Chapter 2: The Spatial Context of the Study

"A land-use decision is also a water decision"

(Malin Falkenmark)[1]

Chapter 2 presents the spatial context of the PARDYP study sites in the HKH region in terms of biophysical and socioeconomic parameters. The five PARDYP catchments and the reasons behind the selection of these catchments are briefly discussed.

The catchment characteristics are described on the basis of morphological, topographical, land-use, and socioeconomic considerations. Finally, the measurement networks and the data management procedures of the selected catchments are introduced. This section should help other projects involved in similar research work to learn from the mistakes and shortcomings of this approach.

The hydrological response of a catchment is primarily based on precipitation and catchment characteristics, including soils, land use/land cover, topography, and others. This relationship is often used to estimate hydrological parameters for ungauged catchments (Mosley 1981; Duester 1994; Weingartner 1999). In Nepal, this approach was used by WECS (1990) to determine methodologies for evaluating hydrologic characteristics, that is, design floods and design low flows of potential hydropower development on a reconnaissance and prefeasibility level. For the purpose of distributed modelling, catchment characteristics likewise play a vital role. In the context of people and resource dynamics as they are studied in the PARDYP project, the change of catchment characteristics on hydrological parameters through human interventions at the micro- to meso-scale is of interest.

In this respect, the catchment characteristics relevant for flooding, degradation, and water availability and changes observed in these characteristics during the study period or on the basis of historical data are discussed after a brief introduction of the larger HKH region. These characteristics were important in designing the measurement network in order to capture the relevance of different characteristics for different processes.

2.1 THE HINDU KUSH-HIMALAYAN (HKH) REGION

The HKH is the highest mountain range in the world and includes the world's highest mountains: Sagarmatha (Mt. Everest), K2, and other peaks of 8000 masl and over. The mountain range, extending about 2400 km from Afghanistan to China in east-west extension, and 250 to 300 km in width, includes parts or all of the mountain areas of Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan (ICIMOD 2002b). This includes, according to Wyss (1993), the mountain ranges in Balochistan, the Karakorum, the Hindu Kush, the Himalayas (defined as the mountain range separating India from Tibet and extending from the Indus Trench below Nanga Parbat to the Yarlungtsangpo-Brahmaputra gorge below Namche Barwa), the Hengduan mountain ranges, and a large part of the Qinghai-Xizang plateau.

2.1.1 Geology and soils

The Himalayas are geologically very young. The main uplift including the evolution of the Indo-Gangetic basin is dated to the late Tertiary/early Quaternary (~1.7-1.5 million) years before the present (Valdiya 1998). The geologic history of the Himalayas, however, began much earlier with the continental collision between the Indian subcontinent and Eurasia 40 to 60 million years ago and the subsequent subduction of the Indian subcontinent (Press and Siever 1986). This led to the

[1] Falkenmark (1999)

overthrusting of slices of the old northern portion of India, stacked one on top of the other through compression, which continues today. Present-day earthquakes are attributed to this continuing drift of the Indian subcontinent at a rate of 56±4 mm/y (Valdiya 1998). This results in rapid uplift movements in different parts of the HKH. Rates documented vary according to region and geological domain. For the central part of Nepal, Jackson and Bilham (1994; cited in Valdyia 1998) report a little less than 8 mm/y for the Great Himalaya (for a definition of this, see below). Rates for the Lesser Himalaya (see below) are in the order of 23 mm/y. Denudation rates vary throughout the HKH depending on climate and geology. An overall average of 1mm was reported for the entire Himalaya in Ives and Messerli (1989) and a maxima of up to 5 mm was estimated for the eastern parts in the Nepal-Sikkim-Darjeeling Himalaya.

Geologically, the HKH can be divided into four domains: the Siwalik, the Lesser Himalaya, the Great Himalaya, and the Tethys domain (Valdiya 1998). The Siwalik or Outer Himalaya forms the southern delineation of the Himalayas and ranges from 250 to 800 masl. North of the Siwalik, separated by the Main Boundary Thrust, rise the ranges of the Lesser Himalaya, up to about 3500 masl, followed by the Great Himalaya, including the highest peaks of more than 8000 masl. The Lesser Himalaya are separated from the Great Himalaya by the Main Central Thrust. To the north, the Himalayas are delimited by the Tethys Domain following the Trans-Himadri Fault. The stratigraphies associated with the different domains are unconsolidated sedimentary rocks in the Siwalik, sedimentary and volcanic rocks covered by metamorphic and granitic rocks in the Lesser Himalaya, high-grade metamorphic rocks and gneissic granites in the Great Himalaya, and sedimentary rocks from the Tethys in the Tethys domain (Valdiya 1998).

In terms of soil resources, cambisols, leptosols, and acrisols dominate the region according to the World Soil Resources Map (FAO 1999). Cambisols frequently occur in mountain areas such as the Himalayan foothills due to the erosion and deposition cycles in these areas. These soils generally have good structured stability, high porosity, good water-holding capacity, and good drainage. They are moderately to highly fertile with an active soil fauna and therefore make good agricultural land. Leptosols, the most extensive soils in the world, are mostly found on the Tibetan plateau and high mountain, cold desert areas. They are a sign of eroding landscape or of climatic constraints that retard soil formation. These soils are very fragile, especially if cleared from their natural vegetation and exploited for agriculture. Acrisoils are mostly found in the eastern part of the HKH. These soils are very easily eroded, which imposes severe limitations on their potential for agriculture.

2.1.2 Topography and drainage

The topography of the Himalayas is unique. Over a distance of only (approximately) 170 km there is a relief from about 80 masl in the Gangetic plains to more than 7000 masl (Figure 2.1)

This suggests unprecedented gravitational forces along very steep slopes and steep river gradients, leading to high erosive potential and fast runoff generation mechanisms. A number of major rivers have their source in the HKH. The best-known rivers include (from west to east) the Indus, the Ganges, the Yarlungtsangpo-Brahmaputra, the Lancang-Mekong, the Yangtze, and the Huang rivers. These rivers are known for their flooding potential and their suspended sediment loads rank amongst the highest in the world (Meybeck and Ragu 1995). The mean discharge of these rivers is given in Table 2.1

There are two types of rivers present in this list. The Indus and the Huang He both have their origin in the Himalayas where most of their flow originates. During the course of flow they cross very dry areas where they have no tributaries. In the case of the Huang He, this is the semi-arid loess plateau, one of the most seriously eroded regions in the world. The Indus passes through the very dry areas of the Punjab and Sindh provinces of Pakistan. As a result, their specific discharge is very low. The other major rivers have specific discharges of between 14 and 22 $l/s*km^2$. This is a higher specific discharge than for European rivers. The Danube, for example, has a specific discharge of 8.8 $l/s*km^2$ (at Vadu-Oii-Hirsova) and the Rhine 14.3 $l/s*km^2$ (at Rees) (GRDC 1998). In general, Alford (1992) identified the altitudinal belt between 1500 and 3500 masl as the region in the Himalayas with the highest specific runoffs.

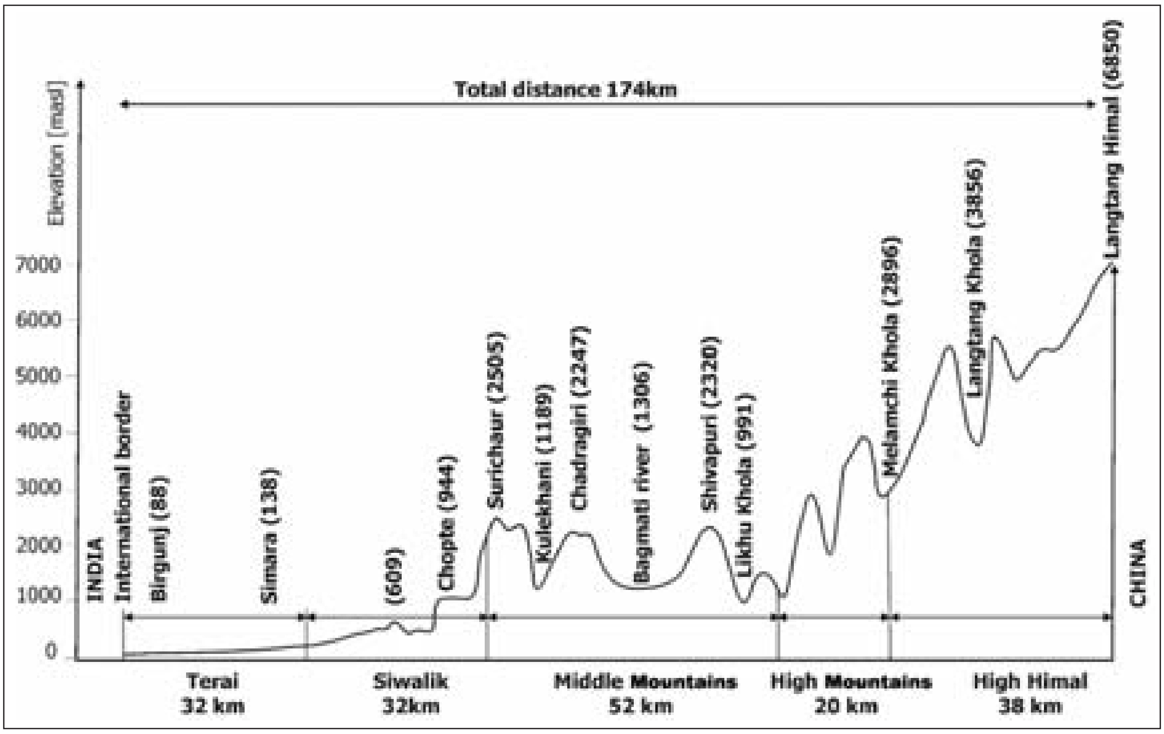

Figure 2.1: **Cross-section of the Himalayas in Central Nepal (from Chalise 1994)**

Table 2.1: **Discharge of the main rivers in the HKH**

(source: Liniger et al. 1998)

River	Basin area km^2	Mean discharge m^3/s	Mean specific discharge $l/s*km^2$
Indus	1,263,000	3850	3.0
Ganges	1,075,000	15,000	14.0
Yarlungtsangpo-Brahmaputra	940,000	20,000	21.3
Lancang-Mekong	795,000	15,900	20.0
Huang He (Yellow River)	445,000	1365	3.1
Yangtze	1,970,000	35,000	17.8
For comparison (data source: GRDC, 1998)			
Danube (Vadu-Oii-Hirsova)	709,100	6217	8.8
Rhine (Rees)	159,680	2280	14.3

2.1.3. Climate

Precipitation in the HKH shows an east-west and north-south variation at the macro-scale. The east-west variation is based on the dominance of different weather systems. Examples are given in Figure 2.2a,b,c,d, and e. In the western part of the HKH, air masses connected to the westerlies bring moisture during winter, leading to a winter peak in rainfall (Figure 2.2a). The eastern part is influenced by the southwest monsoon with a dominant maximum during summer (Figure 2.2c and 2.2e). The maximum rainfall in the area, and globally, is measured in Cherapunjee with an annual maxima of more than 10,000 mm (Figure 2.2d). Wyss (1993) determined the area of the Indian/Pakistani border as the transition zone from one to two peaks. The example for two peaks is shown at the station in Peshawar (Figure 2.2b).

Monsoon rainfall is mainly of an orographic nature, which causes distinct variation of rainfall with elevation, and distinct differences between the southern rim of the HKH and the rain shadow areas

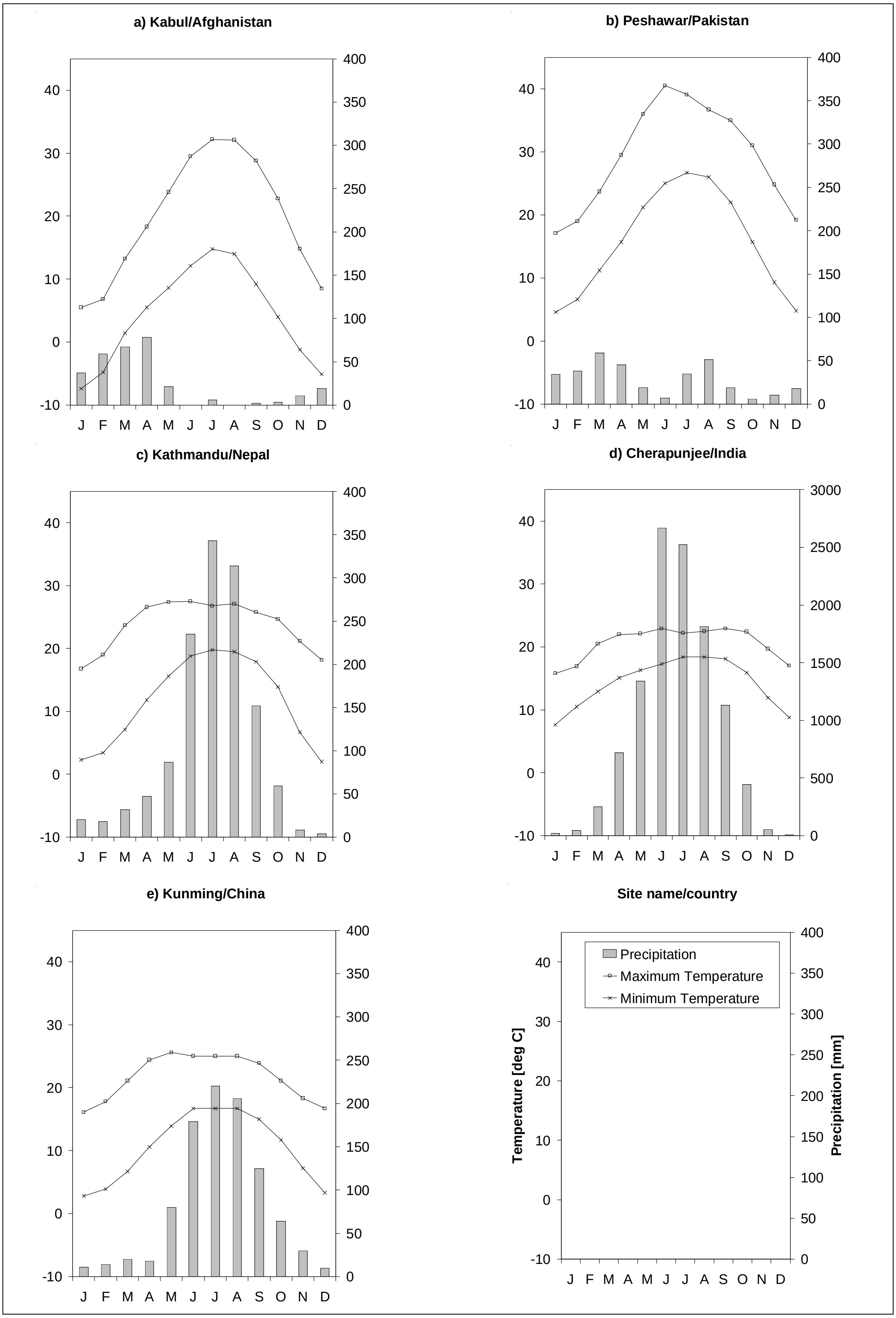

Figure 2.2: **Climatic diagram of five stations in a) the Hindu Kush, b) the Western Himalayas, c) the Central Himalayas, d) the Eastern Himalayas, and e) the Hengduan mountains**
(Data source: FAO 2001b; note: the precipitation axis in Cherapunjee is eight times higher)

of the Qinghai-Xizang plateau behind the main mountain range. Alford (1992) identified the lower and intermediate altitudes as the main source of precipitation, suggesting that there is an altitudinal trend up to about 3500 m after which rainfall again decreases.

