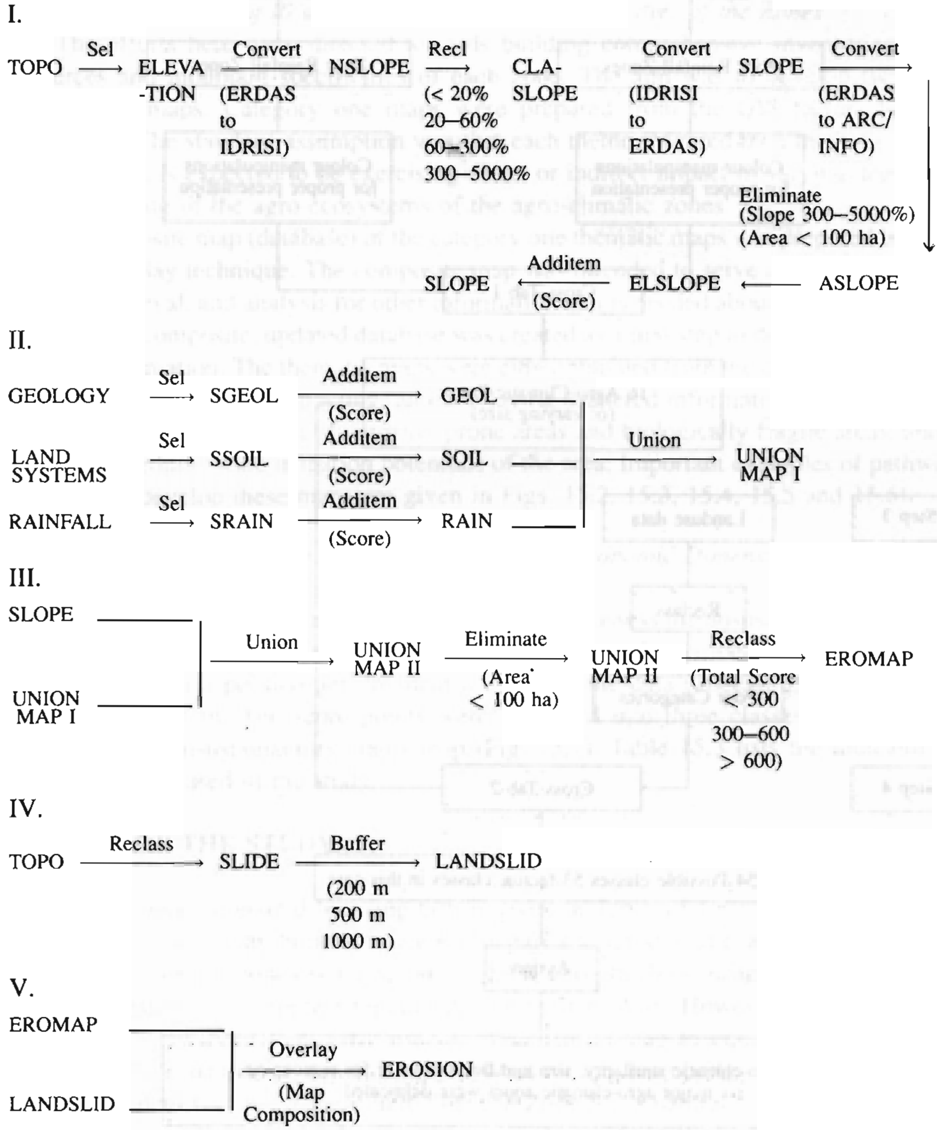


Figure 15.3: Flowchart showing GIS pathways of erosion potential map

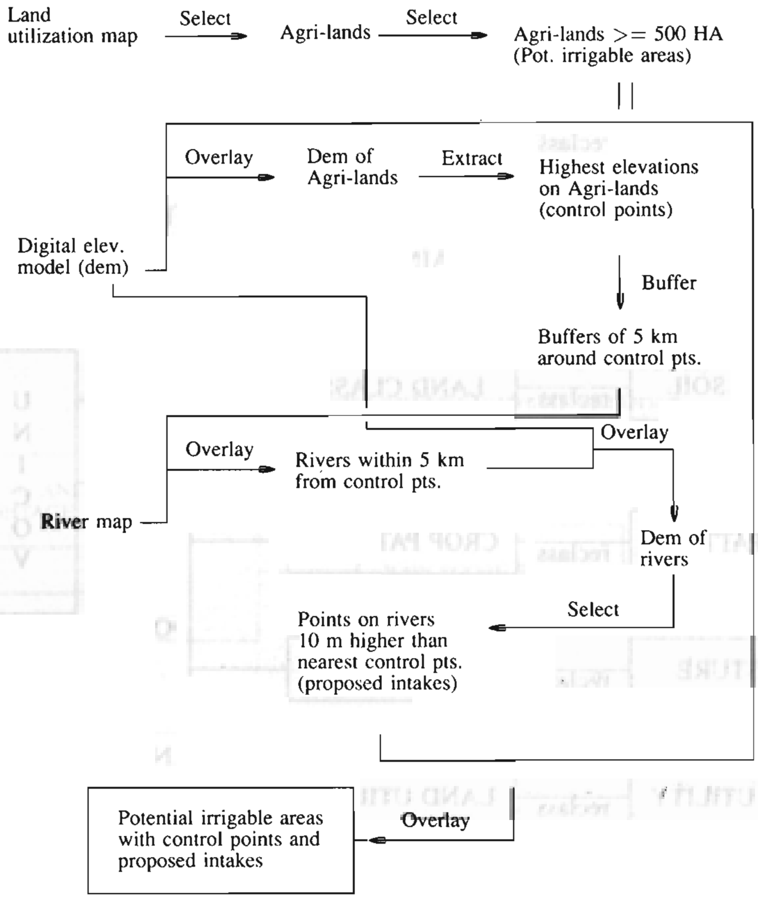


Figure 15.4: Flowchart to identify potential irrigable areas

the high mountain zones I and II. Total rainfall is relatively high and erratic. Areas of maximum and minimum rainfall and growing periods are mostly influenced by mountain orientations.

The GIS study revealed that geologically most agricultural areas of Sindhupalchok are placed on a suitable rock structure. Schist, quartzite, and limestone dominate the agricultural areas. Some areas have a natural supply of calcium from limestone, an ingredient of inorganic fertilizers. Edaphic factors classify Sindhupalchok into four zones. Soils suitable for agriculture are limited to river valleys. Deep soils on slopes of varying degrees allow for large-scale terracing. Shallow soils and steep slopes are areas suitable for other types of land use, e.g., grazing lands and forestry.

