PART I
AGROCLIMATIC ZONES IN GORKHA DISTRICT

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1. INTRODUCTION

Land use planning is seen as an appropriate way to implement agricultural development programmes in the Himalayan areas of Nepal, although to some extent the diversity of the mountain environment restricts the efficiency of such a technique. Since 1952, many efforts have been undertaken to represent the mountain landscape in three dimensions (Troll 1988:39). During this time, it was found that a zonal planning approach that characterises different agro-ecological systems, should be based on a mountain perspective framework and mountain specificities, and consider the whole ecosystem, including human beings (Partap et al. 1992). Besides biophysical factors, other information should also be considered for characterising agro-ecological systems in mountainous areas, e.g., cropping systems, culture, technology, market options, and information linkages (Lundberg 1992).

Different studies have been undertaken in the past to define agroclimatic or agro-ecological zones for Nepal as a whole or for particular districts[1]. A comprehensive model was developed for classifying agroclimatic homogeneous geographic areas, using several factors that are instrumental in creating mountain specificities (Partap et al. 1990, 1992). A geographic information system (using the IDRISI and Arc/Info™ softwares) was used for that case study; Sindhupalchowk District of Nepal was used as a representative mountain area. Agroclimatic zones of Nepal were mapped on a scale of 1:500,000 using temperature and rainfall data (APROSC 1990). Within the framework of the Master Plan for Horticultural Development, an agro-ecological classification (on a scale of 1:250,000) was developed, describing natural resources of Nepal that are significant to horticultural development, i.e., physiography, soils, climate, vegetation, land use, and people (Carson 1990, 1992). Later, a less complex framework for an ecological classification system was proposed for planning in Nepal, one potentially relevant to different sectors, e.g., agriculture, forestry, and natural resource management (Carson and Sharma 1992). Recently, a project conducted a case study on agro-ecological zonation in the Nuwakot District and used a complex strategy, developed by FAO, for agricultural planning using GIS technology (PCArc/Info™) (Sharma and Antoine 1994).

2. METHODOLOGY

This case study was conducted within the wider framework of establishing a database for Gorkha District. The objective of the study was to analyse 'agroclimatic' conditions in Gorkha District using GIS technology and, more particularly, to delineate zones based on climatic parameters. Other parameters, e.g., soils, slope gradients, land use, and aspect, were considered for the purpose of planning in particular developing areas. This is referred to in Part III (Horticultural Development in the Gorkha District) and Part IV (Correlation of Land Use with Climatic Factors) of this report, both of which deal with other aspects of the zonation approach.

This analysis of the agroclimatic zones was based on different sets of information, namely,

- temperature,
- precipitation,
- evapotranspiration, and
- altitude.

[1] Carson and Sharma (1992:2) used the terms 'agroclimatic' and 'agro-ecological' interchangeably because edaphic influences are not important for many planning purposes.

Map sheets of the Indian Survey (on a scale of 1:63,360) and meteorological data were used as the main sources for the study. Classification systems and equations were taken from secondary data. The contour lines in the district were digitised at 500-foot (about 152m) intervals. A meteorological database was established. In Gorkha District itself there are only four meteorological stations where precipitation data are recorded, i.e., Gorkha *Bazaar* (1,097masl), Arughat *Bazaar* (518masl), Jagat (Setibas) (1,334masl), and Larke Samdo (3,650masl); and only one station, Gorkha *Bazaar*, at the district headquarters, provides temperature data as well. There are two other stations which are near the district boundary, Bandipur (965masl), in Tanahu District; and Gharedunga (1,120masl), in Lamjung, located in the south and west. Apart from Gorkha *Bazaar*, all stations are established on valley floors where precipitation is lower than on the adjacent slopes. Therefore, the overall precipitation in the area may be higher than calculated. Climatic conditions of a specific area can be analysed by referring to the overall situation in the region. This method provides a general overview at the macro-level; however, it is not suitable for the analysis of micro-ecosystems. To fill the data gap in the Gorkha District, the climatic conditions of central Nepal were assessed by processing data from 55 stations in the Central and Western development regions of Nepal[2]. The different stations recorded data for periods of from four to 32 years (HMG Nepal). In 28 meteorological stations, air temperature data were recorded (Annex 2) (Map 3). The results achieved were compared to the data provided by the Land Resource Mapping Project of Nepal (on a scale of 1:50,000), including temperature and moisture regimes.