At the meso-scale, climatic effects are driven mainly by local topographic characteristics such as ridges, slopes, valleys, and plateaux (Chalise 2001). In this context, the dry inner valleys and the luv-lee effect (i.e. more rain on the windward side than on the sheltered side of a mountain) have to be mentioned. According to Domroes (1978), the valley bottoms of the deep inner valleys in the high mountains get much less rainfall than the adjacent mountain slopes. This would suggest that the currently measured rainfall, which is mainly based on measurements in the valley bottom, is not representative for the area and major underestimates result from the use of these data. This was also shown by Flohn (1970; cited in Domroes 1978) and suspected by Baillie et al. (2002) for the Paro Valley in Bhutan. The luv-lee effect is best shown with the example of the rain gauges in Pokhara and Jomsom in Western Nepal. Pokhara receives about 3500 mm of rainfall annually, while Jomsom, only 60 km north of Pokhara but located behind the Annapurna Massif, gets only 270 mm of rainfall per annum (Domroes 1978).

The temperature regime according to Voeikov (1981; cited in Wyss 1993) varies from the tropical, with average annual temperatures of more than 24°C in the eastern part in Myanmar and Bangladesh, to alpine in the area of the Qinghai-Xizang plateau and the high mountain peaks, with annual average temperatures below 3°C. Most of the areas on the southern rim of the HKH are sub-tropical, with annual average temperatures of 18 to 24°C followed by small bands of warm-temperate and cool-temperature climates.

Potential evapotranspiration (PET) in the region reaches a maximum in the border area between India and Pakistan and shows a general decreasing trend from west to east and from south to north with increasing altitude (Wyss 1993). PET in the foot slopes of the HKH reaches about 1250 mm per year.

2.1.4 Vegetation and land use/cover

The vegetation cover of the HKH was first described in its east-west extension and its altitudinal variation by Schweinfurth (1957). In general, a variation of species along the Himalayan arc can be observed as well as an extreme vertical zonation. From east to west, vegetation becomes sparse with tropical rain forest in Assam, to sub-tropical, thorn-steppe in the Punjab (Gurung 2002). The forests of the humid regions of the eastern Himalayas are composed of broad-leaved species, while the forests of the central Himalayas are made up of oak and coniferous trees. The western part is home to mainly coniferous species (Gurung 2002).

Land use in the HKH varies from east to west and according to elevation. In the west of the Himalayas, in Balochistan, desert prevails, followed by shrubland in the remaining part of Pakistan. The middle mountains of the HKH are mainly under cropland. North of the main cropping areas at higher altitudes there are extensive pasture areas. In the east of the HKH, large forest areas cover significant parts of Yunnan province and the parts of Myanmar falling within the boundaries of the HKH. In northeast India and parts of Myanmar mostly shifting cultivation is being practised.

The prevailing farming systems are rice-wheat; integrating irrigated rice, wheat, vegetables, and livestock on the southern boundary of the HKH and the inner valleys of the middle mountains; followed by highland mixed farming systems incorporating a range of cereals, legumes, tubers, fodder, and livestock (Dixon et al. 2001). Large areas of Afghanistan and Balochistan are pastoral and sparsely farmed. On the upper slopes of the Himalayan ranges above 3000 m farming depends on potatoes and buckwheat, as well as cattle and yak.

In the HKH, over 80% of the population depends either on full- or part-time farming for their livelihood (Thulachan 2001). Most of the farm households in the HKH there are engaged in subsistence farming and produce mostly grain. This grain production has remained stable over the last 10 to 15 years according to Thulachan (2001). However, with an increase in population, the per capita grain availability is decreasing. In addition, the expansion of agricultural land does not seem to have major prospects. A promising development according to Jodha (1997) and Thulachan (2001) is the increments in high- value cash crop production, such as fruit, vegetables, and medicinal plants. However, there is concern about declining yields of these crops in the region.

2.1.5 Population distribution and livestock

Population is believed to be one of the important driving forces for environmental degradation, as shown in Chapter 1. The foothills of the HKH in particular are under heavy population pressure with population densities of 75 to 500 people/km^2 and more than 5000 people/km^2 in the Kathmandu Valley in Nepal and the upper Indus plains in Pakistan. The high mountain areas and the Qinghai-Xizang plateau are very sparsely populated.

The carrying capacity of the land varies with altitude, since all-year-round cultivation as practised in the foothills of the Central Himalayas can support more people than high altitude farming with only one crop per year. The land's carrying capacity further varies from east to west with shifting cultivation, which is mainly practised in the Eastern Himalayas, since land under shifting cultivation has a lower carrying capacity than that under permanent cultivation in the central Himalayas (Lal 1990). In the Western Himalayas, the cropping season lasts only six to eight months, forcing people to migrate or trade for further income. Pudasaini (1997) estimated the carrying capacity for Nepal only on the basis of food production. On the basis of this estimation, the carrying capacity in the hills and mountains has already been reached and the carrying capacity of the entire country is about to be exhausted.

Population growth in the region is still rapid. Maximum population growth rates as estimated by UNFPA (2001) for the period 2000 to 2005 are expected to be as follow: Afghanistan at 3.7, Bhutan following at 2.6, Pakistan at 2.5, Nepal at 2.3, and Bangladesh at 2.1. Other countries in the region have growth rates of 0.7 (China), 1.5 (India), and 1.2 (Myanmar).

It is important to mention that most of the countries in the region belong to the poorest countries in the world. China (Human Development Index rank: 87), India (115), and Myanmar (118) are classified in the medium human development group (UNDP 2001). However, their mountainous regions are believed to be below the national average. The other countries belong to the low human development group: Pakistan (127), Nepal (129), Bhutan (130), and Bangladesh (132). Afghanistan is not listed in the report, but it is believed to be in the group of low human development due to the long period of war.

Poverty is regarded as another main factor in the degradation of natural resources, mainly due to the lack of alternatives, which forces the poor to use natural resources intensively (Papola 2002).

Livestock are an integral part of the farming systems of the HKH. The most common livestock species are cattle, buffaloes, goats, sheep, and yak at higher elevations. The pressure from livestock on land resources is high and is one of the highest in the case of Nepal (Thulachan and Neupane 1999). Generally, there is a decreasing trend in the cattle and sheep population across the HKH and an increasing trend in the buffalo and goat population, which shows the shift in the economic importance of the respective species for farm households in the HKH (Thulachan 2001). Buffaloes are important for milk production, which has increased in importance across the region. In the case of the Jhikhu Khola catchment in Nepal, the same trend has been observed along with a shift from free grazing to stall-fed animals during the wet season (Brown 2000a).

2.1.6 Synthesis of the above information for study site selection

A number of regionalisation approaches discussed in Ives and Messerli (1989) have been suggested for the HKH on the basis of the above information. More recent regionalisation approaches include the Global Agro-ecological Zones' methodology by FAO and IIASA (FAO/IIASA 2002) at the global scale and the on-going project on Methodologies for Assessing Sustainable Agricultural Systems in the HKH region by ICIMOD (ICIMOD 2002c) at the regional scale of the HKH.

For the purpose of this study, with the aim of understanding the human impact on natural resources in general and on land degradation in particular (PARDYP Phase 1 aim), the geological domains as suggested by Valdyia (1998) were central. The physiographic regions of Nepal as defined by Carson et al. (1986) provided a first step to relate the geologic domains to other parameters and then to scale up to the region. They are primarily based on geological delineation and include physiography, geomorphology, and soils information. The regions are (Carson et al. 1986 including comments on land use and elevation from Zonneveld et al. 1986: in brackets the classification according to Valdiya 1998) as follow.

- **Terai [not included] elevation 60-330 masl**
  The Terai includes the recent and post-Pleistocene alluvial plains adjacent to the mountainous areas and is not part of the HKH. Soils in this region are predominantly loamy textured, slightly acid, and stone free. A high percentage of the Terai is cultivated land and the remaining is made up of mainly large stands of sal (*Shorea robusta*) forests.

- **Siwaliks [Siwalik] elevation 200 -1500 masl**
  The geology of the Siwaliks is weakly consolidated and consists mainly of Tertiary and Quaternary mudstones, siltstones, sandstones, and conglomerates. In addition to the weak geology, the steep slopes tend to be responsible for severe surface erosion despite good forest cover. The extent of agricultural land is very limited. Textures of soils are directly related to the underlying bedrock geology with medium textured soils on siltstones and coarse textured soils with boulders on conglomerates.

- **Middle Mountains [Lesser Himalaya] elevation 800 - 2400 masl**
  The geology of the Middle Mountains consists of phyllites, schists, and quartzites of probably Cambrian to Precambrian age and granites and limestones of different ages. The phyllites are often deeply weathered, whereas the schists are more competent and therefore resist weathering. Soils on these rocks are well developed and moderately fine textured in the case of phyllites, and coarse textured for underlying schists. Soils on quartzites are shallow, strongly acidic, and coarse textured. Areas of quartzites are often associated with pine forest. In general, the Middle Mountains are intensively cultivated.

- **High Mountains [Great Himalaya] elevation 2200 - 4000 masl**
  Generally, the geology of the High Mountains is high grade metamorphic. Soils tend to be shallow due to the increased competence of rocks and a less suitable climate for weathering. They also tend to be stony. Agricultural land is limited and supports only about one crop per year. Forests in this region are usually made up of different coniferous species.

- **High Himal [Great Himalaya] elevation >4000 masl**
  Physical weathering is the predominant process in this region, which consists of gneisses, schists, limestones, and shales of different ages. The only land use in this region is grazing.

The Thetys domain was not included in the Land Resource Mapping Project (LRMP) classification due to the negligible area of this zone within the boundary of Nepal and low significance for agricultural production.

For the assessment of human impact, population distribution and population density in particular were very important. High population pressure mainly exists in the foothills of the HKH region. This includes the middle and high mountains of Nepal (Zonneveld et al. 1986) on the southern rim of the HKH region and on the eastern rim adjacent to the Hengduan mountains. The remaining areas are sparsely populated.

2.2 THE FIVE PARDYP CATCHMENTS

On the basis of the simple classification approach as explained above, five catchments were selected in the middle and high mountains of the HKH to carry out PARDYP activities. All catchments meet scientific criteria that stress the similarity of the catchments, as follows:

- elevation ranges between 700 and 3000 masl;
- the predominant land use is agriculture, both irrigated as well as rainfed;
- mixed highland cropping system with rice and maize-wheat based cropping systems on irrigated, rainfed land respectively;
- population density is more than 75 people/km^2, therefore a lot of pressure is placed on natural resources;
- catchment size is of 10 to 100 km^2, which corresponds to the lower meso-scale according to the hydrological scales presented in Becker (1986; cited in Nemec 1993); and
- each catchment should be representative of a larger area with local factors being represented in sub-catchments of the size 0.1 to 5 km^2; and these sub-catchments should be as homogenous as possible.

On the basis of the elevation criteria (between 700 and 3000 masl) and precipitation criteria of 800 to 2500 mm precipitation per annum, Tashi and Rotmans (2003) report that 11% of the entire HKH region fits into the scientific criteria listed above.

In order to account for the differences within the east-west extension, mainly due to climatic parameters, the catchments were spread along the Himalayan arc from Pakistan to China. To study the altitudinal variation within the foothills, a catchment each from a lower and higher elevation were chosen in Nepal.

In addition to the scientific criteria, each catchment had to satisfy practical demands, including easy access by road, well-delineated catchments, a clear outlet with the possibility for constructing a hydrological station, the interest of local collaborating institutions, and others.

This selection process resulted in the selection of five PARDYP catchments, from west to east (see Figure 2.3):
- the Hilkot-Sharkul catchment, Manshera district, North Western Frontier Province, Pakistan
- the Bhetagad-Garur Ganga catchment, Bageshwor district, Uttaranchhal, India
- the Jhikhu Khola catchment, Kavrepalanchok district, Nepal
- the Yarsha Khola catchment, Dolakha district, Nepal
- the Xizhuang catchment, Baoshan prefecture, Yunnan Province, China

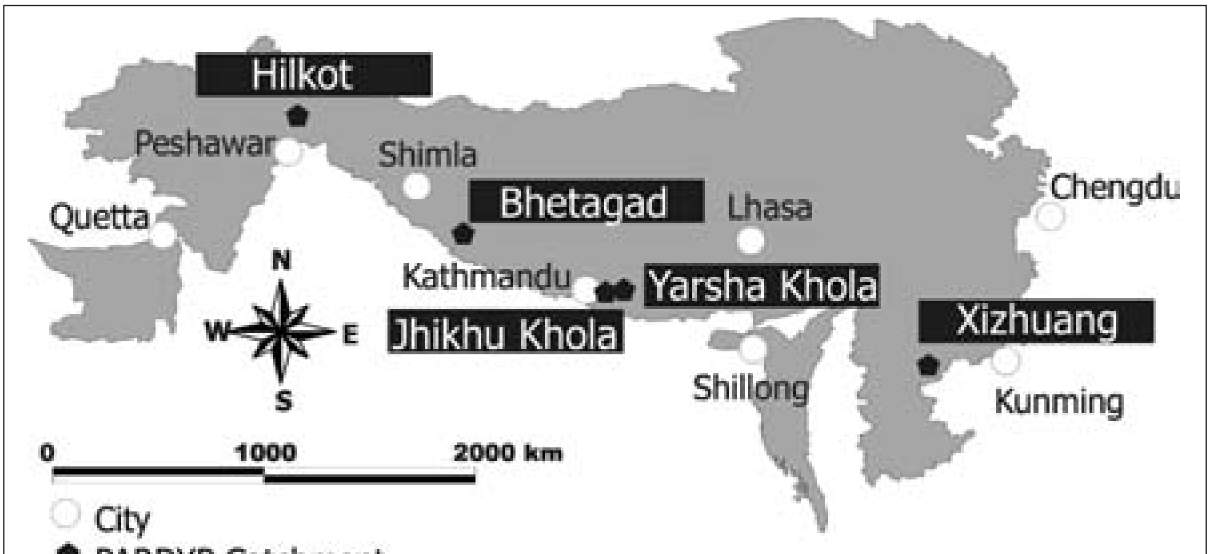

Figure 2.3: The five PARDYP catchments in the middle mountains of the HKH

The catchments are between 34 and 110 km^2 in area and elevation ranges from 800 to 3075 masl. Population density ranges from about 100 to 440 people/km^2. All catchments represent different river basins with the catchment in Pakistan finally draining into the Indus river basin, and the catchment in India and the two in Nepal contributing to the Ganges river basin. The Chinese catchment drains into the Lancang-Mekong river basin.

This study only incorporates full data and information from the catchments in Nepal. The time series available in the case of the Pakistan catchment are too short for meaningful analysis (1999-2000) and appropriate datasets from the Indian catchment up to date are not available. The data from the Chinese catchment were only made partly available. To assess the applicability of the proposed indexes, all catchments are included. While the catchments in Nepal are discussed in detail, the other catchments are assessed only in brief. In the following section, a short description of the catchments in Nepal with the main characteristics are presented in Table 2.2.

Table 2.2: **Brief overview of the PARDYP study sites in Nepal (PARDYP 1999)**

	Jhikhu Khola	Yarsha Khola
Area [ha]	11,141	5,338
Elevation range [masl]	790 - 2200	980 – 3,040
Population (year)	48,728 (1996)	20,620 (1996)
Population density [people/km^2]	437	386
Family size	6	5
Main staple crops	rice, maize, wheat, potato	rice, maize, millet, wheat
Main cash crops	potato, rice, tomato, vegetables	seed potato, garlic, fruit

2.2.1 Jhikhu Khola catchment, Nepal

The Jhikhu Khola catchment is situated approximately 45 km east of Kathmandu on the Arniko Highway. It covers 111.4km^2 with elevation ranging from 800 to 2200 masl. The catchment has a main valley with a large flat valley bottom of alluvial origin, where the major land use is irrigated agriculture. Short and steep slopes confine it on the southern and northern sides. Land use in these areas is mainly rainfed agriculture and forest. There are many pocket-like valleys on the flanks, which make the catchment very heterogeneous. The general aspect of the catchment is southeast, with the main valley extending from southeast to northwest. The Jhikhu Khola catchment is densely populated with 437 people/km^2 in 1996. Most of the agricultural production from the Jhikhu Khola, apart from the staple food, is sold to Kathmandu. This includes potatoes, tomatoes, and, increasingly, different types of vegetables. Agricultural production is very intense with substantial fertiliser and pesticide inputs.