Projections on mountain orientations highlighted of two types: longer chains that run north-south and short chains that go in all directions. They have created two to three major watersheds and more than 30 micro-watersheds (*kholas*). Many of the mountain slopes are facing west or north and have favourable conditions for forestry. Agriculturally, the area is favourable in terms of saving moisture in warmer zones. However, in cooler zones, the same characteristic will limit the growth periods of crops because of low temperature and

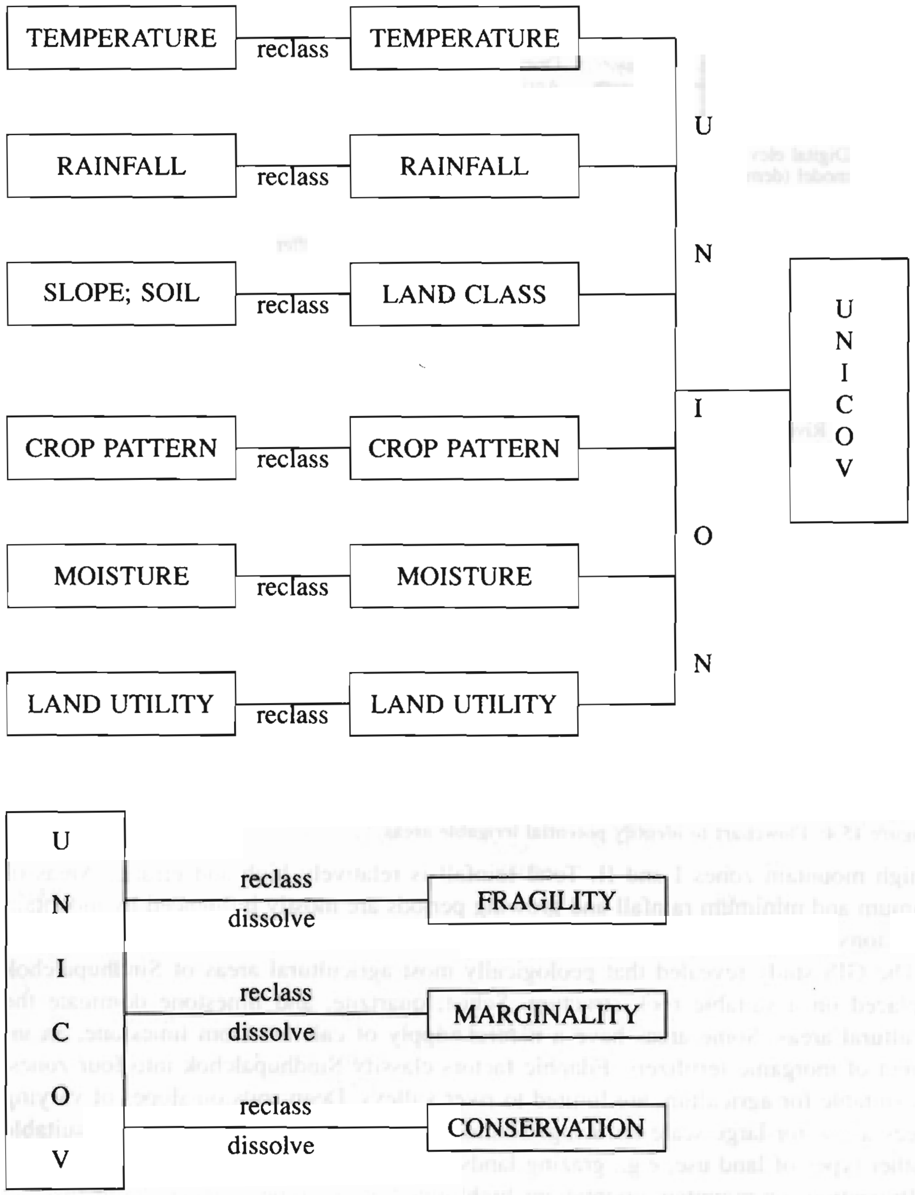


Figure 15.5: Flowchart showing the pathways to fragility, marginality, and conservation scenarios