2.1 Analysis of Temperature Regimes

The model to compute the mean annual air temperature zones of the area used by this study is basically defined through the altitudinal trend of temperature. This means that, in general, for the same altitude the same temperature is calculated. However, meteorological stations, even if they are located at the same altitude, may have different positions - either on a valley floor, on top of a ridge, or on southern/northern slopes - which has a considerable influence on the temperature value. The data available for each station, and used for the analysis, do not include the position of the station, and thus this will influence the result of the model. Other parameters that affect temperature, e.g., latitude and longitude, were not taken into consideration. For the very north-east of the district, data were not available.

The calculation of mean annual temperature zones in the district was based on the linear equation given by Sthapit and Bhattarai (1989):

(1) temperature (°C) = 25.3822 - 0.0054397 x altitude (m).

The mean annual temperature data of 28 meteorological stations where air temperature was recorded were interpolated on to the area using raster GIS modules and a Digital Elevation Model (DEM). First the influence of altitude on the meteorological stations' measurements was removed by calculating 0masl-altitude-equivalent temperatures at each station, according to the equation:

(2) temperature 0 (°C) = temperature (°C) + 0.0054397 x altitude (m).

The 0m-altitude-equivalent temperature data were then interpolated on to the area and the influence of the altitude added to the interpolated temperature using the DEM.

The temperature regimes were reclassified based on LRMP (1986) temperature ranges (Table 2).

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[2] No climatological data are available from the Tibetan Plateau north of Gorkha (compare Domrös and Gongbing 1988).

Table 2: Classification of Temperature Regimes

Temperature regime	Mean annual air temperature (°C)
Arctic	< = 3
Alpine	> 3 < = 10
Cool temperate	> 10 < = 15
Warm temperate	> 15 < = 20
Subtropical	> 20

2.2 Analysis of Moisture Regimes

The classification of rainfall patterns and moisture regimes for the region is subject to severe limitations. There is no clear altitudinal trend of precipitation as there is with air temperature (Alford 1992). Only recently, Hormann (1994) presented the results of a spatial regression model for precipitation distribution in high mountainous areas of the Hindu Kush-Himalayan Region which captures the interdependence between meteorological values and mountain topography; however, the methodology is not yet available. Here, the analysis is based on the relationship between altitude, temperature, and potential evapotranspiration (PET). The higher the altitude, the cooler the temperature and, consequently, the lower the PET. Recorded values of mean monthly precipitation of the 55 meteorological stations and potential evapotranspiration data were used to delineate the moisture regime zones in the area. The moisture regime was based upon the number of wet months, defined as precipitation exceeding potential evapotranspiration.

Carson and Sharma (1992) mentioned that (1) wet months during the vegetation period indicate a surplus of moisture for crop production; (2) during moist months there are slight limitations on available moisture and the moisture is sufficient for the production of crops with low water requirements, but irrigation facilities are still necessary during these months to obtain high yields; and (3) during dry months, crop production is only possible with irrigation.

For each month and meteorological station the potential evapotranspiration was calculated incorporating average monthly rainfall data, the altitude, and an equation given by Lambert and Chitrakar (1989) who adapted the Penman equation for Nepal (Table 3).

Table 3: Parameters for the Calculation of Potential Evapotranspiration (PET) in Nepal; Linear Equation: PET = A - B (Z), for computing PET (in mm/day) from Elevation, Z (in km)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
A	1.60	2.63	4.04	5.27	5.70	5.06	4.35	4.32	3.80	3.30	2.27	1.52
B	0.26	0.37	0.54	0.75	0.90	0.91	0.81	0.78	0.76	0.55	0.44	0.27

Each month was classified as either wet or dry, and the number of wet months was used as the criterion to distinguish between different moisture regimes (Table 4). In a different approach, Carson and Sharma (1992) have used the number of dry months as the differentiating criterion. Their method was also tested for this study and compared with the other approach. To distinguish between wet, moist, and dry months the definition of Carson and Sharma (1992) was applied:

wet: precipitation > PET
moist: 0.5 PET < precipitation < PET
dry: precipitation < 0.5 PET