2.2.2 Yarsha Khola catchment, Nepal

The Yarsha Khola catchment, at 53.4km^2, is located approximately 190 km east of Kathmandu on the Lamosangu-Jiri Road in Dolakha district. The elevation of the catchment ranges from 990 to 3030 masl. The general aspect of the catchment is southwest and the main valley extends from southwest to northeast. It consists of a south- and a north-facing slope with a small middle ridge between. An extensive flat valley bottom of alluvial origin is missing, and irrigated areas are limited, especially in comparison with the Jhikhu Khola catchment. Land use is dominated by rainfed agriculture and forest. The catchment is densely populated with 386 people/km^2 in 1996.

Good markets for seed potatoes and garlic, the two main cash crops in the area, are limited in the Yarsha Khola catchment.

2.2.3 Summary

In general, a strong altitudinal variation for most parameters can be observed. This leads to zones roughly parallel to the Himalayan arc, such as the physiographic zones discussed above in terms of geology, geomorphology, climate, vegetation, and land use. In addition, climate shows an east-west variation in terms of rainfall and humidity, influencing land use and vegetation. With the selection of one zone, the most populated zone in the HKH, the altitudinal variation is kept to a minimum. The east-west variation is studied with the spread of catchments from Pakistan in the west to China in the east.

The spatial context of the PARDYP catchments in the HKH shows that the region has

- high natural potential for erosion due to
  - present uplift rates of 2 to 7mm/y
  - unconsolidated geology
  - steep slopes and steep river gradients

- high potential of erosive forces due to
  - short and intense rainfall periods
  - high intensity rainfall events

- a high degree of human impact and pressure on natural resources due to
  - population pressure
  - poverty
  - land-use change
  - subsistence agriculture

- highly seasonal behaviour of water resources
  - long and extended dry season
  - short and intense rainy (monsoon) season

The PARDYP catchments are located in a vulnerable, resource poor, and mainly subsistence agriculture-based region. They generally range from 800 to 4000 masl, have a catchment area of 10 to 100 km^2, are predominantly cultivated, and have intense population pressure. In all catchments, the mixed highland cropping system is practised with rice on the irrigated land and maize on the rainfed land as the main monsoon season staple crops. Wheat is the main staple crop during the dry season.

2.3 PRESENT CATCHMENT CHARACTERISTICS

The comparison of catchment characteristics will establish a first fingerprint of the catchments under investigation in terms of hydrologically important characteristics and may explain similarities and/or differences in their hydrological behaviour at a later stage. Falkenmark (1999) stresses the importance of understanding the interactions between land and water, the land-water linkages. This is not only to understand the impact of human interventions, but also to avoid negative impacts such as floods, erosion, and environmental pollution.

This comparison is divided into morphometric, land use, other biophysical, population and socioeconomic characteristics. The potential impact on hydrological parameters is discussed at the end of the section. A general introduction to the catchments is given in the preceding section.

2.3.1 Data origin and quality

The variables discussed below were calculated on the basis of the GIS and map database from PARDYP. This includes the following maps:

- 1:20,000 topographical base map of the Jhikhu Khola catchment with 50 m contour interval (Integrated Survey Section 1989) (digital)
- 1:25,000 topographical base map of the Yarsha Khola catchment (compilation of four 1:25,000 maps of HMG (1996a-d) (digital)
- 1:20,000 land use map of the Jhikhu Khola catchment, 1996 (digital)
- 1:25,000 land use map of the Yarsha Khola catchment, 1996 (digital) (Shrestha 2000a)
- 1:20,000 geological map of the Jhikhu Khola catchment, 1996 (digital) (Nakarmi 2000a)
- 1:25,000 geological map of the Yarsha Khola catchment, 1998 (digital) (Nakarmi 2000a)
- 1:20,000 land systems map of the Jhikhu Khola catchment, 1990 (digital) (Maharjan 1991)
- 1:20,000 sediment source map of the Jhikhu Khola catchment, 2002 (digital) (MRE 2002)

All maps that are available in digital format can be found on the CD-ROM in Appendix B.7 as *.jpg files. The comparability of the maps and spatial datasets should also be mentioned. It is understood that, strictly, a comparison of maps of different scales cannot be made. For comparison's sake, however, it was deemed possible to compare the topographical and land-use information, as the scale difference is minimal. However, drainage parameters could not be compared between the catchments as the mapping procedures and the details for the drainage network were very different among the maps of the different catchments.

The agronomic information from the Jhikhu Khola and Yarsha Khola catchments is derived from a survey related to water demand and supply in the two catchments (Merz et al. 2002) if not stated otherwise. The information on water demand and supply in the two catchments is derived from the same survey.

2.3.2 Morphometric analysis and comparison

2.3.2.1 Importance and definition of morphometric parameters

Dyck (1980) proposed that morphometric parameters be structures into linear, areal, and topographical parameters. The investigated parameters are briefly discussed below.

The rivers themselves with their lengths and their distribution in the catchment are considered to be the **linear parameters** of a catchment. For this study, the parameters' total drainage length, the length of the main river, and stream order according to Strahler (e.g. Wilhelm 1993) were considered to be important.

The most important **areal parameter** is the area of the catchment. The area generally determines, together with precipitation, the discharge, which becomes greater as the catchment area increases (Wilhelm 1993). Exceptions are given in areas with karst or high percolation and evaporation rates (Baumgartner and Liebscher 1996). The specific discharge, on the other hand, is indirectly related to the catchment area and decreases with an increase in catchment area. Flood peaks decrease likewise with increasing drainage area due to increased retention of floodwaters in the areas adjacent to the riverbed. The peak is not only influenced by the increased retention, but also by increased concentration times leading to a flattening of the peak. Variability of discharge is the highest in small catchments where heavy rainfall may lead to a sharp increase in water level. This increase in level stops immediately after the end of the rain. In larger catchments this effect is averaged out. Drainage density, defined as the total length of all rivers in a catchment divided by the total area of the catchment (Wilhelm 1993), is an indicator of the geological and pedological conditions of the catchment. High infiltration and percolation and therefore increased groundwater flow lead to low drainage densities. According to Baumgartner and Liebscher (1996), the annual discharge is more evenly distributed in catchments of low drainage density. Karstic areas also usually show low drainage densities. In addition to the influence of the inherent conditions, the drainage density is influenced by the precipitation.

The shape of a catchment mainly influences the concentration time, that is, the time after which all parts of the catchment contribute to the flow at the catchment outlet, and therefore the flood generation in a catchment. The influence on mean flows and low flows is limited (Baumgartner and Liebscher 1996).

Topographically, elevation is important for the determination of evapotranspiration rates, soil moisture regime, and investigations into snow and ice cover — all of them important factors of the water balance and related to the temperature regime of a catchment. Vegetation is directly related to elevation and herewith interception. It also influences the flood behaviour, as certain elevation zones are often forest covered. Above the tree line, precipitation in the form of rainfall can often run off undisturbed. Furthermore, aspect plays a major role as this parameter is related to the microclimate, particularly with regard to radiation and temperature in particular.

Streamflow concentration is one of the sub-processes of a flood, which can be described with the help of catchment characteristics — topographical parameters in particular (Duester 1994). This parameter mainly describes the magnitude and the intensity of a flood event and depends on a number of variables. According to Duester (1994) there many variables that should influence the streamflow concentration are discussed in the literature. One of the characteristics most frequently associated with streamflow concentration is slope. Steep slopes often produce short hydrographs with high peaks. Additionally, the increasing mean slope of a catchment leads to a greater proportion of overland flow and therefore fast streamflow processes (Baumgartner and Liebscher 1996). Breinlinger (1995) identified parameters affecting the permeability of the ground (soil characteristics and land use/cover) and slope critical for flood generation.

Certain hydrological models are directly based on the prior analysis of the catchment topography, such as the TOPMODEL (Beven et al. 1995a) or THALES (Grayson et al. 1995). TOPMODEL is based on the Topoindex defined as follows (Quinn et al. 1991):

$$\textbf{Topoindex} = \ln(a_i/\tan ß_i) \qquad \textbf{Equation 2.1}$$

where

a_i = area of the hillslope per unit contour length that drains through point i
$ß_i$ = slope [°]

The Topoindex represents the propensity of any point in the catchment to develop saturated conditions (Beven et al. 1995a). The index is high with long slopes, or upslope contour convergence, and low slope angles. For the calculation of the contributing area the index is expressed in a distribution function. In this study the Topoindex was calculated as described in Schulla and Jasper (1999).

Another index describing the topographic conditions but this time in relation to the drainage system is the concept of relative area contribution (Duester 1994). The concept of relative area contribution describes the probability of a particular area contributing to a flood event (Weingartner 1999). It is based on the assumption that the entire area of a catchment contributes to a flood. But each part of the area contributes to a different extent, depending on the distance from the channel and on the slope. The influence of the slope is calculated with the help of a coefficient (Duester 1994)

$$C_i = (90/ß_i)^{0.5} \qquad \textbf{Equation 2.2}$$

where

C_i = coefficient [without dimension]
ß = slope [°]

The distance from the channel is calculated according to the least accumulative cost distance. This includes the geographic distance from the channel as well as the slope in this case. For this the cost distance function implemented in ArcView 3.1 was used with the channel network as input grid and the C^i coefficient grid as cost surface. The relative area contribution can then be determined as (Duester 1994)

$$R_i = 1/CD_i \qquad \textbf{Equation 2.3}$$

where

R_i = relative contribution of cell i
CD_i = cost-distance value of cell i

Once streamflow generated on the slopes reaches the rivers, the process of open channel flow is initiated. This process is governed by the channel characteristics including channel slope, roughness, and width (Chow et al. 1988). The river elevation profile shows graphically the relationship between the length and the elevation and therefore overall steepness of the drainage system.

2.3.2.2 Area and shape

The two main catchments selected for this study and the remaining sites of the PARDYP project are in the range of 30 to 111 km^2 (Figure 2.4a). According to the hydrological scale classification of Becker (1986; cited in Nemec 1993), the catchments can be classified as small to large meso-scale catchments.

The project's monitoring and research network, which was set up according to the nested approach (Figure 2.15 (p.53) and Hofer 1998b), observes hydrological processes from 100 m^2 on the plot (micro scale) over approximately 100 ha in a sub-catchment (small meso-scale) to a catchment at about 100 km^2 (large meso-scale). For a visual comparison, the sub-catchments of the Jhikhu Khola catchment (which will be studied in further detail) are added to the figure (Figure 2.4b).

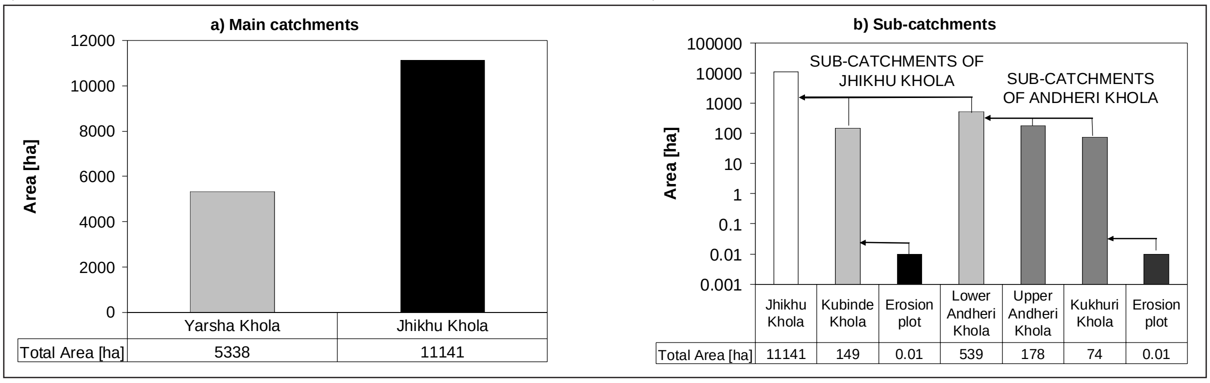

Figure 2.4: **Area of selected catchments: (a) Jhikhu Khola and Yarsha Khola catchments; (b) sub-catchments of Jhikhu Khola catchment**
(note: logarithmic scale in (b)

The Jhikhu Khola catchment is double the size of the Yarsha Khola catchment. The biggest sub-catchment in the Jhikhu Khola catchment is the lower Andheri Khola sub-catchment. including another two monitored sub-catchments of smaller size, the upper Andheri Khola and the Kukhuri Khola sub-catchments. The size of the Kubinde Khola sub-catchment is comparable to the upper Andheri Khola sub-catchment.

In terms of the shape of the catchment, the ratio between catchment width and elongation reveals that the Yarsha Khola catchment has a nearly balanced width/length relationship at a ratio of 0.8. The Jhikhu Khola catchment as well as its sub-catchments (with the exception of the Lower Andheri Khola) show a ratio of 0.5 to 0.6, which indicates that the catchment is twice as long as it is wide. The very long Lower Andheri Khola is three times longer than it is wide.

2.3.2.3 River length and drainage density

Note: Due to the use of maps of different origin with slightly different scales and different details in terms of drainage network mapping, this section can only be presented for the sub-catchments of the Jhikhu Khola catchment. These figures are all based on the same maps. The length of the main river is presented for all catchments: these values are, however, tentative.

The Jhikhu Khola catchment has a drainage network of 737 km (Table 2.3). This includes streams of the order 1 to 6 according to the method of Strahler. This calculates to a drainage density of 6.6 km/km^2 over the entire catchment area. The minimum drainage density is observed in the Upper Andheri Khola sub-catchment with a total drainage length of 12.2 km calculating to a drainage density of 6.9 km/km^2. The drainage density of the remaining catchments ranges from 7.5 km/km^2 in the Lower Andheri Khola sub-catchment to 7.9 km/km^2 in the Kubinde Khola sub-catchment.

Table 2.3: **River-related catchment characteristics**

Catchment name	Drainage length [km]	Drainage density [km km^2]	Length of the main river [m]
Jhikhu Khola	737.2	6.6	25,464
Kubinde Khola	11.7	7.9	2930
Lower Andheri Khola	40.3	7.5	7389
Upper Andheri Khola	12.2	6.9	2728
Kukhuri Khola	5.8	7.8	1449
Yarsha Khola	-	-	11,609

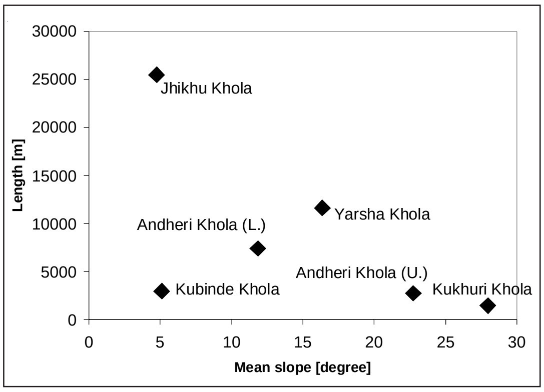

Figure 2.5: **Relationship between length of the mainstream and mean slope of the river**

The main river length determined in all catchments will be discussed in relation to the slopes of the catchment below and is shown in Figure 2.5.

2.3.2.4 Elevation

The two catchments are located in the Middle Mountains of the Himalayas. In general, they range from about 800 to 3100 masl. The elevation of the Jhikhu Khola catchment ranges from 790 to 2200 masl. The Yarsha Khola catchment has a relief of 2000 m (1000 to 3030 masl). The distribution of elevation classes differs between the two catchments (Figure 2.6a). While the Yarsha Khola catchment shows a distribution of the elevation classes resembling a normal distribution, with a peak of between 1500 – 1750 masl, the distribution of the elevation classes in the Jhikhu Khola is positively skewed. This is due to the extended valley bottom, which can be found in other Middle Mountain valleys such as the Kathmandu Valley, the Pokhara Valley, Dhadingbesi, Tansen in Nepal, the Paro Valley in Bhutan or the Doon Valley in India.