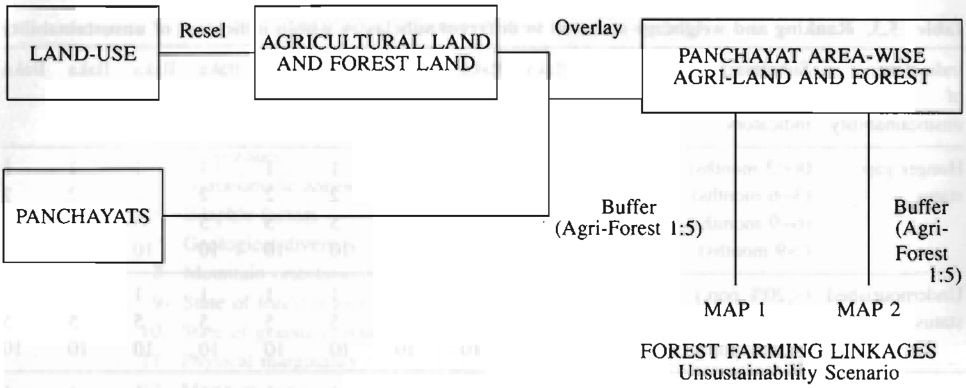


Figure 15.6: Flowchart showing pathways to identify equilibrium

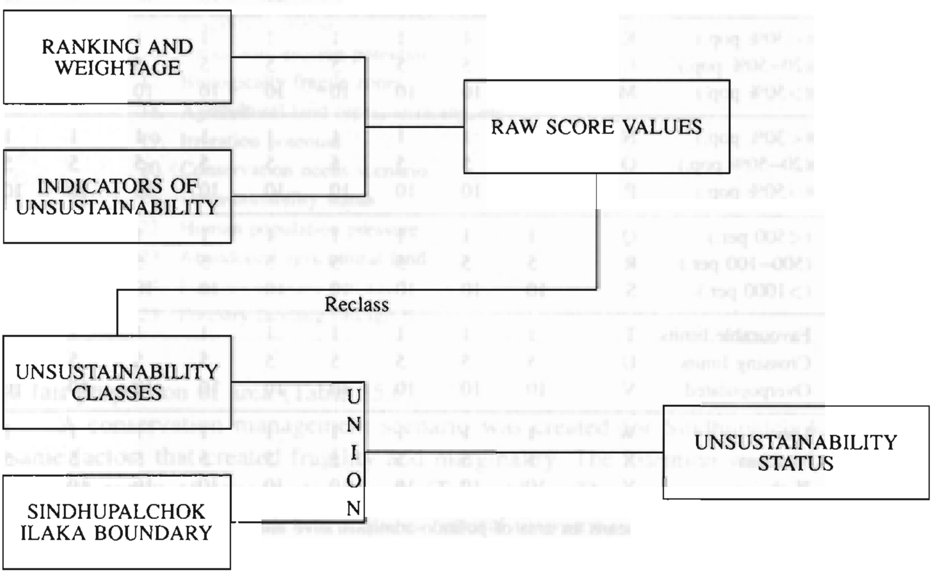


Figure 15.7: Flowchart showing pathways to develop unsustainability map

lesser radiation periods in winter, leading to monocropping in these same areas. Equally, large areas facing eastwards have the advantage of crop cultivation being possible up to very high altitudes. Rice cultivation in the high mountain areas of Sindhupalchok is one such example. For populations living in the valleys, two faces of watersheds should provide a unique 'niche' of both conditions. Some areas have major advantages of this kind. The land-use profile of the Sindhupalchok Area showed that it has an alpine ecosystem, temperate forest ecosystem, grasslands, and agricultural systems as its major ecosystems. Forest resources fall into three major types: the coniferous, hardwoods, and shrublands. Areas that should be supporting agriculture because of strong forestry-farming linkages are under mixed forests and shrubs. There are some scattered patches of mountain pastures, and only one or two watersheds have significant grasslands.

Cropping pattern mapping revealed that crop resources in Sindhupalchok are dominated by rice and maize. Both paddy and upland rice are extensively grown throughout

Table 15.3. Ranking and weightage assigned to different subclasses within indicators of unsustainability

Indicators of unsustainability	Subclasses within the indicators	Code	Ilaka	Ilaka	Ilaka	Ilaka	Ilaka	Ilaka	Ilaka	Ilaka	Ilaka
Hunger gap status	0(<3 months)	A	1	1	1	1	1	1	1	1	1
	(3–6 months)	B	2	2	2	2	2	2	2	2	2
	(6–9 momths)	C	5	5	5	5	5	5	5	5	5
	(>9 months)	D	10	10	10	10	10	10	10	10	10
Undernourished status	(<20% pop.)	E	1	1	1	1	1	1	1	1	1
	(20–40% pop.)	F	5	5	5	5	5	5	5	5	5
	(>30% pop.)	G	10	10	10	10	10	10	10	10	10
Malnutrition status	(<20% pop.)	H	1	1	1	1	1	1	1	1	1
	(20–40% pop.)	I	5	5	5	5	5	5	5	5	5
	(>40% pop.)	J	10	10	10	10	10	10	10	10	10
Uneconomic land holding	(<30% pop.)	K	1	1	1	1	1	1	1	1	1
	(20–50% pop.)	L	5	5	5	5	5	5	5	5	5
	(>50% pop.)	M	10	10	10	10	10	10	10	10	10
Subsistent land holdings	(<30% pop.)	N	1	1	1	1	1	1	1	1	1
	(20–50% pop.)	O	5	5	5	5	5	5	5	5	5
	(>50% pop.)	P	10	10	10	10	10	10	10	10	10
Migration status	(<500 per.)	Q	1	1	1	1	1	1	1	1	1
	(500–100 per.)	R	5	5	5	5	5	5	5	5	5
	(>1000 per.)	S	10	10	10	10	10	10	10	10	10
Livestock pressure	Favourable limits	T	1	1	1	1	1	1	1	1	1
	Crossing limits	U	5	5	5	5	5	5	5	5	5
	Overpopulated	V	10	10	10	10	10	10	10	10	10
Population pressure	Low	W	1	1	1	1	1	1	1	1	1
	Medium	X	5	5	5	5	5	5	5	5	5
	High	Y	10	10	10	10	10	10	10	10	10

Source: Kansakar et al. 1989. (Ilaka means an area of politico-administrative unit)

the whole district. In rainfed areas, upland rice is grown with maize as an intercrop. Finger millet (*Eleusine coracana*) is another favourite relay crop with maize. In the high mountain areas, scattered throughout Zones III, IV, and V, buckwheat, potatoes, and barley are grown as summer crops to a limited extent. Wheat dominates as a winter crop in almost all areas.

Constraints Created by Mountain Specificities

Considerable areas of each agro-ecological zone and *Ilaka* (the politico-administrative units) were influenced by marginality according to the map. The marginality scenario developed for Sindhupalchok (Table 15.6) showed that most areas of Sindhupalchok supporting agriculture have various degrees of marginality. Agricultural areas are increasingly becoming marginal. Forest and grassland resources have been substantially degraded. Similarly, the fragility scenario (Map 2) projected three classes of fragile zones, covering

Table 15.4. Maps prepared in the case study

1.	Temperature zones
2.	Rainfall zones
3.	Land cover
4.	Crop zones
5.	Agroclimatic zones
6.	Edaphic factors
7.	Geological diversity
8.	Mountain orientations
9.	State of forest resources
10.	State of grassland resources
11.	Physical marginality
12.	Moisture zones
13.	Marginality scenario
14.	Physical fragility
15.	Fragility scenario
16.	Areas with erosion potential
17.	Biologically fragile zones
18.	Agricultural land types, terracing, etc.
19.	Irrigation potential
20.	Conservation needs scenario
21.	Unsustainability status
22.	Human population pressure
23.	Abandoned agricultural land
24.	Forestry farming linkage-I
25.	Forestry farming linkage-II

a fair proportion of area (Table 15.6).

A conservation management scenario was created for Sindhupalchok by using the same factors that created fragility and marginality. The intention was to identify the areas and extent of conservation needs (Table 15.6). The scenario showed that at present a large area of Sindhupalchok requires natural resource conservation measures, e.g., agricultural land needing topsoil, and degraded forests and grazing lands need ecological restoration. Hildreth (1986) confirmed such a state of affairs in the Nepal hills by recording that forest resources have been heavily degraded in the Nepal Himalaya. Near the agricultural areas, the productivity of forests and grasslands has declined to the lowest limits. This is because a large proportion of forest land is needed to support agricultural land.

An exercise was conducted to assess the potentials of water resources and the elevation 'niche' for medium-scale irrigation facilities in all areas of Sindhupalchok. Several rainfed agricultural areas were identified for irrigation. Their river water sources were within reasonable range of the distribution points.

Evaluating Zonal Agricultural Development Priorities

The state of unsustainability in nine politico-administrative areas of Sindhupalchok was evaluated using selected socioeconomic indicators (Table 15.3, Map 3).