Table 4: Classification of Moisture Regimes

Moisture regime	Number of wet months per year
Arid	< 2
Semi-arid	2 - 3
Subhumid	4 - 5
Humid	6 - 8
Perhumid	> 8

Source: Lawson 1979, in Müller-Sämann 1986

3. RESULTS

3.1 Temperature Regime

The mean annual air temperature in the region ranges from 5.9°C in Mustang (Lomangthang) District (3,705masl) in the alpine temperature zone to 22.7°C at Chapkot (460masl) and Khaireni Tar (500masl) in the subtropical zone. The station at Gorkha *Bazaar* (1,097masl), with a temperature mean of 20.2°C, is located between the subtropics and the warm temperate zone. The meteorological stations for which air temperature data were available are distributed almost equally throughout the subtropical (11), warm temperate (9), and cool temperate (7) zones. Only one station is located in the alpine zone and none in the arctic zone. Due to the different positions of the stations, isolines of air temperature do not match the contour lines.

The temperature regime in Gorkha covers five major zones, dominated by the subtropics in the south and the arctic zone in the north. The subtropical zone, covering about 22.8 per cent of total area, reaches far north into the Budhigandaki Valley, and also along the Daroundi and Chepe rivers. The warm temperate zone (11.9 %) is mainly located along or above these rivers up to Rana (Bihi VDC) in the Budhigandaki Valley; there are also some patches on top of the middle mountains in the south. The cool temperate zone (12.3 %) follows a similar pattern high above the rivers and reaches up to Lho and Chumchet VDCs in the north. Alpine and arctic zones cover more than 50 per cent of the area in the northern part of the district (Table 5) (Map 4).

Table 5: Area of Temperature Zones in Gorkha District

Temperature zone	Area in sq.km.		Percentage of total	
	MENRIS	LRMP	MENRIS	LRMP
Subtropical	829.7	721.6	22.7	19.8
Warm temperate	432.8	534.8	11.9	14.7
Cool temperate	447.7	529.9	12.3	14.5
Alpine	721.7	968.8	19.8	26.6
Arctic	1,210.7	891.1	33.2	24.4
No data	3.6		0.1	
Total	3,646.6	3,646.2		

The analyses carried out by this study and the LRMP show a similar pattern for temperature regimes in Gorkha. However, both the subtropical and the arctic zones are larger in this current analysis, whereas the alpine, warm temperate, and cool temperate zones are smaller (Map 5). The LRMP delineated the mean annual temperature lines along the altitude contours, e.g., setting the upper limit of the subtropical zone at 1,000m or the lower boundary of the arctic zone at 4,500m. Furthermore, the project mentioned that the values could vary about 300m. This study, however, assigned the calculated 20°C mean annual temperature isoline to the upper limit of the subtropics, with the result that the zone, to some extent, lies above 1,000m. A similar explanation is given for the arctic zone; however, there it was assumed that a larger area is found below 3°C mean annual temperature.

3.2 Moisture Regime

There is limited precipitation from November to February throughout the region. About 80 per cent of the annual precipitation occurs during the months from June to September. In the study area, precipitation varies from 1,800mm in the south to 1,100mm in the north. The heavy pre-monsoon rainfalls in spring have the highest deterioration effect in the area since, at that time, the soils are still bare, or crops are too meagre to protect soil from erosion.

The analysed precipitation data of the meteorological stations covered range from a low of approximately 180mm at the station in Mustang (Lomangthang), north of the Great Himalayan Range at an altitude of 3,705masl, to about 5,200mm at the Lumle station, south of the range at 1,642masl This decrease in precipitation is caused by (1) lee effects north of the Dhaulagiri and Annapurna Himalayan ranges; (2) special effects in the upper Kali Gandaki Valley (Thak Khola), producing increased precipitation at higher altitudes but dryness in the valley bottom; and (3) the 'nozzle effect' in which the valley enlarges in the upper part and consequently affects the air current from the south so that it becomes divergent north of the narrowest part and produces additional dryness (Hormann 1994: 7). For the area of the upper Marsyangdi Valley, east of the Kali Gandaki Valley, Hormann describes similar effects for items (1) and (2) caused by the Annapurna Himal, although in Manang Bhot (3,420masl) higher mean annual precipitation values were recorded (472mm). As for the Larke Samdo station, at an altitude of 3,650masl, these effects seem to be invalid for the upper Budhigandaki Valley in Gorkha District, east of Manang. There, a mean annual precipitation of 1,121mm was recorded during eight consecutive years from 1978 to 1985. One reason for the higher value might be that, unlike the Dhaulagiri and Annapurna ranges, Manaslu Himal stretches from southeast to northwest and, subsequently, does not cause such a tremendous lee effect in the north.