A similar picture is shown by the sub-catchments of the Jhikhu Khola catchment (Figure 2.6b). The entire area of the Kubinde catchment is in the lowest class (750 -1000 masl). The lowest point of this catchment is the outlet at 850 masl. The other catchments show a bell-like distribution of altitudinal classes around 1000 to 1200 m in the case of Lower Andheri Khola catchment, and around 1250 to 1500 m in the case of Upper Andheri Khola and Kukhuri Khola catchments.

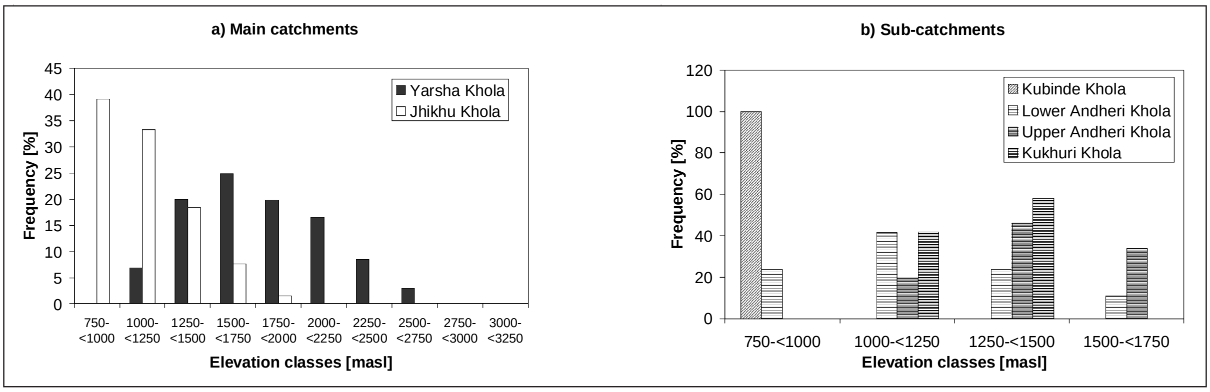

Figure 2.6: **Elevation distribution of (a) the main catchments, (b) the sub-catchments of the Jhikhu Khola catchment**

2.3.2.5 Slope

The mean slope of the main catchments varies from 17 degrees in the Jhikhu Khola catchment to 22 degrees in the Yarsha Khola catchment. This low mean slope value in the Jhikhu Khola catchment is mainly a result of the extended flat areas in the catchment. Nearly 40% of the catchment has a slope of below 5 degrees (Figure 2.7a). The remaining areas of this catchment are very steep and even steeper than the Yarsha Khola catchment. The slope distribution in the Yarsha Khola catchment peaks between 15-20 degrees.

The sub-catchments' mean slopes are 18 degrees (Lower Andheri Khola), 23 degrees (Upper Andheri Khola), 21 degrees (Kukhuri Khola), and 12 degrees (Kubinde Khola) with the distribution of slope peaking at 20 to 25 degrees in the case of the Kubinde Khola and degrees to 30 degrees in the remaining sub-catchments, respectively (Figure 2.7b). In order to express the relationship between steep slopes and flat areas of the catchments, a ratio of the slope classes 0 degrees to 5 to the sum of all slope classes from 15 degrees to >45 degrees was calculated. The selection of these classes is based on Breinlinger (1995) who identified the slope classes below 3 degrees and the classes above

15 degrees as most important for flood generation in addition to mean slope. The ratio is lowest for the Yarsha Khola catchment with 0.11. The Jhikhu Khola's flat valley shows a ratio of 0.70. The Kubinde Khola sub-catchment, in general very flat as shown above, has a ratio of 0.88, with the sub-catchments to the south having ratios between 0.32 and 0.57. These high values for the slope ratio in these catchments seem suspect as there is hardly any flat portion in reality and these values may be the result of an inaccurate contour map.

The difference in topography is also shown in Figure 2.5. The Yarsha Khola catchment shows a similar slope-river length relationship as the small and steep sub-catchments of the Jhikhu Khola catchment. The Kubinde Khola sub-catchment, on the other hand, is very similar to the Jhikhu Khola catchment in terms of slope, but is of course much smaller than the main catchment.

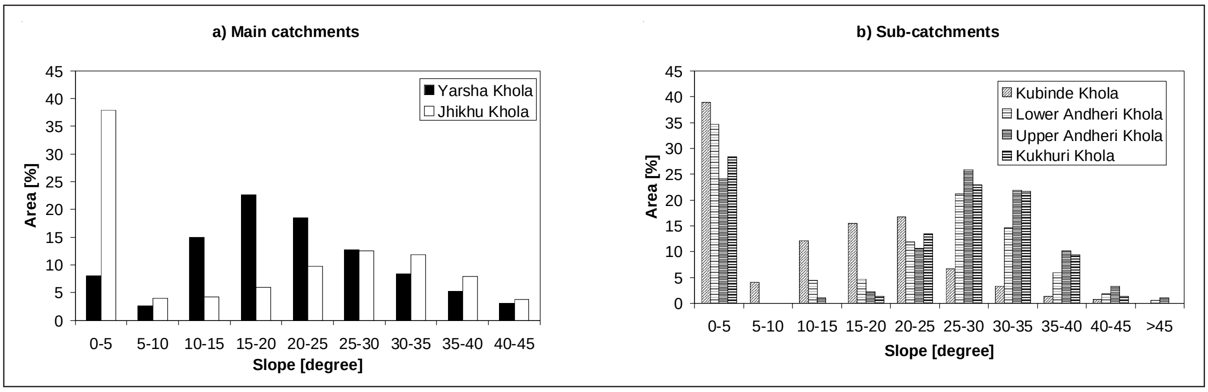

Figure 2.7: **Distribution of slope classes of (a) the main catchments and (b) the sub-catchments of the Jhikhu Khola catchment**

2.3.2.6 Aspect

The distribution of aspect classes in the two main catchments shows two different positions (Figure 2.8):

1) The Yarsha Khola catchment has an extended area facing towards north-northwest and south-southwest. The general orientation of the catchment is southwest.
2) The Jhikhu Khola has a general orientation towards the southeast with the main area of the catchment facing towards east-northeast. It is important to note the extended area of flat land, that is, areas without specific aspect. About 35% of the catchment is flat.

The overall orientation of the catchments is southeast for the Jhikhu Khola and southwest for the Yarsha Khola. The sub-catchments of the Jhikhu Khola show a general orientation towards the north (Lower Andheri Khola and Upper Andheri Khola), northwest (Kukhuri Khola), and southwest (Kubinde Khola).

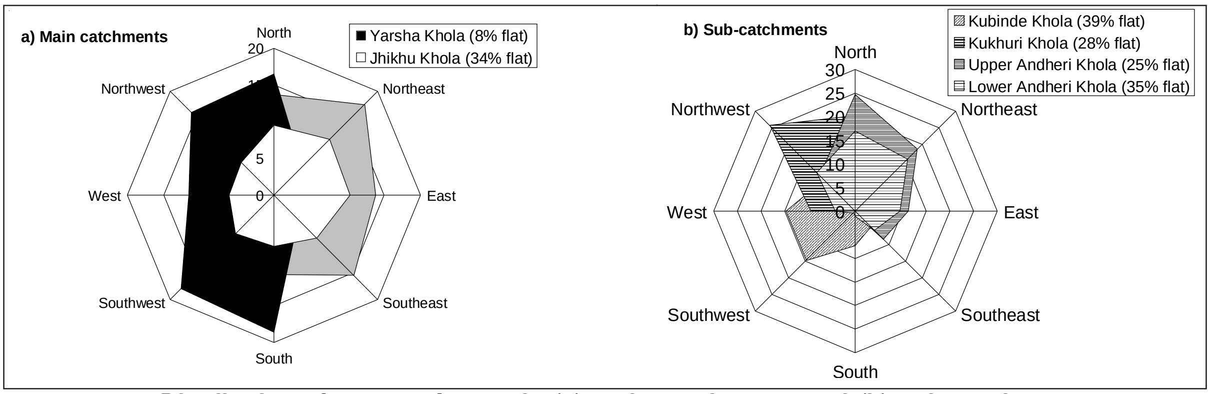

Figure 2.8: **Distribution of aspect classes in (a) main catchments and (b) sub-catchments**

2.3.2.7 *Topoindex*

The Topoindex is a measure of the likelihood of a cell in space contributing to runoff generation due to saturation. The analysis of the Topoindex in all catchments shows that the catchments all follow the same distribution, peaking at a Topoindex of 5 (Figure 2.9a) However, the Yarsha Khola catchment shows a higher percentage of low Topoindexes, indicating that this catchment is slower to saturate than the Jhikhu Khola catchment. The Yarsha Khola catchment, with a mean Topoindex of 6.4, is followed by the Jhikhu Khola catchment with a Topoindex of 7.0.

Except for Kubinde Khola sub-catchment, the other sub-catchments of the Jhikhu Khola catchment show the same pattern (Figure 2.9b). The Kubinde Khola sub-catchment's distribution peaks at a Topoindex of 6, indicating that this catchment is the quickest to saturate due to its low topography and slope. The mean Topoindex shows the same, with a value of 7.4 in this sub-catchment. In the Lower Andheri Khola, the mean Topoindex is 6.6, in the Upper Andheri Khola and the Kukhuri Khola it is 6.2.

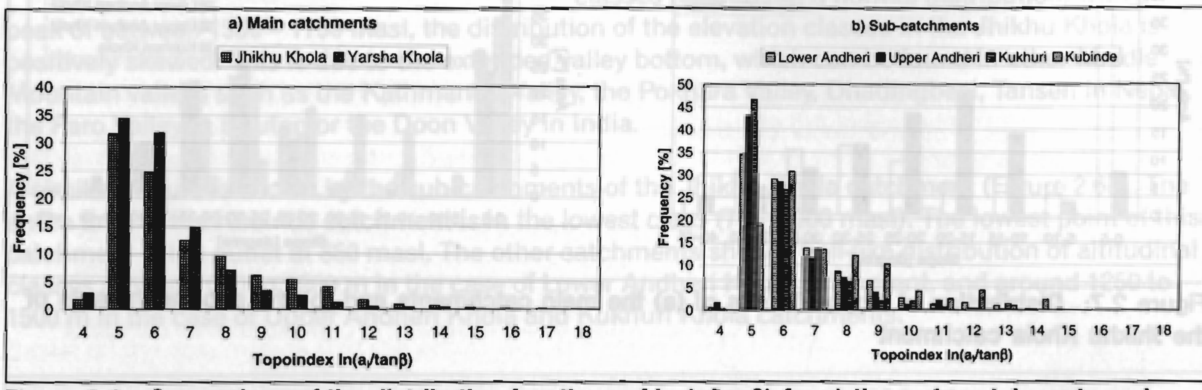

Figure 2.9: **Comparison of the distribution functions of ln (a/tanß) for a) the main catchments and b) the sub-catchments**

2.3.2.8 *Relative contribution area*

As in the case of the drainage network, the relative contribution area cannot be compared between different catchments unless the same data source or exactly the same data collection methodology has been applied for the drainage network. The reason for this is the strong dependence of the relative contribution area concept on the drainage network. However, a comparison of the sub-catchments in the Jhikhu Khola is presented below (Figure 2.10).

The Upper Andheri Khola sub-catchment at Site 7 shows the highest percentage of medium to large contributing areas, including the drainage system, closely followed by the Upper Andheri Khola sub-catchment and the Lower Andheri Khola catchment. Only about 37.5% of the Kubinde Khola sub-catchment is considered to contribute to a medium to large extent to runoff events. The average value per cell follows a similar pattern with 11.7 in the case of the Kukhuri Khola followed by the Upper Andheri Khola with 10.8. The lowest value is reported for the Kubinde Khola with 9.9 and the entire Jhikhu Khola catchment with 10.0.

It is important to note that the Topoindex and the relative contribution area are inversely related. As the relative contribution area is problematic in the case of different map sources with different details of the drainage network mapping, the Topoindex provides the same information and can be used exclusively.

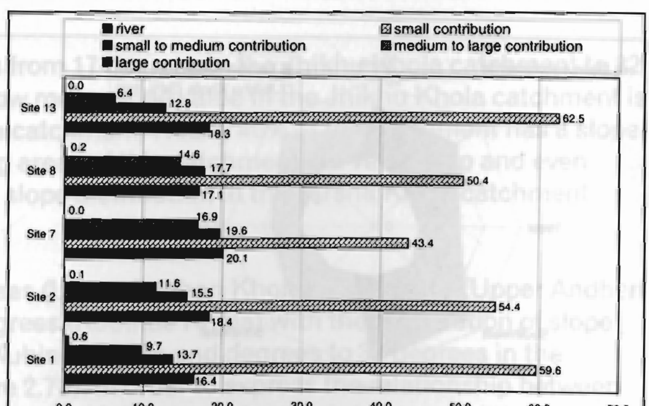

Figure 2.10: **Area of different relative contribution classes**

2.3.2.9 Summary

In summary, the catchments have the following characteristics (see also Table 2.4).

- The Jhikhu Khola catchment is the largest catchment generally oriented from northwest to southeast with very steep side slopes facing towards north and south and an extended flat valley bottom. It further shows the highest likelihood of saturation.
- The Yarsha Khola catchment covers the highest elevation range in a medium- sized catchment with general orientation from northeast to southwest. The topography is dominated by steep slopes, while flat areas are mostly not to be found. This is shown by a high mean slope and a low mean Topoindex.

The sub-catchments' characteristics can also be summarised as follows (see also Table 2.4).

- The biggest monitored sub-catchment, the Lower Andheri Khola sub-catchment, shows the largest elevation range, which is from the valley bottom to the catchment boundary with a general orientation towards the north. With a mean slope of 18 degrees it has similar overall slope conditions as the main catchment. The mean Topoindex shows medium propensity towards saturation.

Table 2.4: **Summary of morphometric catchment characteristics**

Catchment	Area [km²]	Elevation [m]				Slope	DD	Topo-index	Rel. area
		Mean	Max	Min	Range	Mean		Mean*	Mean
Yarsha Khola	53.4	1775	3040	980	2060	22	-	6.4	-
Jhikhu Khola	111.4	1118	2200	790	1410	17	6.6	7.0	10.0
Lower Andheri K.	5.4	1182	1700	850	850	18	7.5	6.6	10.6
Upper Andheri K.	1.8	1408	1700	1070	630	23	6.9	6.2	11.7
Kukhuri Khola	0.7	1280	1500	1070	430	21	7.8	6.2	10.8
Kubinde Khola	1.5	908	1000	850	150	12	7.9	7.4	9.9

K. = Khola DD = drainage density Rel. area = relative contribution area

* The Topoindex was calculated on the basis of 50m*50m grid cells

- The two sub-catchments within the Lower Andheri Khola,viz., the Upper Andheri Khola and the Kukhuri Khola sub-catchments, are generally steep and show low inclination towards saturation. They can be characterised as typical upland catchments within the Jhikhu Khola catchment.
- The Kubinde Khola sub-catchment, on the south-facing slopes of the Jhikhu Khola catchment, shows a very low elevation range and low mean slope with high mean Topoindex.

The potential impact on water and erosion parameters can be described as follows.