Indicators of unsustainability showed that, although there is a total hunger gap of

Table 15.5. Agroclimatic zones of Sindhupalchok produced by using automated GIS

Agroclimatic zones at stage I		Land cover area				
		Total area	Agriculture	Forests	Grazing land pastures	Land not available
I.	Cold sub-tropical high Himal zone temp. < 3° rain variable	24,462	73	36	1500	22,847
II.	Cool sub-tropical high mountain zone temp. 3–10°C; rain variable	5,361	+	9,752	28,075	16,030
III.	Moderately cool semi-arid mountains temp.10–20°C; rain 1000–2000 mm	27,818	9,858	1,833	15,867	259
IV.	Moderately cool sub-humid mountains temp.10–20°C; rain 2000–3000 mm	109,574	41,024	6,129	62,310	111
V.	Moderately warm humid, middle mountaiins temp. 10–20°C; rain >3000 mm	18,326	5,168	800	12,298	40
VI.	Sub-tropical warm valley areas temp. >20°C; rain variable (<1000–>3000 mm)	15,517	7,447	13	7,789	268

Table 15.6. Percentage area of Sindhupalchok under three classes of marginality, fragility, and conservation scenarios, using GIS

Classes	Score value out of 160	% area under each category		
		Marginality	Fragility	Conservation
1.	Low, <50	34.13	19.54	53.77
2.	Medium, 50–100	61.73	63.73	30.81
3.	High, >100	4.13	16.47	15.51

Note: Map exhibits numbers of polygons falling under each class and scattered geographically

around three months in all areas, the situation is even more serious at a closer look (Fig. 15.8). A certain percentage of the population (14–19%) in all areas is already under severe strain (> nine months) vis-à-vis food availability. Similarly, population percentages ranging from 14 to 25 per cent have a hunger gap of three to six and six to nine months (Fig. 15.8). This also brings to light prevailing inequality among farm families.

Investigations also highlighted that 30 to 40 per cent of the population of all areas of Sindhupalchok are undernourished and live well below the poverty line (Fig. 15.9).

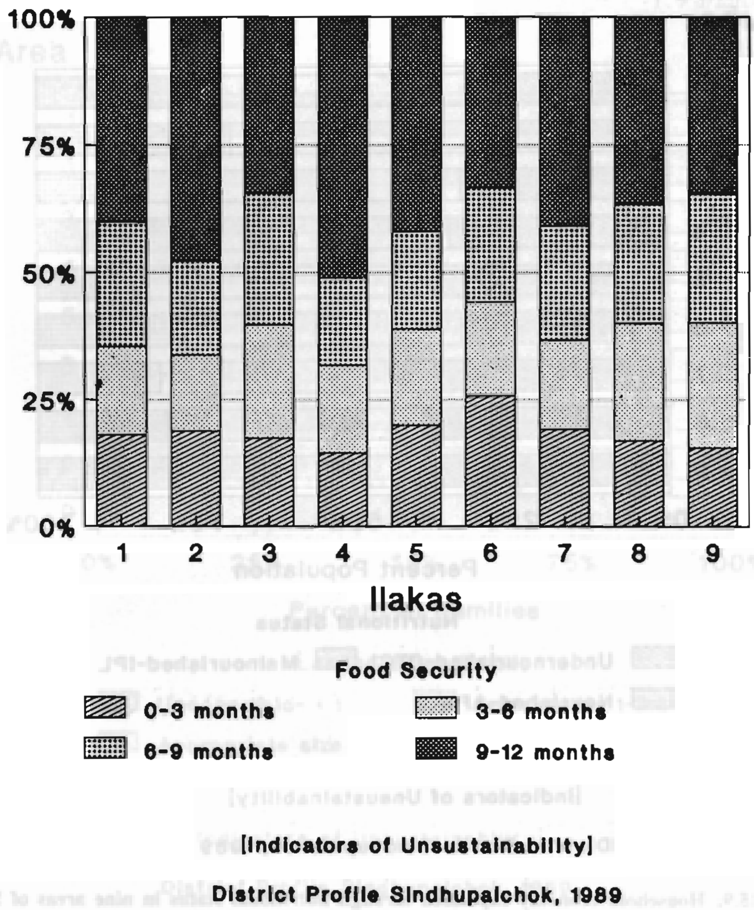


Figure 15.8: Hunger gap status in the nine Ilakas of Sindhupalchok

An equal percentage managed to provide food but remained malnourished because of economic constraints. Only a limited percentage seemed to receive reasonable nutritive food. The hunger gap and nutritional deficiency have their reasons, and these lie in uneconomic land holdings, size of families, and poor land resource quality. Figure 15.10 shows that more than 80 per cent of families are holding lands which are uneconomic, and this has both economic and environmental consequences of a harmful nature.

An assessment of the human and animal pressure on agriculture, forests, and grazing land was also made (Fig. 15.11). In most cases, animal and human populations are equal and density is very high. While assessing the impacts of density, it has to be borne in mind that the area under consideration has a high scale of marginality. Therefore, the overall carrying capacity of this area is much lower.

Forestry-Farming Linkages

A scenario was developed for the unsustainability of agricultural land as a consequence of the weakening forestry-farming linkage in Sindhupalchok (Map 4). Hildreth (1986)

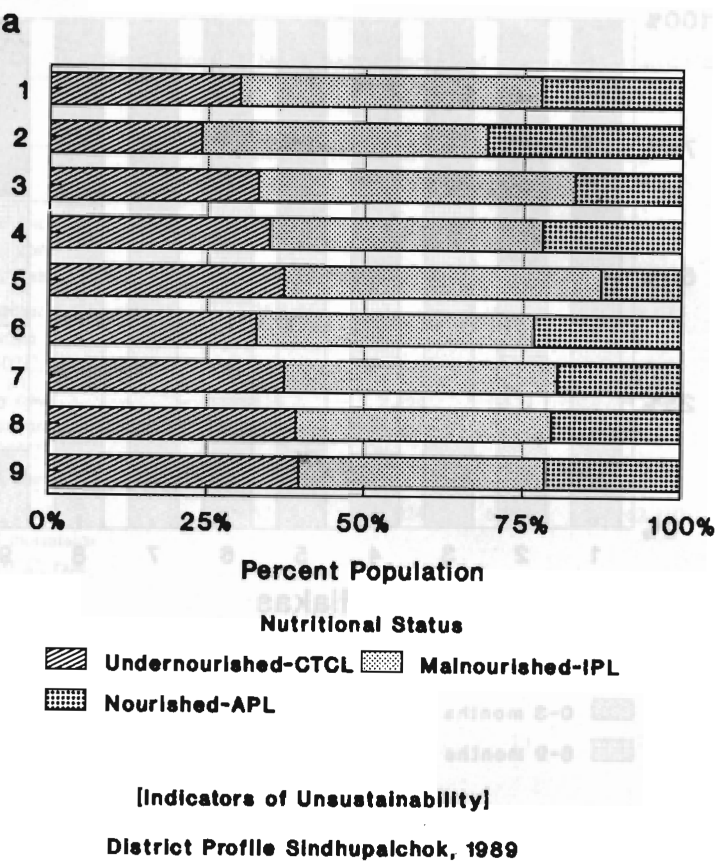


Figure 15.9: Household economy expressed through nutritional status in nine areas of Sindhupalchok