The analysis of the moisture regimes showed that the stations in Gorkha are either located in a subhumid moisture regime, i.e., Gorkha *Bazaar*, Arughat, and Jagat (Setibas), or in a perhumid moisture regime, i.e., Larke Samdo. The 55 stations used for analysing the distribution of precipitation are mainly located in subhumid (23) and humid (22) moisture regimes. Three stations each were found under arid, semi-arid, and perhumid conditions. Most of the stations used for the analysis, where temperature and precipitation data were available, were located in the subtropics (11) or in either of the warm (9) and cool temperate (7) zones and in either subhumid (14) or humid (11) moisture regimes. Three stations in the upper Thak Khola Valley, i.e., Thakmarpha, Jomsom, and Lomangthang, were classified as arid or semi-arid.

The methods of Carson and Sharma (1992) were also tested. These two used the number of dry months as the differentiating criterion for moisture regimes. Applying the equation of Lambert and Chitrakar (1989) for the calculation of PET results, all arid and semi-arid stations, i.e., Jomsom, Thakmarpha, Ghami (Mustang), and Lomangthang, were classified as subhumid or humid, and the station of Manang Bhot, unexpectedly, as perhumid. This is due to the fact that many more months in stations at higher altitudes, as well as in areas with low precipitation, were classified as moist, given their low potential evapotranspiration.

There are three major moisture regimes in the district, i.e., subhumid, humid, and perhumid. The arctic temperature zone, which was not included in the moisture analysis, was added on. In the extreme north-eastern part of Gorkha, about 74sq.km. were not analysed due to lack of rainfall data. Along with the *arctic temperature zone, the areas of the subhumid and humid zones cover the major part of the district, with 27.3 per cent and 24.8 per cent respectively. The perhumid zone amounts to 12.7 per cent only* (Table 6) (Map 6).

Table 6: Area of Moisture Zones in the Gorkha District

Moisture zone	Area in sq.km.		Percentage of total	
	MENRIS	LRMP	MENRIS	LRMP
Subhumid	995.0	1,134.5	27.3	31.1
Humid	905.7	928.5	24.8	25.5
Perhumid	460.9	692.1	12.7	19.0
Arctic	1,210.7	891.1	33.2	24.4
No data	73.9	-	2.0	-
Total	3,646.2	3,646.2		

The results for the moisture regime of this study differ from LRMP figures (Map 7). The moisture regimes of LRMP were based on mean annual precipitation in combination with mean annual air temperature (LRMP 1986b: 20); and it seems that the project delineated the moisture zone boundaries also according to temperature zones. In this study, potential evaportranspiration, precipitation, and altitude were taken as parameters for the analysis of the moisture regime, and these are included in the equation of Lambert and Chitrakar (1989). Different results occur, in particular in the perhumid zone. This moisture regime was basically found in the north, in contrast to LRMP, and is based on the precipitation and altitude data of Larke Samdo (Samagaun VDC). Only a limited perhumid area was calculated for the south of Manaslu Himal where a high amount of precipitation is expected. The comparably low calculated precipitation values are probably due to the locations of the stations, which are mainly concentrated in valley areas and are not evenly dispersed in the district.