- The Jhikhu Khola catchment has high erosive potential along the side slopes where steep slopes prevail. The flat valley bottom acts as a sediment depository and therefore a low sediment delivery is expected for the entire catchment. Similar observations are expected in terms of runoff generation with high potential for runoff along the foot slopes of the catchment, and high infiltration and percolation in the flat valley bottom leading to lowered flood peaks at the outlet of the catchment. In terms of water availability, morphometric characteristics have little influence, except that the flat valley bottom may act as major groundwater storage. This, however, is dependent on the geology of the catchment (see below). The low altitude of the catchment is expected to have an impact on the rainfall amount as well as the evapotranspiration rates.
- In the Yarsha Khola catchment, fast response to rainfall is expected due to its steep slopes as well as missing flood plains within the catchment. This is not only shown by the slopes, but also by a relatively low mean Topoindex. In addition to this, the balanced shape of the catchment may lead to a rapid concentration of floods. Sediment output as well as flooding is therefore expected to be high at the outlet of the catchment. In terms of water availability, the high mean elevation may reduce the evapotranspiration and have an effect on the rainfall amount.

The observed impact of the catchment characteristics is further described in Chapter 3, Section 3.5 (rainfall-runoff event analyses) and Section 3.6 (sediment transport and mobilisation) in particular.

2.3.3 Comparison of land use and land-use change

2.3.3.1 Importance of land use and land-use change

The importance of land use and land-use change on different aspects of the hydrological cycle, including water availability and flood behaviour, has been mentioned on many occasions and was discussed in Chapter 1. From Table 1.6 it is evident that forest plantations and deforestation as major land-use changes affect larger areas only a little. While these changes reflect themselves on micro- to lower meso-scale catchments, the effects on larger catchments are negligible. This is particularly true for all directly water-related parameters. Water quality and pollution-related parameters are found to show changes on all scales through the effect of land-use change. These are important considerations for up-scaling from micro and meso-scale information to macro-scale management.

Mean annual runoff and therewith overall availability of water is mainly influenced by altered vegetation cover and changing soil properties, which are both closely linked to land use and land management. Changing vegetation cover results in changing rates of evapotranspiration and interception. Altered soil properties mainly manifest themselves in terms of changed water-holding capacity and infiltration rates (Merz and Mosley 1998). The following changes were observed and reported in the literature (FAO 2002):

- in general, a change in land cover from low to high evapotranspiration rates decreases the annual mean flow;
- in general, a reduction in forest cover increases water yield; and
- exceptions to the rule are cloud forests and very old forests, which may consume less than newly-established forests.

Flow during the dry season depends largely on the base flow and the groundwater availability. Increased evapotranspiration rates through afforestation may lead to decreased base flows, as examples in Thailand have shown (FAO 2002). It was also shown that dry periods and droughts might not be substantially altered due to changes in forest cover (Brooks et al. 1991). Local observations by farmers from the Jhikhu Khola have shown that certain springs dried up after an afforestation programme in the area that planted Chir pine (*Pinus roxburghii*).

Peak flows are mainly a function of soil properties in addition to rainfall characteristics. With increased compaction of the soils through changes in land use or management, the infiltration capacity of the soil decreases and therefore increases the probability of runoff generation (Scherrer 1997). However, this effect diminishes with increasing event size (Merz et al. 2000a; Bruijnzeel 1990).

Sediment load is less influenced by land use, and more by land management (Calder 2000; Dangol et al. 2002). A poor quality forest with hardly any understorey yields more sediment than a well-maintained and well-managed piece of agricultural land. Dangol et al. (2002) showed that the biggest soil losses in a period of seven years occurred within ten days of weeding in terraced, rainfed agricultural land.

2.3.3.2 Current land use

The catchments of this study are all smaller or around 100 km^2, and therefore differences in hydrological parameters should be evident. The land use in the three main catchments is divided into classes, as follow.

- Irrigated agricultural land (level terraces; Zonneveld et al. (1986)

  In Nepal, this category is commonly known as ‘khet’, which can be defined as level terraces with a bund along the terrace riser (Figure 2.11). This land is irrigated by applying conventional flood and furrow irrigation.
- Rainfed agricultural land (sloping terraces; Zonneveld et al. (1986)

  The common name for this class is ‘bari’ in Nepal, which can be defined as sloping terraces without a bund along the riser (Figure 2.11). There is no provision for conventional irrigation on this land.

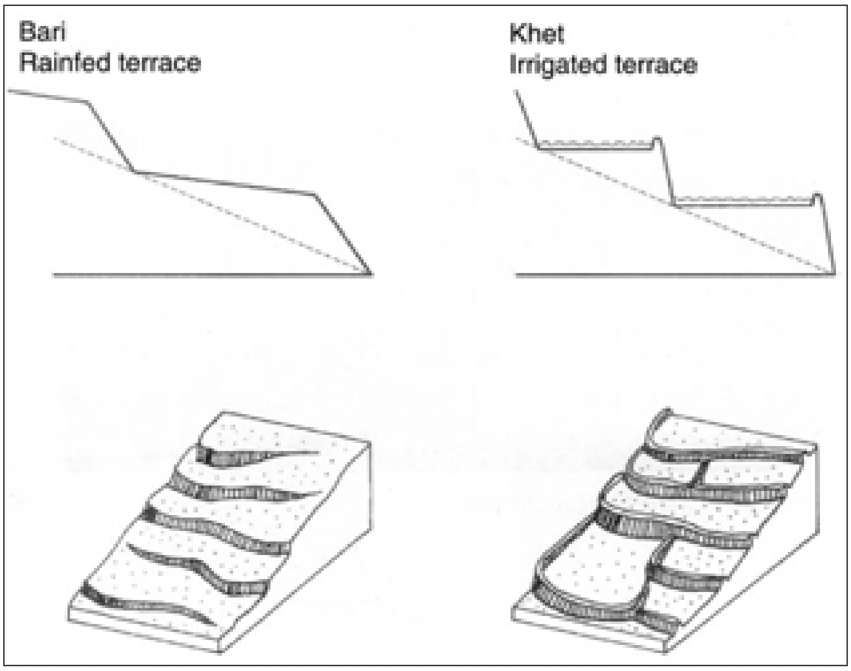

Figure 2.11: **Comparison of irrigated and rainfed agricultural terraces (from Ries 1994)**

- Forest land

  Zonneveld et al. (1986) defines a forest as an area with a crown density of more than 10% of the area.
- Grassland

  Zonneveld et al. (1986) defines grass lands as those areas mainly used for grazing, which lack sufficient shrub or tree cover to appear as forestland.
- Others

This class includes rock outcrops, settlements, roads, landslides/gullies/slips and water bodies.

It is evident that the two catchments from Nepal are heavily dependent on rainfed agricultural land, which accounts for up to 40% of the area of the two catchments (Figure 2.12). The total agricultural land accounts for more than 50% of the total area. Forested land contributes approximately 30% to the total area in the case of the Nepal catchments, while the amount of grazing land is very small.

As shown in the case of the catchments above, the sub-catchments of the Jhikhu Khola also differ mainly in terms of areas of forest and rainfed agricultural land (see also Figure 2.13). The two tributaries to the Andheri Khola, the Upper Andheri Khola, and the Kukhuri Khola have a high percentage of rainfed agricultural land (55 and 63% respectively). Their forest areas are about 20% of the total catchment area. In both sub-catchments there is hardly any irrigated land as both are

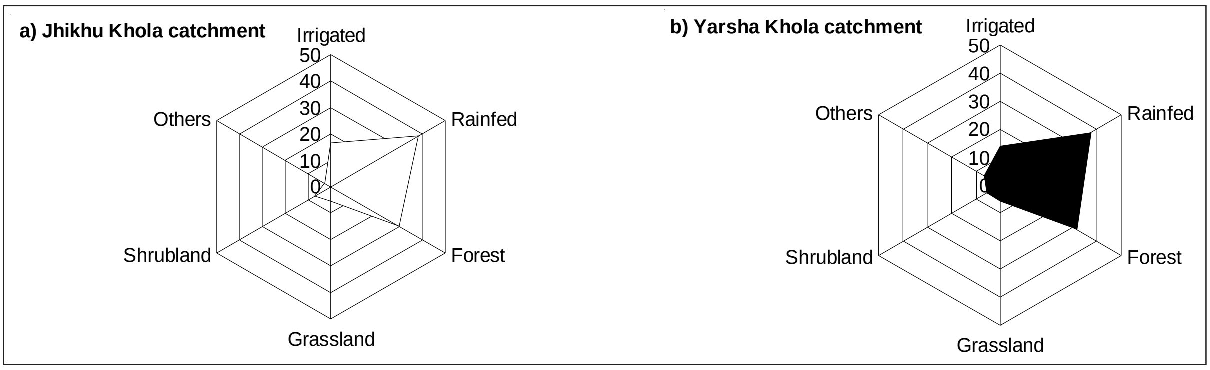

Figure 2.12: **Land use in a) the Jhikhu Khola catchment and b) the Yarsha Khola catchment**

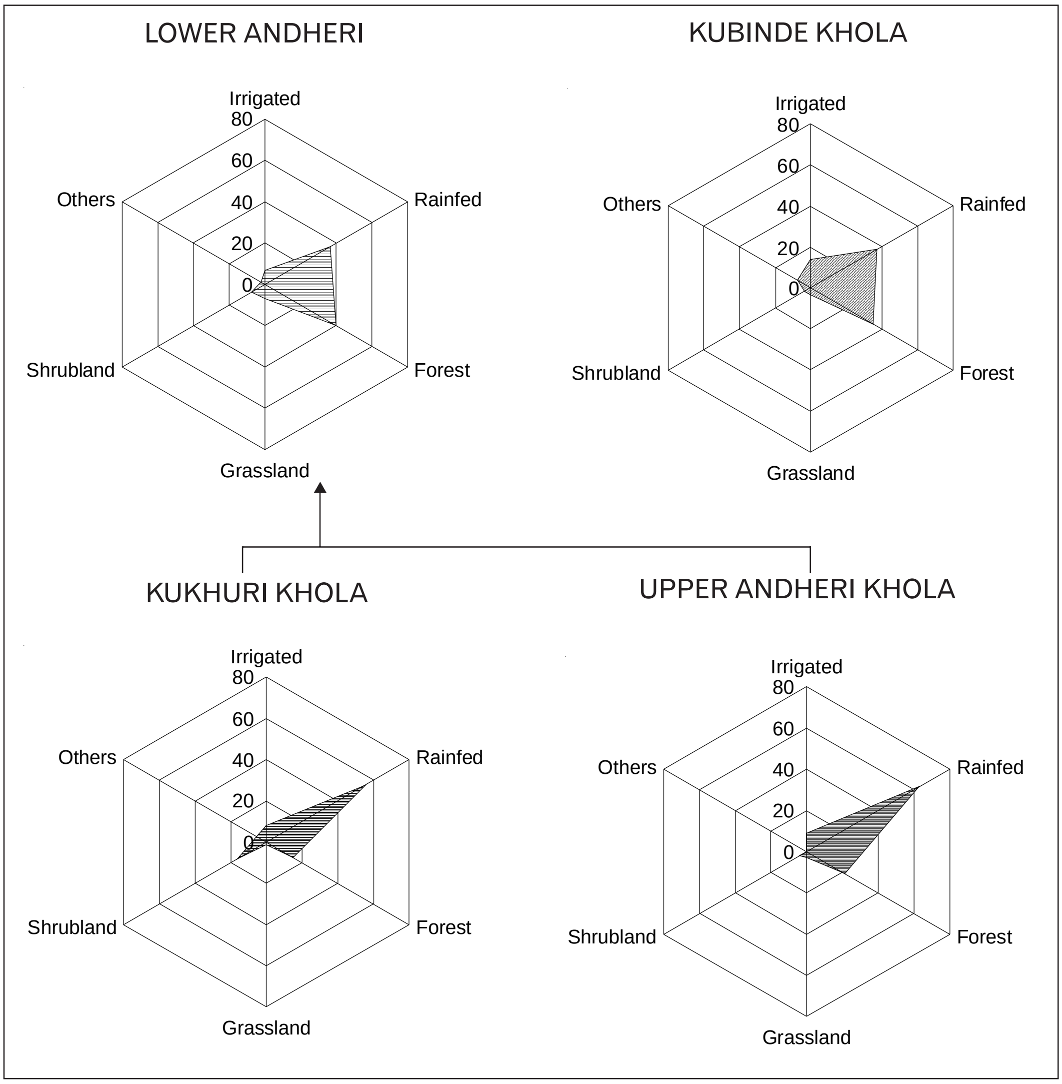

Figure 2.13: **Land use in the sub-catchments of the Jhikhu Khola catchment**

upland catchments with narrow valley bottoms, often only as broad as the river course. The Lower Andheri Khola and the Kubinde Khola sub-catchments are comparable in terms of land use, as in both cases rainfed agricultural and forest land contribute around 40% to the total area. The contribution of irrigated land is slightly higher in the case of the Kubinde sub-catchment (Table 2.5).

The most intensively cultivated catchments are the two headwater catchments of the Andheri Khola, where the area of the cultivated land is two to three times the uncultivated area (Table 2.6). The Lower Andheri Khola sub- catchment, on the other hand, is only sparsely cultivated in the lower stretches, shown with the ratio of 0.8.

Table 2.5: **Land-use related catchment characteristics**

Catchment name	Survey year	Scale	Total Area in ha	Irrigated land in%	Rainfed land in%	Forest in%	Grass-land in%	Others in%	Shrub-land in%
Jhikhu Khola	1996	1:20'000	11141	16.5	38.3	29.8	5.5	2.9	7.0
- Kubinde Khola	1996	1:20'000	149	14.1	37.6	34.9	3.4	7.4	3.4
- Lower Andheri Khola	1996	1:20'000	539	6.9	36.7	39.9	6.9	2.2	7.6
- Upper Andheri Khola	1996	1:20'000	178	9.0	62.9	21.3	2.8	0	3.9
- Kukhuri Khola	1996	1:20'000	74	8.1	55.4	14.9	1.4	5.4	16.2
Yarsha Khola	1996	1:25'000	5338	13.9	37.4	31.5	5.8	6.4	5.4

Table 2.6: **Ratio of cultivated / uncultivated and rainfed / irrigated land for all catchments**

Catchment name	Cultivated / uncultivated	Rainfed / irrigated
Jhikhu Khola	1.2	2.3
- Kubinde Khola	1.1	2.7
- Lower Andheri Khola	0.8	5.4
- Upper Andheri Khola	1.7	7.0
- Kukhuri Khola	2.6	6.8
Yarsha Khola	1.0	2.7

The project was initially started in 1990 due to the perceptions of extensive land degradation in the middle mountains of the HKH. Here, degraded lands are defined as areas with minimal vegetation cover on landslides, rilled and gullied surfaces, areas subject to frequent sheet erosion, and continuously eroding river banks (Shah et al. 2000). The comparison of the contribution of degraded areas to the total area of the study catchments and sub-catchments shows that the Kubinde Khola catchment displays the largest area of degraded land, about 12% of its catchment area. The Lower Andheri Khola catchment is about 10% degraded. These areas are mainly confined to the lower stretches of the sub-catchment, as the upper parts show only low degradation. The Kukhuri Khola has no degraded areas and the Upper Andheri Khola has only about 2% degraded areas. Approximately 5% of the entire Jhikhu Khola catchment has degraded lands according to the definition above.

Gullies and badlands, the most severe forms of land degradation, are not the only way in which the degradation of land resources manifests itself. Overuse of forest resources or afforestation with the wrong species can lead to degraded forests where there is no undergrowth. Overgrazing of grasslands can lead to decreasing vegetation cover and finally support sheet and rill erosion. These forms of degradation have not been considered in the above classification of degraded lands, but play a major role in the hydrological response of a catchment.

2.3.3.3 Land-use change and agricultural intensity

In rural catchments of the Hindu Kush-Himalayas, land-use change and agricultural intensity go hand in hand. Where agronomic intensity is decreasing, land use may change towards extensificiation and abandonment of agricultural fields. An increase in agronomic intensity is first manifested in the extension of irrigated land to all possible areas, followed by an extension of the rainfed areas to steep and marginal land. Finally, already developed fields are intensively cultivated with multiple crops and high fertiliser and pesticide application rates.