had observed that around 5 ha of forest, in the present degraded state, are required for each hectare of agricultural land in the middle mountains. This was taken as the basis for mapping sustainable agricultural land in the first case, scenario. In the second scenario, 1:5 and 1:15 ha were taken as a general future scenario for forestry-farming linkages for the middle and high mountains. In the first scenario Zones I and II were excluded but in the second scenario they were included. Very few agricultural areas seem to receive enough inputs from forestry, and the rest of the area is experiencing declining fertility because of weakening forestry-farming linkages.

Zonal Agricultural Development Imperatives

An overview of the results projects the following scenario of agricultural development imperatives. The land is unable to provide a decent quality of life to the existing population at present levels of technological application and institutional intervention. Existing farming systems are under strain because of lack of energy subsidies (input) and the traditional sources of energy are weakening. Available indicators show that, even at subsistence level, the land cannot sustain the existing population unless steps are taken to

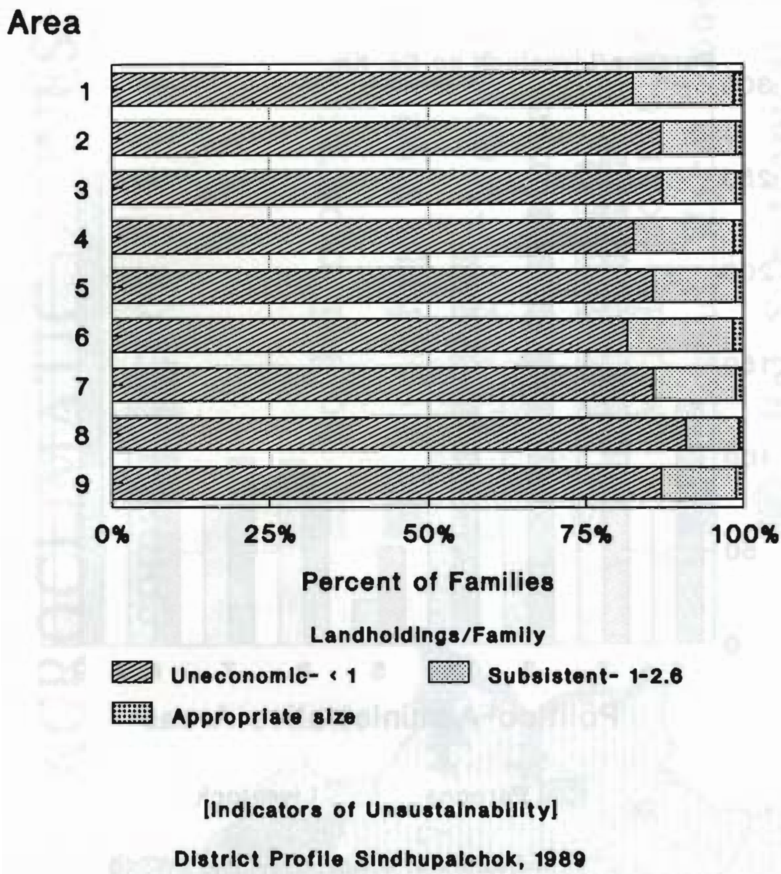


Figure 15.10: Uneconomic agriculture status expressed through landholding size in nine areas of Sindhupalchok

improve the fertility of agricultural land.

Evidence of the dependence of agriculture on forestry call for ecological restoration measures, mechanisms that will help reduce the present unsustainable agricultural conditions.

There is an overriding problem of hunger in each zone, apart from the lack of balanced diet. Use of land resources to increase food production is limited by both the marginality of agricultural land and the weakening support from forest and grazing lands. While zonal agricultural development priorities call for a focus on food security, followed by income generation, the mountain specificities impose limits on the expansion of agriculture and its maintenance. Physical diversity offers scope for the diversification of farming among the zones to incorporate horticulture and other commercial initiatives, but socioeconomic factors, i.e., small land holdings and inaccessibility, are a deterrent to these measures. Improving productivity by irrigation and multiple cropping, and partly by removing pressure through off-farm employment, could produce alternatives. Agricultural land in some zones still possesses the potential to increase productivity and carrying capacity levels but only if backed by appropriate inputs for fertility.