3.3 Agroclimatic Zones

The agroclimatic zones in Gorkha District are characterised by different cropping patterns and different crop productivity levels as well as by different levels of fodder yields from sources other than agricultural land. The district area is split into about nine different zones.[3] The huge subtropical area in the south, below approximately 1,000masl and along the Budhigandaki Valley up to Machha *Khola,* was classified as subhumid. Some subtropical areas along the upper valleys of the Daroundi and Chepe rivers were classified as humid. Further north, there is a similar pattern for the warm temperate zone up to about 2,000masl along and above the two western valleys south of Manaslu Himal, the moisture regime was defined as humid; the deep valley of the Budhigandaki river lies in a subhumid zone. Some patches of the warm temperate/subhumid zone are located on the southeastern hills of the district. The cool temperate zone is mainly characterised by humid conditions, but some areas high above the Budhigandaki River were classified as subhumid. The alpine zone, from about 3,000m to 4,500m, is, in general, perhumid; nevertheless, in the lower part of this zone, the moisture regime was found to be humid (Table 7) (Map 8).

[3] This does not include the alpine area for which no moisture data were available.

The results of this study and LRMP figures differ in many agroclimatic zones. Overall it can be stated that, in contrast to this analysis, LRMP expected the warm temperate zone to be more humid and the cool temperate zone to be, in general, more perhumid. As already mentioned above (see Chapter 3.1), the analysis of this study resulted in larger subtropical and arctic areas than the LRMP figures due to the application of the mean annual temperature rates rather than the altitudinal contour lines applied by LRMP. Accordingly, the areas of warm and cool temperate zones, as well as the alpine zone, were found to be smaller in this study than in LRMP results. Although the total area sizes of the moisture zones do not differ very much, apart from the arctic zone, the distribution of these zones varies considerably (Map 9).

Table 7: Area of Agroclimatic Zones in Gorkha District

Agroclimatic zone	Area in sq.km.		Percentage of total	
	MENRIS	LRMP	MENRIS	LRMP
Subtropical/subhumid	705.4	721.6	19.4	19.8
Subtropical/humid	122.7	-	3.4	-
Warm temperate/subhumid	210.2	17.1	5.8	0.5
Warm temperate/humid	222.5	517.7	6.1	14.2
Cool temperate/subhumid	79.4	78.1	2.2	2.1
Cool temperate/humid	367.5	65.3	10.1	1.8
Cool temperate/perhumid	-	386.5	-	10.6
Alpine/subhumid	-	323.5	-	8.9
Alpine/humid	193.0	339.8	5.3	9.3
Alpine/perhumid	460.9	305.6	12.7	8.4
Alpine/no data	69.0	-	1.9	-
Arctic	1,210.7	891.1	33.2	24.4
No data	4.9	-	0.1	-
Total	3,646.2	3,646.2		

The major differences in this study, with respect to LRMP figures, are (1) the occurrence of an area under a subhumid moisture regime along the Budhigandaki Valley in the warm temperate zone, which is mainly based on data from the meteorological stations at Jagat (Setibas) and Arughat *Bazaar* where precipitation has been recorded for 26 and 28 years respectively; (2) the existence of an extensive humid area in the cool temperate zone, which was classified in a similar distribution area as perhumid by LRMP, (these results are based on data from two stations located in Lamjung District, i.e., Gharedhunga and Kunchha); and (3) the alpine zone in the upper Budhigandaki Valley which was classified as perhumid in this study, in contrast to the LRMP which held this area to be subhumid. As already discussed in Chapter 3.2, the data from the meteorological station at Larke Samdo validate the perhumid moisture regime in that area.

In general, the application of different methodologies to the analysis of moisture regime zones affects the results. The LRMP based the analysis of moisture regimes on mean annual precipitation in combination with mean annual temperature, whereas this study, in addition to precipitation, used potential evapotranspiration. This study also used the number of wet months to distinguish between different moisture regimes, whereas LRMP used the number of dry months in its classification. This means that, in this study, the meteorological station at Gorkha *Bazaar* is located in a subhumid moisture regime, whereas the LRMP classified it as humid.

4. CONCLUSIONS

The application of GIS is an appropriate tool for the assessment of agroclimatic zones in an area planning and development framework at a macro- or district-level. In view of the small map scale (1:50,000) used to establish the database and the extensive variability of the mountain ecosystem, its application is limited at the micro-level. Major constraints to the analysis were data availability and data quality. These aspects need to be improved for better assessment of the climatic conditions in the area. Still, the system developed showed its flexibility and can be updated or extended at any time when further data are available or a methodology is developed for the use of GIS technology to assess the mountain perspective holistically.