Land use changes in the Jhikhu Khola between 1947 and 1990 are well documented in Shrestha and Brown (1995). A period of deforestation between 1950 and 1960, when forests in Nepal were nationalised, was followed by an increase in forest cover through active afforestation programmes in the area. In the period 1947 to 1981 agricultural and shrubland increased at the cost of the forest land. This trend was followed between 1972 and 1990 by decreased grazing and decreasing shrub areas, and increasing areas of rainfed agriculture. The irrigated agricultural land remained stable throughout the entire period.

For the period between 1990 and 1996, Upadhyay (2001) showed that land use in the Jhikhu Khola catchment was stable. Only small changes in the magnitude of 1 - 2% occurred in all land-use types.

The trend of stabilising or even increasing forest area will most probably continue, as about a third of the forest in the catchment (11.8 km^2) is under the protection of the community forestry regulations, which does not allow clear felling. This includes the area of 36 of the total 39 community forest areas in the catchment in the year 2002 (Shrestha and Tuladhar 2002). Furthermore, some of the shrubland (0.9 km^2), grazing land (0.4 km^2), and rainfed agricultural areas (1.2 km^2) are also included in the community forest area, which suggests that they should remain stable or will be covered in forest in the future.

Land-use change in the Yarsha Khola catchment is documented in Shrestha (2000a). In the period between 1981 and 1996 the areas of rainfed agricultural land and shrub were observed to decrease. Forest cover increased from 21 to 31% of the total area. Grazing and other uses, amongst them settlements and infrastructure, likewise increased in area over this period. Although Shrestha

Table 2.7: **Current trends for land-use change**

Land use	Jhikhu Khola	Yarsha Khola
Irrigated agricultural land	stable	stable
Rainfed agricultural land	stable	decreasing
Forest	increasing	increasing
Grassland	decreasing	increasing

(2000a) stresses that the figures have to be considered with caution, the trend shows that forest land has gained at the cost of rainfed agricultural land and shrub. A comparison of the two catchments can be found in Table 2.7.

The two catchments differ largely in terms of access to markets, which is considered to be one of the major factors influencing agricultural intensity. The Jhikhu Khola catchment is only 45 km from Kathmandu, providing the farmers of the catchment with first class possibilities for selling their produce. Many farmers have started to grow cash crops such as potato, tomato, bitter gourd, chilli, and others in the catchment (Pujara and Khanal 2002). Cash crop production is closely related to increasing use of fertilisers and pesticides. The environmental risk of using large quantities of pesticide was closely studied by Herrmann and Schumann (2002) in the Jhikhu Khola catchment. Preliminary results of this study show that the actual environmental pollution through pesticide storage in the topsoil and its water bound transport is less than expected. However, health risks may still be present due to unsafe application practices and accumulation in the food chain.

The dynamics of agricultural intensity in the catchment can be shown by the historic changes of cropping intensity and changes in cropping patterns. According to Multidisciplinary Consultants (1988), the crops on irrigated land in Kavrepalanchowk district in the 1980s included rice, wheat, and potato. According to Shah (pers. comm.), during the late 1980s and early 1990s potatoes were grown in this district during the dry season on irrigated land, mainly in the area of Banepa, Panauti, and Dapcha Khola. Only a few farmers grew potatoes during the dry season in the Jhikhu Khola catchment. In addition, farmers often kept their land fallow in the dry season. A comparison of survey data from 1989 and 1999 has shown that the usual fallow periods, which were indicated by the farmers in 1989, have largely disappeared (Dangol et al., in prep). Rice and wheat dominated the cropping calendar in 1989. In 1999, the cropping diversified with a number of cash crops–including many farmers growing tomatoes, potatoes and different vegetables.

Yarsha Khola, on the other hand, is about 10 hours by bus from Kathmandu and therefore has only limited market access. Cash crop production is limited and includes mainly seed potatoes and garlic. Due to the elevation, the pest problem is not acute for these crops and pesticides are only used to a limited extent. In the Xizhuang catchment only one to two crops are grown on the irrigated land, with maize grown during the monsoon followed by wheat as a dry season crop. On the dry land, maize is grown and sometimes intercropped with soybean. Tea has, in many cases, taken over from maize on the dry land. It is the tea gardens which receive high pesticide doses. Otherwise pesticides are only used to a limited extent.

Livestock are an integral part of the farming systems in the middle mountains of the HKH (Dixon et al. 2001). The animal composition consists mainly of buffaloes, cattle, and goats (Table 2.8). In the Yarsha Khola, a number of families own 'chauri', a cross between yak and zebu cattle. Other animals, such as pigs, are only rarely found and are therefore not included in the calculations below. In order to compare the different animals and calculate stocking densities, tropical livestock units (TLU) were used as reported by Brown (1997). The stocking densities as reported by Brown (1997) show a similar magnitude with 3.8 TLU/ha cultivated land compared to 4.0 TLU/ha cultivated land in this study.

Brown (1997) notes that the maximum stocking densities in the Jhikhu Khola catchment belong to the highest in the world. According to FAO (1990; Thapa and Paudel 2000) Nepal's stocking is about 7 TLU/ha cultivated land, a very high density compared to other countries in the Asia Pacific region. Kiff et al. (no date) compiled stocking densities of 2.9 to 5.8 TLU/ha on the basis of different studies from Nepal. The values from the two studied catchments, 4.0 in the Jhikhu Khola catchment and 5.8 TLU/ha cultivated land in the Yarsha Khola catchment, can therefore be assumed to be high in an overall context. However, Thapa and Paudel (2000) argue that carrying capacities based on cultivated land are not appropriate as livestock in the middle mountains of Nepal depend primarily

Table 2.8: **Livestock numbers and stocking density in the Jhikhu and Yarsha Khola catchments**

Animal	TLU* equivalents	Jhikhu Khola (8002HH)[2] No./HH#	TLU	Yarsha Khola (4362 HH) No./HH#	TLU
Buffalo	1.0	1.2	9602.4	1.1	4798.2
Bullock	1.0	0.8	6401.6	1.5	6543.0
Cow	0.8	0.9	5761.4	0.9	3140.6
Goat	0.1	3.5	2800.7	3.3	1439.5
Total			24,566.1		15,921.3
Stocking density entire catchment [TLU/ha]			2.2		3.0
Stocking density per cultivated land [TLU/ha]			4.0		5.8

* according to Brown (1997)
# according to Merz et al. (2002)

on forest and, secondarily, on grasslands. They propose that stocking densities be determined on the basis of the entire catchment area. Using this approach, stocking densities of 2.2 in the Jhikhu Khola catchment and 3.0 in the Yarsha Khola catchment, respectively, are reported.

An overall assessment of agronomic intensity allows the view that the Jhikhu Khola is probably one of the most intensively cultivated catchments in the middle mountains of Nepal, and therefore shows much more of an extreme than a representative case (Table 2.9). This allows the studies in the catchment to venture into the possible future direction of other areas which are intensifying their agriculture. The Yarsha Khola catchment is of medium agricultural intensity, mainly due to its missing or limited cash crop production.

Table 2.9: **Agronomic intensity**

	Jhikhu Khola#	Yarsha Khola*
No. of crops on irrigated land	2-3 crops (up to 4)	2-3 crops
Productivity on irrigated land	high	low
No.of crops on rainfed land	1-2 crops (up to 3)	1-2 crops (up to 3)
Productivity on rainfed land	high	low
Fertilizer use	very high	medium
Pesticide use	very high	low
Livestock stocking density	high	high
Overall agricultural intensity	**very high**	**Medium**

Merz et al. (2002)
* Shrestha and Neupane (2002)

2.3.3.4 Summary

The two catchments in Nepal are dominated by agricultural land and large forest areas, which have been increasing in recent years. The large area of irrigated land in particular is noticeable, indicated by the low ratio of rainfed to irrigated land. Land use in general is stable with minor changes in forest and grassland in the Yarsha Khola catchment, observed mainly with the abandoning of rainfed agricultural land on the steepest slopes and in inaccessible locations (Table 2.10).

Table 2.10: **Summary of land-use related catchment characteristics**

	Jhikhu Khola	Yarsha Khola
Ratio cultivated/uncultivated	1.6	1.4
Ratio rainfed/irrigated	2.3	2.7
Land use change	stable	increasing forest and grassland
Livestock stocking density	high	high
Overall agricultural intensity	very high	medium

In general, and on the basis of a comparison with catchments from the Andes (Schreier et al. 2002), the catchments of the HKH region seem to be very intensively cultivated with multiple cropping and high inputs of both organic and inorganic fertilisers.

The land-use parameters and agricultural intensity are most likely to have a major impact on the water quality parameters in the catchments. But water quantity is also considered to be affected by

2 **Household**

the high percentage of irrigated land as well as cropping intensification and use of new varieties. For flood and sediment considerations, both the high degree of human intervention with respect to the high percentage of cultivated land as well as the considerable areas of degraded land may be of importance. Major land- use changes are not expected in Nepal, unless there are major policy decisions such as in China with reference to the Upland Conversion (Xu and Salas 2002) or economic driving forces that pressurise people to abandon or expand their cultivated areas.

2.3.4 Other biophysical characteristics and their comparison

Some of the other important biophysical characteristics of a catchment include its geology, the soils, and the landforms and geomorphologic setting (Baumgartner and Liebscher 1996). These characteristics are all closely interlinked. Geology's influence on the hydrological cycle is mainly evident in terms of water availability, water storage in aquifers, and release of the water during the dry season as baseflow. Porous and fractured rocks as well as quaternary formations in particular support water storage. This is closely linked with landforms, for example, an extended sediment deposition in a valley bottom is more likely to act as a major aquifer than the same sediment on a valley slope. Karstic areas, on the other hand, show very low water availability on the surface as most of the available water percolates into the shallow or deep groundwater, feeding often large and extensive karst aquifers and springs with large yields (Baumgartner and Liebscher 1996). An example for one of these good spring sources is the Tiger Cave spring in the Xizhuang catchment yielding about 200 l/min (Gao et al. in prep.).

The interrelationship between soils and water is important for runoff generation, land degradation, and water storage. For runoff generation, physical soil properties, such as texture and bulk density, are important for the determination of flow through the soil's column. Soil compaction with subsequent decrease in infiltration capacity may lead to an increase in peak flows (Scherrer 1997). The increase in terms of peak flows after land- use change towards lower infiltration capacity is expected to be largest in small events and smallest in large events (FAO 2002). The same was shown by Merz et al. (2000a) for the Yarsha Khola catchment in Nepal on the basis of 1998 data, where at a certain threshold land use did not matter for the generation of runoff at a plot scale, but all plots yielded high runoff volumes.

2.3.4.1 Geology

Nakarmi (2000a) elaborates on the geology of the Jhikhu and Yarsha Khola catchments. The Jhikhu Khola catchment area belongs to two domains, the Lower Kathmandu Complex and the Upper Nuwakot Complex, dissected by the Mahabarat Thrust. Lithologically, six formations–including meta-sandstone, schist and quartzite intercalation, mica schist, quartzite, marble, and garnetiferous mica schist– make up the Lower Kathmandu Complex. The Upper Nuwakot Complex consists of dark grey slate, intensively-folded green schist, grey phyllite, limestone, and dolomitic limestone. Hydrogeologically and for water availability considerations, the carbonate rocks (Shrestha 1999) and the alluvial valley fill are important (see also Section 3.4).

The Yarsha Khola catchment's geology consists of low- to medium-grade metamorphic rocks. The valley is basically formed by a syncline with graphitic schist and dark slate in the synclinical fold and mainly gneiss and phyllite along the flanks of the syncline. The black schist is underlain by a succession of talc, magnesite, and medium to thickly bedded quartzite. Green phyllite and chlorite schist underlay the quartzite bed, on the basis of which gneiss is found. This geological constellation does not show a particular constraint or benefit for water storage. In terms of water quality, however, the south- facing slopes tend to be more acidic as they are located on gneissic rocks. Water draining the talc and magnesite band exhibits very high electrical conductivity (Shrestha et al 2001).

2.3.4.2 Soils

The soils of the Jhikhu Khola were first described by Maharjan (1991) on the basis of a comprehensive soil survey. In general, the soils are of loamy texture and are moderately well to rapidly drained. Shah (1995) presents the indigenous soil classification in the catchment. A good relationship was found between this classification based on the vast knowledge and experience of the local farmers and selected land quality parameters. Since then, several publications have described the soil fertility issues and dynamics in this catchment. The issues include soil acidification (Schreier et al. 1995), nutrient losses, and dynamics — in particular phosphorous (Carver and Schreier 1995; Brown 1997; Brown and Schreier 2000; Von Westarp 2002). While the phosphorous levels used to be well below desirable levels (Schreier and Shah 2000), phosphorous is now in surplus in the very intensively-used fields due to increased fertiliser availability and inputs (Von Westarp 2002). Simultaneously, phosphate levels in groundwater as well as surface water is likewise elevated and is, in places, above guideline values (Merz et al. 2003c).

The soils of the Yarsha Khola catchment were described in Schreier and Shah (2000) with particular reference to soil fertility issues. It was found that the conditions in the Jhikhu Khola catchment were also represented in this catchment, that is, acidification and phosphorous dynamics. The latter issue was even more pronounced in the Yarsha Khola catchment, as there is only limited access to phosphorous fertiliser in this catchment as shown by Brown (2000b). The soils in the Yarsha Khola catchment tend to have adequate carbon content, particularly at the higher elevations.

According to Shah et al. (2000), red soils (Rhodustalfs; Carson et al. 1986) are particularly sensitive to degradation. Their chemical properties are inherently different, mainly dominated by iron and aluminium oxides, with kaolinite as the dominant clay mineral. The surface of these soils is often encrusted and their infiltration rates and permeability are low. This leads to a constant hazard of sheet, rill, and gully erosion on bare red soil surfaces (Carson et al. 1986).

Red soils are very common in the PARDYP catchments, making up more than a third of the area of the Jhikhu Khola catchment (Table 2.11). More than 3/4 of the area of the Kubinde Khola (a sub-catchment of the Jhikhu Khola) is covered by red soils.

Table 2.11: **Red and non-red soils in the catchments**

Catchment name	Red soil [ha]	Red soil [%]	Non-red soil [ha]	Non-red soil [%]	Ratio red / non-red
Jhikhu Khola	4132	37	7009	63	0.59
- Kubinde Khola	114	77	35	23	3.26
- Lower Andheri Khola	203	38	336	62	0.60
- Upper Andheri Khola	35	20	143	80	0.24
- Kukhuri Khola	17	23	57	77	0.30
Yarsha Khola	665	12	4673	88	0.14

In this sub-catchment, the area of red soils is higher than the area of non-red soils, which is shown with the ratio red/non-red soils. The Jhikhu Khola catchment displays a high ratio as well. The Yarsha Khola catchment has only very small patches of red soils, generally in the lower stretches of the catchment and on the middle ridge.

Additional information collected over time in the Jhikhu Khola catchment on biophysical characteristics includes landforms (Maharjan 1991) and sediment sources (MRE 2002). In the Yarsha Khola, Tschanz (2002) documented the geomorphologic processes on the south-facing slopes. This information is referred to and described in more detail in Section 3.6, dealing with sediment issues.

It should also be noted that the red soils represent the oldest and most weathered soils in Nepal, and they are usually not present above 1700 to 1900 m elevation due to climatic effects and more extensive degradation processes at higher elevations (steeper soils).

2.3.4.3 Summary

The main geological and soil characteristics of the two catchments are compiled in Table 2.12. The geology is dominated by rock formations favouring acidic soil conditions. This is in addition to the acidifying chemical fertilisers discussed above. The catchment of the Jhikhu Khola shows a very high percentage of red soils, which are generally very vulnerable to surface erosion and gullying.