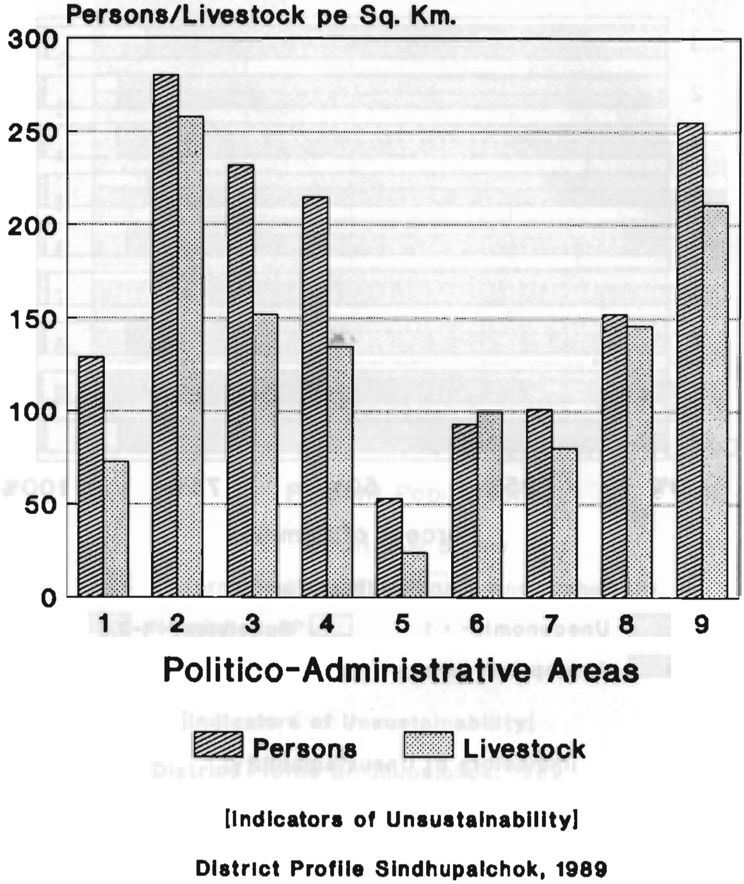
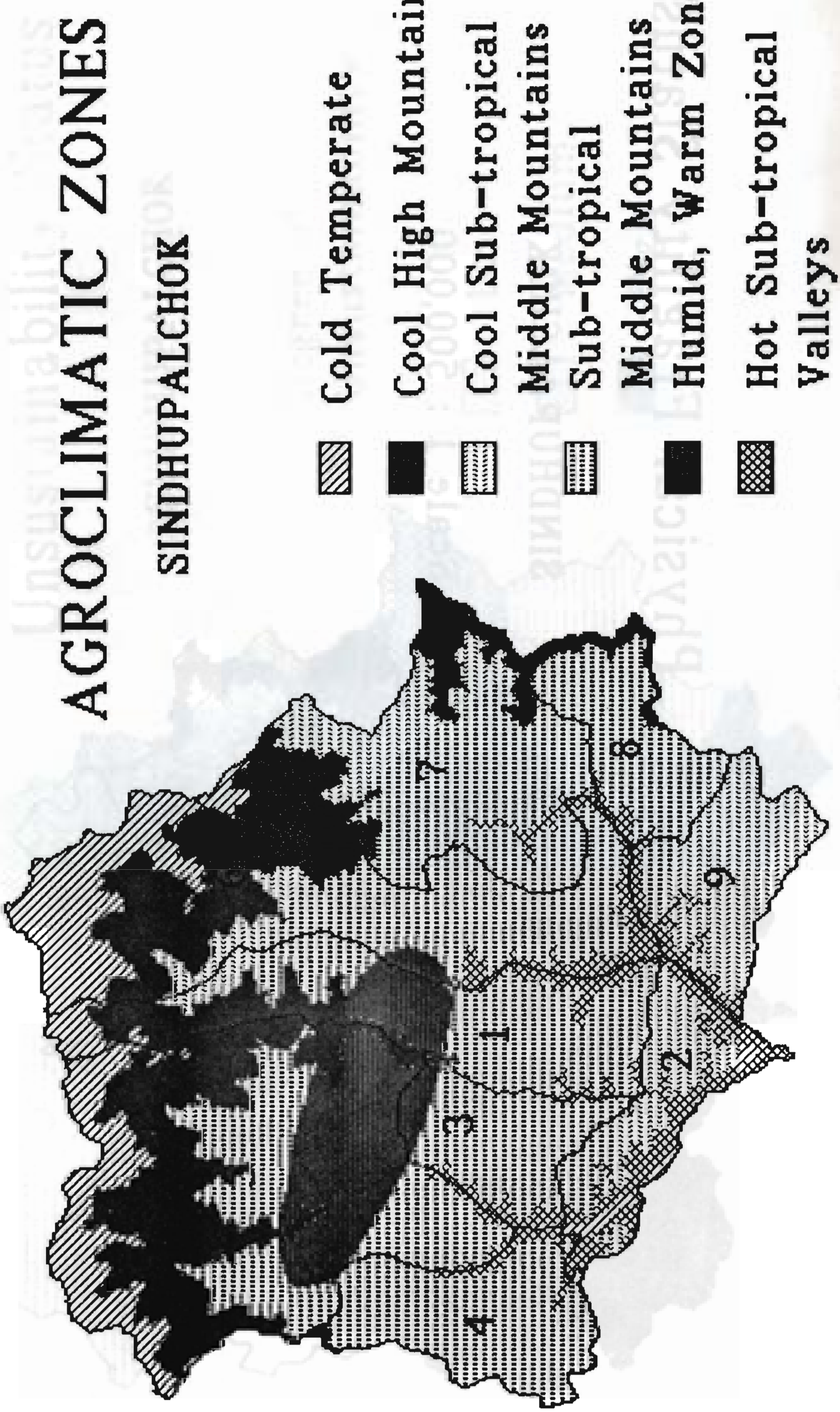


Figure 15.11: Pressure on usable land expressed through both human and animal population density in nine areas of Sindhupalchok

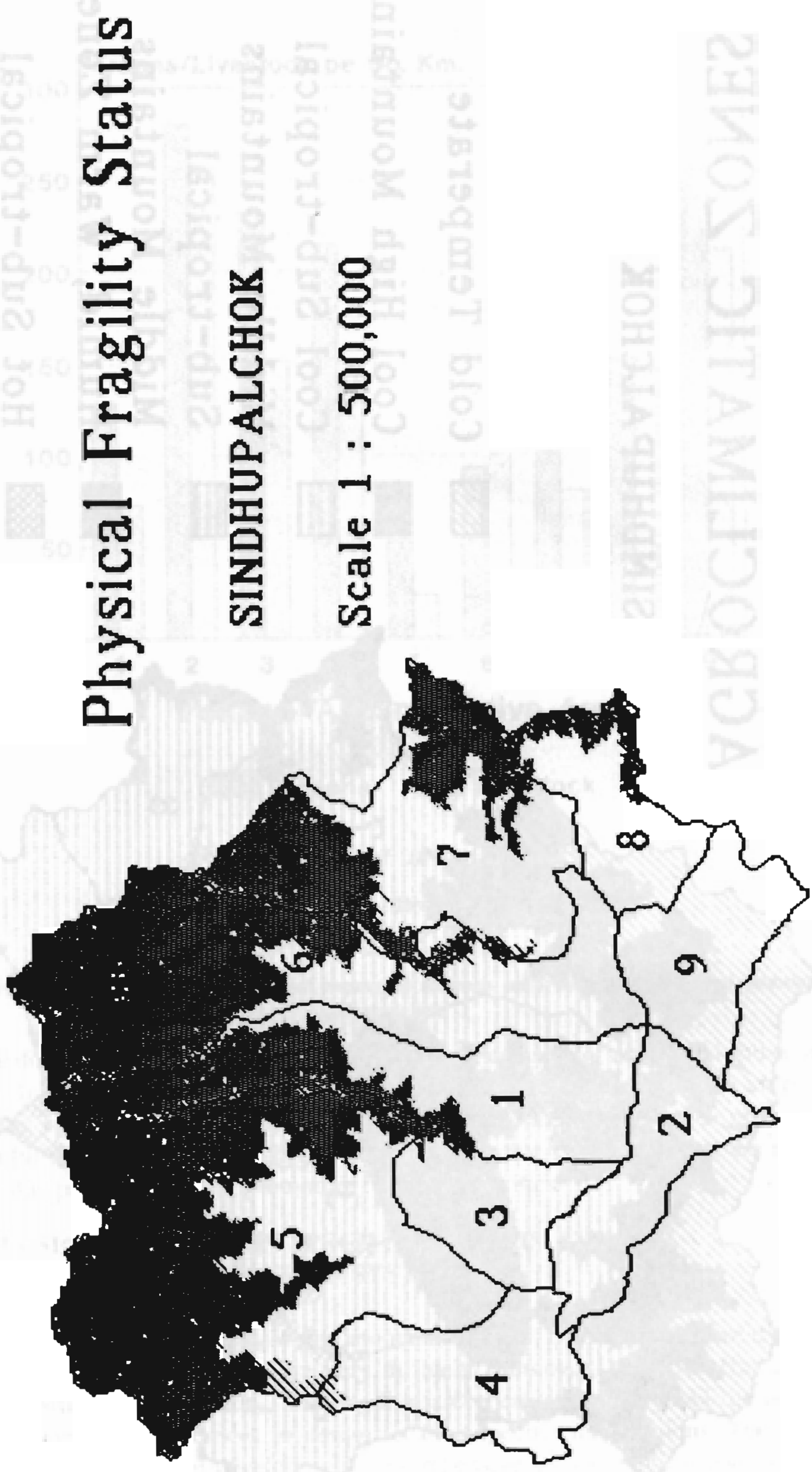
The diversity of zonal crop resources has to be increased for nutritional and economic reasons. In order to base the cash income of farming families outside the crop sector, harnessing agroclimatic and bioresources 'niche' to produce some special products may be a useful alternative. There is heavy pressure on arable land and efforts are needed to remove this pressure through promoting off-farm activities.

CONCLUSIONS: MOUNTAIN SPECIFICITIES, GIS AND THE AGRO-ECOLOGICAL ZONATION SYSTEM

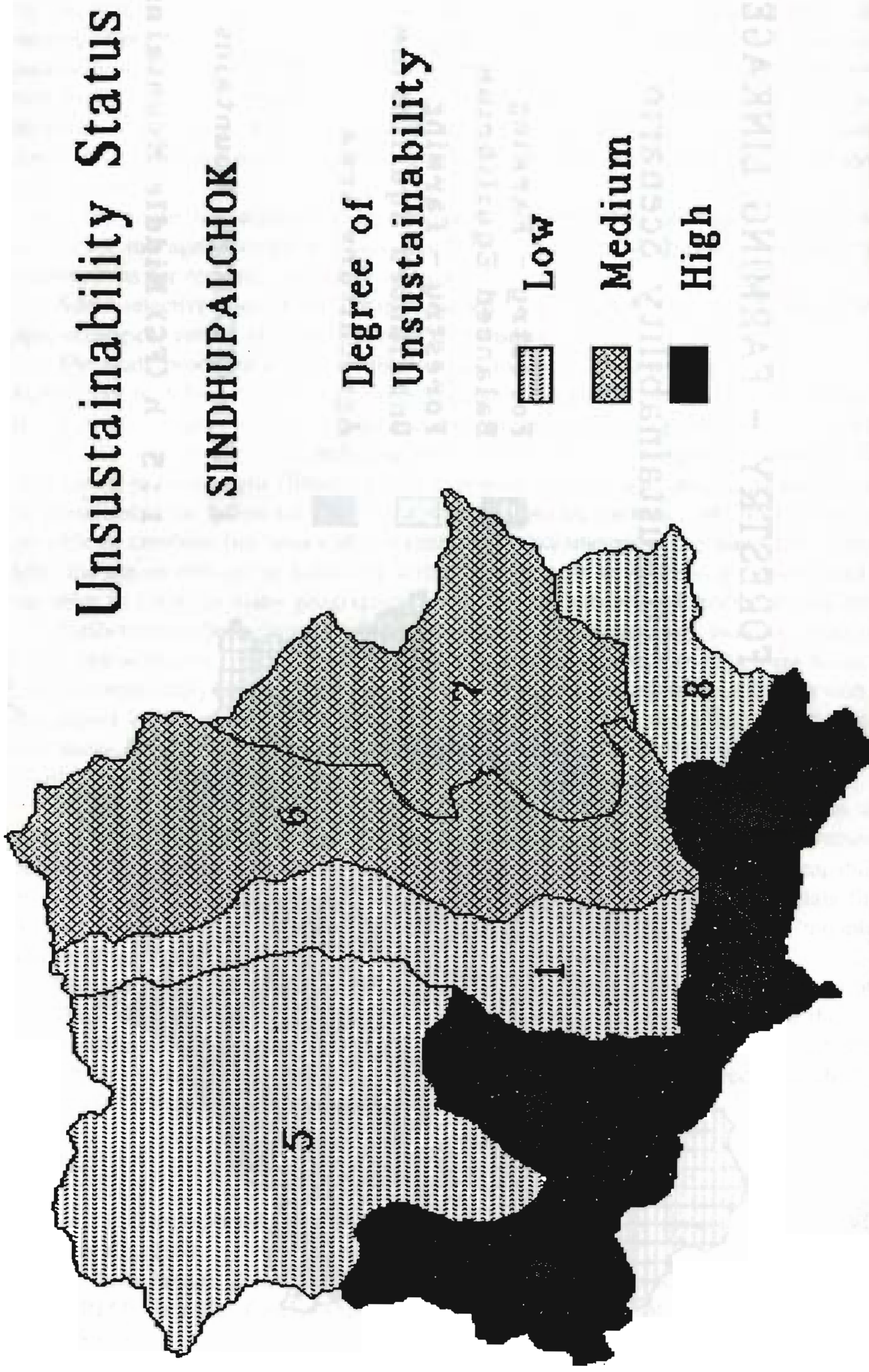
In view of the extreme diversity within mountain regions, the replicability of experiences and generalization of situations are very difficult. Moreover, mountain characteristics, e.g., inaccessibility, marginality, and fragility, and their associated problems restrict the scope for harnessing resources to design location-specific interventions. The argument put forward here involved developing a comprehensive agro-ecological zonation system


AGROCLIMATIC ZONES
SINDHUPALCHOK
Cold Temperate
Cool High Mountain
Cool Sub-tropical
Middle Mountains
Sub-tropical
Middle Mountains
Humid, Warm Zones
Hot Sub-tropical
Valleys
1
2
3
4
7
8
9