Table 2.12: **Summary of biophysical catchment characteristics**

	Jhikhu Khola	Yarsha Khola
Dominant geology	mica schist and calcareous schist	gneiss and slate+graphitic schist
Dominant soils	well-drained soils of loamy texture; red soils in the lower part of the catchment	loamy textured soils
Ratio red/non-red soils	0.59	0.14
Soil fertility issues	soil acidification, phosphorous dynamics, low cation exchange capacity (CEC) and base saturation	soil acidification, phosphorous dynamics, low CEC and base saturation

The Yarsha Khola catchment has only some patches of red soil in the lower stretches of the catchment. The soil fertility issues are very similar in all three catchments, with soil acidification and phosphorous dynamics being the main problems.

The impact on the water resources from these biophysical characteristics was touched upon above. The low phosphorous levels in the soils in all catchments forces farmers to use high doses of fertiliser, which they often apply in excessive amounts (see Merz et al. 2002). While this is certainly true in the Jhikhu Khola, in the Yarsha Khola access to fertiliser is still limited but may be a major problem in the near future. Soil acidity may further lead to acidic water in the catchment.

In terms of water quantity, the existence of carbonate rocks and karst features may have an impact on increased water availability in terms of well-yielding springs and also in terms of dry surface conditions due to rapid percolation.

2.3.5 Population and socioeconomic characteristics and their comparison

High population density and increasing population growth are often held responsible for resource degradation in the HKH. As shown above, this is an issue in the middle mountains of the HKH region with population densities of 500 people/km^2. The catchments studied all have high population densities above 75 people/km^2. The Jhikhu Khola catchment has the highest density with 437 people/ km^2, followed by the Yarsha Khola catchment with 386 people/km^2. These densities are amongst the highest population densities in the region when compared with data from Sharma (1994). Population increase is rapid in the Nepal catchments. In the Jhikhu Khola catchment an annual population growth rate of about 3.5% was determined between 1947 and 1996 (Figure 2.14) and 3.1% during the period from 1990 to 1996. The last five to ten years in particular have experienced rapid population increase due to natural growth and immigration. Brown (2000a) documented a 1.8% growth rate per annum between 1972 and 1990 and 2.6% between 1990 and 1995 in the Bela-Bimsensthan sub-catchment of the Jhikhu Khola catchment. For the Yarsha Khola catchment the annual growth rate was 2.7% for the period from 1981 to 1996.

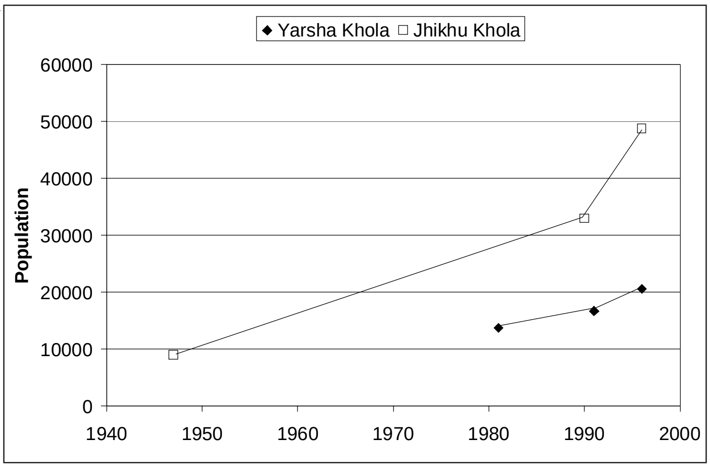

Figure 2.14: **Population dynamics in the Jhikhu Khola and Yarsha Khola catchments**
(data source: PARDYP)

The households in the Nepal catchments are quite large. In 2000 in the Jhikhu Khola catchment household size ranged from 2 to 27 with an average of 6.9 people per household (Merz et al. 2002). Shrestha and Neupane (2002) reported an average of 6.6 people per household for the Tinpiple sub-catchment in 1999. The household size in the Yarsha Khola catchment was 5.8 in 1999, ranging from 2 to 13 people per household (Merz et al. 2002).

The ethnic groups and castes represented in the Jhikhu Khola catchment are Brahmin, Chhetri, occupational groups (including Kami, Sarki, and Damai), Newar, Tamang, Danuwar, Magar, and Gurung. In the Yarsha Khola, Danuwar, Magar, and Gurung are replaced by Sherpas (Allen et al. 2000).

Land provides the major source of income for most rural households in the Nepal middle mountains. The social and economic status of a household therefore depends heavily on the amount of land, the type of land (rainfed vs. irrigated), the quality of land, and its accessibility. In general, land holdings in Nepal's middle mountains are small and fragmented. Yadav and Sharma (1996; cited in Thulachan 2001) reported an average parcel size of 0.2 ha with average holdings of 3.9 parcels or 0.78 ha per household in the high and middle mountains of Nepal. Approximately two-thirds of farm households have small land holdings of less than 0.05 ha and can be classified as marginal farmers. Less than a quarter of the households in these physiographic regions own 0.051 to 1 ha of agricultural land and 20% own more than 1 ha. Median land holding per household in the Bela-Bimsensthan sub-catchment was 0.92 ha during a survey of 85 households in 1994, with 53% of the households owning only 25% of the land or land holdings below 1 ha (Brown 2000a). Shrestha and Neupane (2002) report similar figures from a survey in 1999, with 52% of the households owning 22.5% of the land in the Tinpiple sub-catchment, another sub-catchment of the Jhikhu Khola catchment. In their study area more than 93.5% of the households (187 of 200) belonged to the group of marginal to small farmers with marginal farmers owning below 0.5 ha and small farmers between 0.5 to 1.5 ha land. Average land holding size was 0.60 ha (note the difference in classification of land holding sizes compared with Yadav and Sharma (1996), above.

In the Yarsha Khola catchment, Brown (2000b) reported a median land holding size of 0.8 ha per household in a survey of 150 households in 1998. Of these households, 67% owned 38% of the land and had holdings below 1 ha. A recent report by the Centre for Environmental and Agricultural Policy Research, Extension and Development (CEAPRED 2003) reports average land holding sizes of 0.94 ha/household in selected VDCs of the Kavrepalanchowk district, most of them in the Jhikhu Khola catchment.

Of the households taking part in various surveys, 21 to 50% reported that the land their farms did not yield enough for them to be self-sufficient (Shrestha and Brown 1995). In the Yarsha Khola catchment, 53% of the households were not able to fulfil their food demand from farming (Brown 2000b). CEAPRED (2003) indicates that only households with good access to irrigation water are self-sufficient in food. To keep up with demand, some household members are forced into off-farm employment, which together with the sale of agricultural products forms the main source of cash income for rural households in Nepal. The main off-farm activities reported by Shrestha and Brown (1995) were brick making, carpentry and masonry, shop/businesses, and farm labour. Lack of jobs and, in some cases, also landlessness forces many people in Nepal to migrate, mainly to urban centres, but also abroad (K.C. et al. 1998).

It can be summarised that, in the catchments of PARDYP Nepal, the population exerts significant pressure on the availability of natural resources, including water. The current population densities are amongst the highest in rural areas of the region (Table 2.13). Although agricultural production is very intense, in particular in the valley bottom of the Jhikhu Khola catchment, many households still do not produce enough food to reach self-sufficiency. This is mainly due to very small land holdings in these areas. Off-farm employment and often seasonal or even lifetime migration are solutions to lack of jobs in the rural areas as well as landlessness.

Table 2.13: **Summary of population and socioeconomic characteristics**

	Jhikhu Khola*	**Yarsha Khola****
Total population (year)	48,728 (1996)	20,620 (1996)
Population density [people/km^2]	437	386
Growth rate [%] (period)	3.5 (1947-1996)	2.6 (1971-1996)

* Allen et al. (2000)
** Shrestha (2000)

2.3.6 Summary

The Yarsha and Jhikhu Khola catchments range from 50 to 110 km^2 in size. Due to their steep slopes, they have a high erosion and flood generation potential. While the Yarsha Khola catchment is expected to transmit the mobilised sediment and runoff through the outlet, the flat valley floor of the Jhikhu Khola catchment is expected to dampen the flood wave and act as a sediment depository.

Agriculture demands most water, with the majority of the area under irrigated or rainfed cultivation systems. Forest areas have the next biggest need for water. The forest areas have increased to a small degree in both catchments. Land-use changes, however, are believed to be stable. Both catchments have extensive red soil areas as well as large areas of degraded land. While the gullies and badlands are the most visible form of degraded land, a large part of the forests and grazing areas are also strongly degraded, visible through very poor vegetation cover and, often, low biodiversity. Agricultural areas are very intensively cultivated in the Jhikhu Khola catchment. A medium intensity of agricultural cultivation can be seen in the Yarsha Khola catchment

2.4 MEASUREMENT NETWORK AND DATA PREPARATION

Data availability for in-depth process studies has been the main limiting factor to improving the understanding of environmental issues in the HKH region. For this purpose, PARDYP has set up a research monitoring network across the HKH in five catchments. While this is by no means a representative sample of the entire region, it will provide an insight into the relevant processes leading to flooding, water availability constraints, and sediment mobilisation and transport at a high spatial and temporal resolution. The high resolution is achieved by means of automatic monitoring of temporal key parameters and detailed field surveys of spatial parameters. After an introduction of the basic principle of the measurement network design, the three steps from the field to the available data are discussed. This includes data collection, data management, and data dissemination.

2.4.1 The nested approach

This approach to measurement network design has its origin in the understanding that hydrological processes vary with scale, as, for example, described in Ives and Messerli (1989) and recently in FAO (2002). The idea of this network design is based on the investigation of processes and balances at different scales. For each scale, all input variables are determined by means of measurements, that is, at the plot scale rainfall is measured with a rain gauge, and runoff and soil loss are measured by means of the erosion plot method (see below for details). At the next larger scale, measurements are conducted by means of one or several representative rain gauges for the assessment of areal rainfall, by hydrological measurements at a hydrological station located at the outlet of a well-defined sub-catchment. The integral systems' response of the entire catchment is monitored at the outlet by means of hydrological and sediment measurements after establishing areal rainfall from a number of representative and well-distributed rain gauges. The approach is schematically described in Figure 2.15

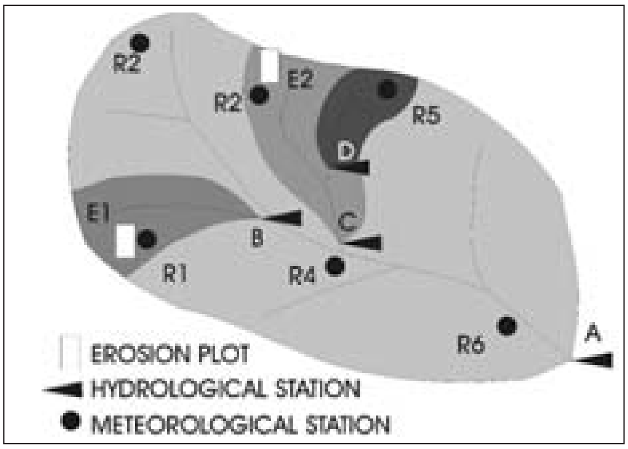

Figure 2.15: The nested approach – a schematic explanation (abbreviations are explained in the text)

Using the example in Figure 2.15, the response of the surface to a rainfall event measured at the raingauge R1 is investigated in the erosion plot E1 adjacent to the rain gauge. The response to the same event is then observed at the hydrological station of the sub-catchment B and finally at the outlet of the main catchment A. Relating the processes from the rain gauge, to the erosion plot, to the hydro stations at the sub-catchment and catchment levels allows one to draw conclusions about the processes involved. For this project the approximate size of the catchment scale was determined to be about 30 to 120 km^2 corresponding to the hydrological meso-scale. The catchments are believed to be representative of their environment or already showing the possible impacts of future processes in the region. The sub-catchments in the catchments are between 0.7 to 17 km^2. They either represent a specific part of the catchment, such as the north-facing slopes, or homogenous land use/land cover (as far as possible). The plot scale is of 100 m^2 representing dominant land use believed to be decisive in the runoff generation and sediment mobilisation process.

2.4.2 Data collection

The first step in the development of a database is data collection. For this purpose, PARDYP set up (as of July 15, 2002) a network of 19 hydrological stations, 31 meteorological stations, and 24 erosion plots in the China, India, Nepal, and Pakistan catchments. The stations in the Yarsha Khola were closed down in 2001 due to political instability in the area, and are therefore not counted. All networks are designed according to the nested approach (see above).

In general, automatic instruments are crosschecked with manual readings of the station readers wherever possible. This also helps in case of instrument failure due to battery or electronic problems. All stations are maintained by local employees, usually the owner of the land, a shopkeeper close by, or anybody else trustworthy and supported by the community. The readers get a monthly salary and annually receive two one-day training sessions, including a technical session, a discussion on operational problems, and a social event with lunch. This helps keep the readers up-to-date with their daily job, provides an atmosphere conducive to the discussion of problems and issues, and maintains a close link between the full-time project personnel and readers. In this respect the readers are an important part of the project and are valuable for other project activities as they are loyal to the project (Box 2.1).

Monthly record sheets are collected on the day of salary distribution. Automatic instruments are downloaded by the field staff, either in the field office if the readers can bring the loggers on salary distribution day, or in situ at the station using laptops and data shuttles or storage modules.

Box 2.1: **Hydro-meteorological readers as extensionists: an example from India**

PARDYP India has successfully used the services of their hydro-meteorological readers as extensionists of PARDYP activities. The readers, who draw a monthly salary and therefore enjoy a welcome cash-income from activities close to their homes, are loyal to the project. They are often in contact with project staff and therefore exposed to the new ideas the project tries to implement. In this context, the readers in India have all tested new ideas such as fish farming (Kothyari et al. 2003), poly tunnels, poly houses, and other on-farm technologies. From there, other farmers in the vicinity are exposed and can learn from the experiences of their peers with these appropriate technologies in a farmer-to-farmer exchange. Other PARDYP teams such as PARDYP Nepal are planning to follow the same approach in future.

2.4.2.1 The instruments and data collection methods

The selection of appropriate instruments and methods has a major impact on data quality. After a short description of the applied methods and instruments, a list of experiences with the selected methods will be shown.

Hydrological monitoring

Hydrological monitoring in the Jhikhu Khola and Yarsha Khola catchments in Nepal was carried out at hydrometric stations at the catchment outlet as well as in selected sub-catchments. At the stations, the water level was recorded using water-level recorders of the pressure transducer and floater types (see Table 2.14 for details). These automatic measurements were substantiated and compared with manual measurements from staff gauges twice a day (8:00 NST and 16:00 NST), with more frequent readings being taken during flood events. Discharge was measured on an irregular basis with the aim of obtaining discharge values for different water levels in order to generate a rating curve (that is, water level-discharge-relationship). For further detail on the rating curves, refer to Appendix A 3.1. Depending on the local site conditions, dilution methods (Uranin and salt tracers)

Table 2.14: **Hydrological data collection methods and instruments in JK & YK**

Instrument	Parameter	Type	Stations*	Remarks
Pressure transducer	Water level	Vega or Kern sensor logger: KERN FL-2	JK 1 YK 1	Digital, 5 min interval in monsoon, 15 min interval in dry season
		Pressure sensor logger: Smartreader 7	JK 2, 7, 8	Digital, 2 min interval
Floater	Water level	OTT R16	JK 13 YK 2, 5, 7	Analogue
Conductivity meter	Discharge	WTW LF 330	JK 7, 8 YK 5, 7	Used with momentary injection method and salt tracer (NaCl)
Current meter	Discharge	Price A, Gurley USA	JK 1, 2, 13	Used with wading rod or cable
Mariott bottle/ Spectrofluorimeter	Discharge	Swiss Hydrological Survey	YK 1, 2	Used with constant injection method and Uranin tracer
Sediment sampler	Sediment concentration	DH-48	JK 1	Used with suspension cable
		DH-76	JK 2, 7, 8, 13 YK 1, 2, 5, 7	Used with wading rod

* JK 1 = Jhikhu Khola catchment site 1 YK1 = Yarsha Khola catchment site 1

or current metering were applied to measure discharge. The applied methods are described in Merz (1998; salt dilution technique; Appendix B.3), Dongol et al. (1998; current metering; Appendix B.4) and Spreafico and Gees (1991; dilution method using Uranin tracer). Additionally, sediment samples were taken with DH-48 and DH-76 sediment samplers depending on the local site conditions, initially on a regular basis and only later above a certain flood threshold. This was due to high processing costs and the time-consuming tasks of sediment analysis (see more details in the section on erosion plot monitoring).