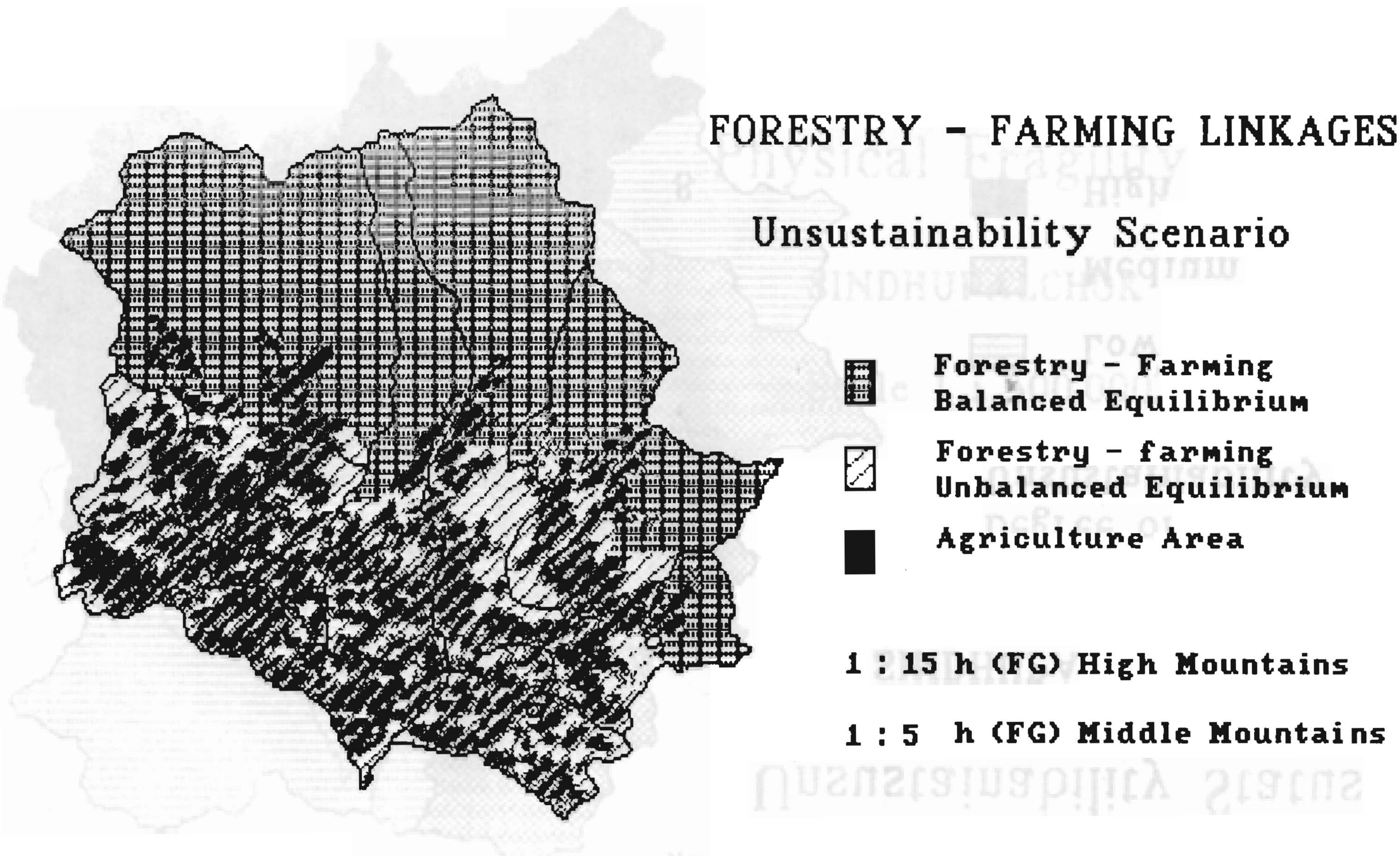
Map: 1


Physical Fragility Status
SINDHUPALCHOK
Scale 1 : 500,000
1
2
3
4
5
6
7
8
9

Map: 2


Unsustainability Status
SINDHUPALCHOK
Degree of Unsustainability
Low
Medium
High
1
5
6
7
8

Map: 3


FORESTRY - FARMING LINKAGES
Unsustainability Scenario
Forestry - Farming
Balanced Equilibrium
Forestry - farming
Unbalanced Equilibrium
Agriculture Area
1 : 15 h (FG) High Mountains
1 : 5 h (FG) Middle Mountains

Map: 4

for the mountain areas that could capture all such features having a bearing on the harnessing of resources. In the mountain perspective-based agro-ecological zonation system, parameters for classifying homogeneous geographic units (the zones) and zonal information profiles can be developed by using several factors that are instrumental in creating mountain specificities. Giving mountain specificities a geographic touch, e.g., within zones, facilitated the projection of development and resource management imperatives for each zone.

Furthermore, it is argued that identifying the socioeconomic indicators of unsustainability for the agro-ecological zones would help in setting priorities for development interventions for regional and zonal agricultural planning.

Some selective uses of the computer-aided GIS in developing the aforementioned agro-ecological zoning system have been demonstrated.

The study produced several thematic maps to show that computerized GIS is an effective tool in delineating any number of mountain micro-climates and agro-ecosystems. It effectively projects the geographic factors representing a mountain specificity. In the study, GIS was applied for combining three parameters, i.e., temperature, rainfall, and land cover, to create agro climatic zones. Likewise, several other zoning parameters can be combined in the following way. Using another software package, ARC/INFO, it is also possible to combine (unionize) all relevant zoning parameters at the same time. Therefore, the option remains of following a step-wise process or combining (unionizing) all variables to create as many geographic entities (recommendation domains) as possible.

Furthermore, the technique offers mechanisms for information building processes concerned with zonal resources. In the case of mountain specificities which are based on several contributory factors, common origins, and shared consequences, GIS can sum up the impact values of all factors for a given area and quantify the effect of a mountain specificity. This is highly significant in the whole process. Exercises on marginality, fragility, and conservation demonstrate the suitability of GIS for this purpose.

The application of GIS in evaluating the potential 'niche' of zones or areas is also another significant point. It can be very useful in locating any scale of hydropower potential in mountain areas on the lines of exploring for irrigation potential. The capability of GIS in building mountain specificities-based spatial limitations and potentials filter showed that both the technique and the concepts are useful for developing mountain agro-ecological zoning and zonal resource management.

The use of socioeconomic data for projecting unsustainability scenarios appears useful. There could, however, be questions on the nature of the data. Most data of this kind are available on an administrative-cum-development area basis. For effective results from GIS, the conventional approaches to collection of socioeconomic data need to be changed to suit the GIS system and zoning method.

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