Meteorological monitoring

In general, a meteorological station in PARDYP Nepal consists of a tipping bucket rain gauge, a standard rain gauge as used by the DHM, and a thermistor in a Stevenson screen surrounded by a fence to keep animals out. The manual standard rain gauge is read once a day at 8:45 NST, the Department of Hydrology and Meteorology's (DHM) standard time for morning meteorological readings in Nepal. Refer to Table 2.15 for further details of the instruments used.

Table 2.15: **Meteorological data collection methods and instruments in JK & YK**

Instrument	Parameter	Instrument/Sensor Height	Stations	Remarks
Tipping bucket	Rainfall amount/ Rainfall intensity	1m above ground level	all sites	8" diameter 0.2 mm - 1.0539 mm buckets Event recording logger HOBO or Smart Reader 9
Ordinary rain gauge	Rainfall amount	1m above ground level	all sites	8" diameter
Thermistor (Temperature logger)	Air temperature	1.25 m – 1.50 m above ground level	all sites	In Stevenson screen
Thermistor (Temperature logger)	Soil temperature	20 cm below ground level	all sites	
Temperature probe	Air temperature	1.25 m – 1.50 m above ground level	YK 7	Connected to Campbell CR10X
Soil temperature probe	Soil temperature	10 cm, 20 cm, 50 cm below soil surface	YK 7	Connected to Campbell CR10X
Humidity probe	Relative humidity	1.25 m – 1.50 m above ground level	YK 7	Connected to Campbell CR10X
Anemometer/Wind vane	Wind speed/ wind direction	1.25 m – 1.50 m above ground level	YK 7	Connected to Campbell CR10X
Net radiometer	Net radiation	1.25 m – 1.50 m above ground level	YK 7	Connected to Campbell CR10X

Erosion plot monitoring

Plots to monitor erosion, with areas of about 100 m^2 per plot (note that the Bela plot in the Jhikhu Khola catchment is only about 65 m^2), were established on lands under different usages. The plots consist of a (usually) 20 m long by 5 m wide area delimited by metal sheets. Runoff and eroded material are collected in a gutter system, funnelling them to a first 200 l drum. To provide further storage, another drum is placed in sequence. This second drum has a 10-slot divider only allowing $^1/_{10}$ of the runoff into the last drum.

For detailed information about all the plots and their properties, refer to the section below. Runoff observations and sediment samples from these plots are taken by local observers. They are responsible for collecting representative samples by thoroughly agitating the drum content and filling 0.5 l leak-proof plastic sample bottles after major rainfall events. However, they visit the sites and make observations at 9:00 every day even if there is no rainfall, in order to ensure clean and empty drums.

The samples are accompanied with observation details, indicating data and time of recording, runoff height, and the drum number from which the sample originated. The sampled volume is measured and sediment is filtered and dried at 65 - 75°C in an electric oven at the PARDYP field lab. The water collected in all drums represents the runoff from the plot in the given rainstorm. The sediment derived from the sample is extrapolated to the content of the entire drum. The results from all drums are then summed up to determine the total soil loss from the plot.

All calculations are performed in an MSExcel macro developed by PARDYP, which creates a data entry sheet, then calculates and summarises the data. Runoff and soil loss are calculated per unit hectare. For additional information on the use of the macro and the method of erosion plots, refer to Nakarmi (2000b; Appendix B5).

Two BSc (Shrestha and Sharma 2000) and one MSc study (Voegeli 2002) were first experiences with surface flow collectors. These surface flow collectors are 1 m wide gutters located in large numbers on a hill slope. Tests with no delineation, with 1 m^2 plots and 2 m^2 plots were made. More details on this method can be found in the above theses.

Experiences with the applied methods

In general, the chosen instruments have proven successful, this includes OTT R 16 floaters, tipping buckets, thermistors, WTW conductivity meters, and HACH photometers. Operationally, discharge measurements were a major problem. Because of the security situation, night measurements (it is during the night that most events occur) could not be obtained. All sites have highly variable cross-sections making rating curve development a difficult task (see also Appendix A3.1). The approach of employing local observers has supported the data collection additionally during the political turmoil, when project staff were not allowed to visit the sites. Furthermore, the local observers proved to be very loyal and helpful in many other project activities.

2.4.2.2 Jhikhu Khola catchment

The development of a measurement network in the Jhikhu Khola catchment was initiated in 1989 by the Soil Fertility project of UBC and the Integrated Toposection of HMG Survey Department. This network was continuously upgraded and new stations were added to the network. On July 15, 2002, 5 hydrological plots (Table 2.16), 11 meteorological plots (Table 2.17), and 7 erosion plots (Table 2.18) were monitored with the instruments as described below and situated as shown in Figure 2.16.

2.4.2.3 Yarsha Khola catchment

The Yarsha Khola catchment activities were initiated in 1997 and had to be closed down due to political unrest in that area in 2001. At the time of closure, four hydrological stations (Table 2.19), eleven meteorological stations (Table 2.20), and four erosion plots (Table 2.21) were established (Figure 2.17).

Table 2.16: **Hydrological station network of the Jhikhu Khola catchment**

(July 15, 2002)

Site No	Site Name	Stream Name	Easting UTM	Northing UTM	Altitude [masl]	Catchment Area [ha]	Available Data	Start of Record
1	Main Hydro Station	Jhikhu Khola	369444.2	3053484.3	800	11141	WL, D, S	01/01/93
2	Lower Andheri Khola	Andheri Khola	365960.7	3055503.8	850	539	WL, D, S	01/01/93
7	Kukhuri Khola	Kukhuri Khola	363935.5	3054196.9	1075	74	WL, D, S	01/01/93
8	Upper Andheri Khola	Andheri Khola	363864.9	3054180.6	1075	178	WL, D, S	14/05/97
13	Kubinde Khola	Kubinde Khola	365527.3	3058502.7	830	149	WL, D, S	10/07/97

Available Data: WL = Water level; D = Discharge; S = Sediment concentration

Table 2.17: **Meteorological station network of the Jhikhu Khola catchment**

(July 15, 2002)

Site No	Site Name	Aspect	Easting UTM	Northing UTM	Altitude [masl]	Available Data	Start of Record	End of Record
3	Acharyatol-Baluwa	Flat	366556.6	3056431.6	830	RA, AT,ST	01/01/93	-
4	Baghkhor	NE	365074.5	3055689.8	940	RA, RI	25/04/97	-
6	Bela	NW	364207.0	3053631.6	1260	RA, RI, AT, ST	01/01/93	-
9	Dhulikhel	N	357515.6	3056403.3	1560	RA, AT	01/01/93	31/12/98
10	Bajrapare	SE	358619.3	3059374.7	1100	RA	01/07/97	-
12	Tamaghat	Flat	364014.1	3059221.7	865	RA, RI, AT, ST	01/01/97	-
14	Kubindegaun	SW	365535.5	3059647.8	880	RA, RI, AT	01/03/97	-
15	Bhimsensthan	Flat	367553.9	3057460.7	880	RA, RI, AT, ST	01/01/93	-
16	Bhetwalthok	SW	369056.2	3057419.3	1200	RA, RI, AT, ST	01/01/93	-
19	Kalikasthan	NE	359007.2	3055528.4	1700	RA, RI, AT, ST	01/01/98	-
20	Higher Chiuribot	NW	363661.1	3053412.7	1275	RA	01/01/00	-
21	Lower Chiuribot	NW	363765.0	3053991.7	1190	RA, RI	19/07/00	-

Available Data: RA = Rainfall amount; ST = Soil temperature
RI = Rainfall intensity; AT = Air temperature

Table 2.18: **Erosion plot network in the Jhikhu Khola catchment**

(July 15, 2002)

Site No.	Site name	Land use	Elevation [masl]	Aspect	Orientation	Plot size [m x m]	Area [m^2]	Slope [degree]
4	Baghkhor	Grassland	940	N	NE	19.8 x 5.03	99.6	11.5
6a	Bela	Rainfed terrace	1240	N	NW	13.61 x 4.54	61.8	24.7
6b	Bela	Rainfed terrace	1280	N	NW	20.43 x 4.97	101.6	18.0
14a	Kubindegaun	Degraded	880	S	SW	20.62 x 5.02	103.5	15.0
14b	Kubindegaun	Degraded (treated)	880	S	SW	19.88 x 5.03	100.0	16.2
16	Bhetwalthok	Rainfed terrace	1200	S	SW	12.64 x 7.66	96.82	6.7
17	Ghartithok	Rainfed terrace	1150	S	SW	19.01 x 5.02	95.43	9.2
20	Higher Chiuribot	Rainfed terrace (outward sloping)	1275	S	NW	20.16 x 4.96	100.0	24.5

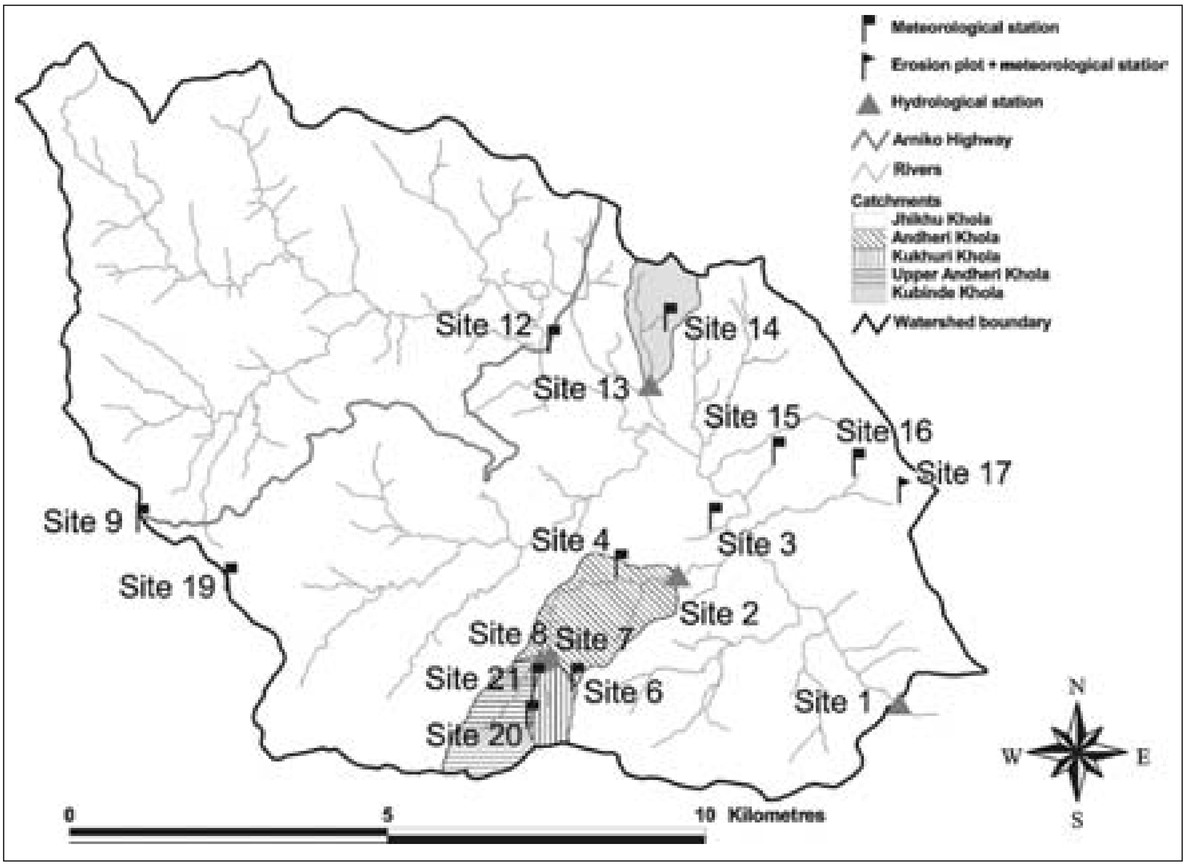

Figure 2.16: **Research monitoring network of the Jhikhu Khola catchment (July 15, 2002)**

Table 2.19: **Hydrological station network of the Yarsha Khola catchment**

Site No	Site Name	Stream Name	Easting UTM	Northing UTM	Altitude [masl]	Catchment Area [ha]	Available Data	Start of Record	End of Record
1	Main Hydro Station	Yarsha Khola	410597.9	3055928.5	990	5338	WL, D, S	15/05/97	25/06/01
2	Gopi Khola	L. Gopi Khola	410883.6	3055434.8	1040	1737	WL, D, S	17/05/97	25/06/01
5	Thulachaur	U. Khahare Khola	416903.0	3059409.6	2280	32	WL, D, S	27/06/97	25/06/01
7	Bagar	L. Khahare Khola	415838.0	3058148.1	1740	208	WL, D, S	24/06/97	25/06/01

Available Data: WL = Water level; S = Sediment concentration; D = Discharge

Table 2.20: **Meteorological station network of the Yarsha Khola catchment**

Site No	Site name	Aspect	Easting UTM	Northing UTM	Altitude [masl]	Available data	Start of record	End of record
1	Main Hydro Station	NW	410574.9	3055796.8	1005	RA, RI, AT, ST	01/06/97	27/06/01
3	Gairimudi	N	413165.8	3053855.4	1530	RA, RI, AT, ST	25/06/97	25/06/01
4	Yarsha Forest Site	NW	417474.5	3057291.2	1990	RA, RI, AT, ST	25/08/97	30/06/01
5	Thulachaur	S	417166.2	3059502.3	2300	RA, RI, AT, ST	23/06/97	27/06/01
6	Jyamire	S	416315.9	3058667.9	1950	RA, RI, AT, ST	01/06/97	26/06/01
7	Bagar (NARC)	SW	415703.9	3058154.4	1690	RA, RI, AT, ST, WS, WD, N, H	23/06/97	31/05/01
8 (old)	Nimkot	S	415011.6	3056921.6	1420	RA, RI, AT, ST	22/08/97	22/06/98
8 (new)	Lapse	S	414317.6	3057011.5	1420	RA, RI, AT, ST	04/07/98	25/06/01
9	Namdu	S	411365.6	3056816.6	1410	RA, RI, AT, ST	24/06/97	26/06/01
10	Thuloban	S	418720.4	3059978.4	2640	RA, RI, AT, ST	01/01/98	28/06/01
11	Mrige	N	415636.7	3055491.7	1610	RA, RI, AT, ST	01/06/98	25/06/01
12	Pokhari	N	414377.4	3051781.2	2260	RA, RI, AT	08/07/98	26/06/01

Available Data: RA = Rainfall amount; WS = Wind speed; RI = Rainfall intensity; WD = Wind direction; AT = Air temperature; N = Net radiation; ST = Soil temperature; H = Relative humidity

Table 2.21: **Erosion plot network of the Yarsha Khola catchment**

Site No.	Site name	Land use	Elevation [masl]	As-pect	Orien-tation	Plot size [m x m]	Area [m^2]	Slope [degree]	Start of Records	End of Records
5	Thulachaur	Grass/shrub	2300	S	SW	20.2 x 5.0	100.4	19.1	04/06/97	24/06/01
6	Jyamire	Rainfed terrace	1950	S	S	20.1 x 5.0	99.9	17.0	03/06/97	23/06/01
9a	Namdu	Rainfed terrace	1410	S	S	20.1 x 5.1	101.8	17.5	04/06/97	23/06/01
9b	Namdu	Grass/fallow	1410	S	S	20.3 x 5.0	100.7	17.5	04/06/97	23/06/01

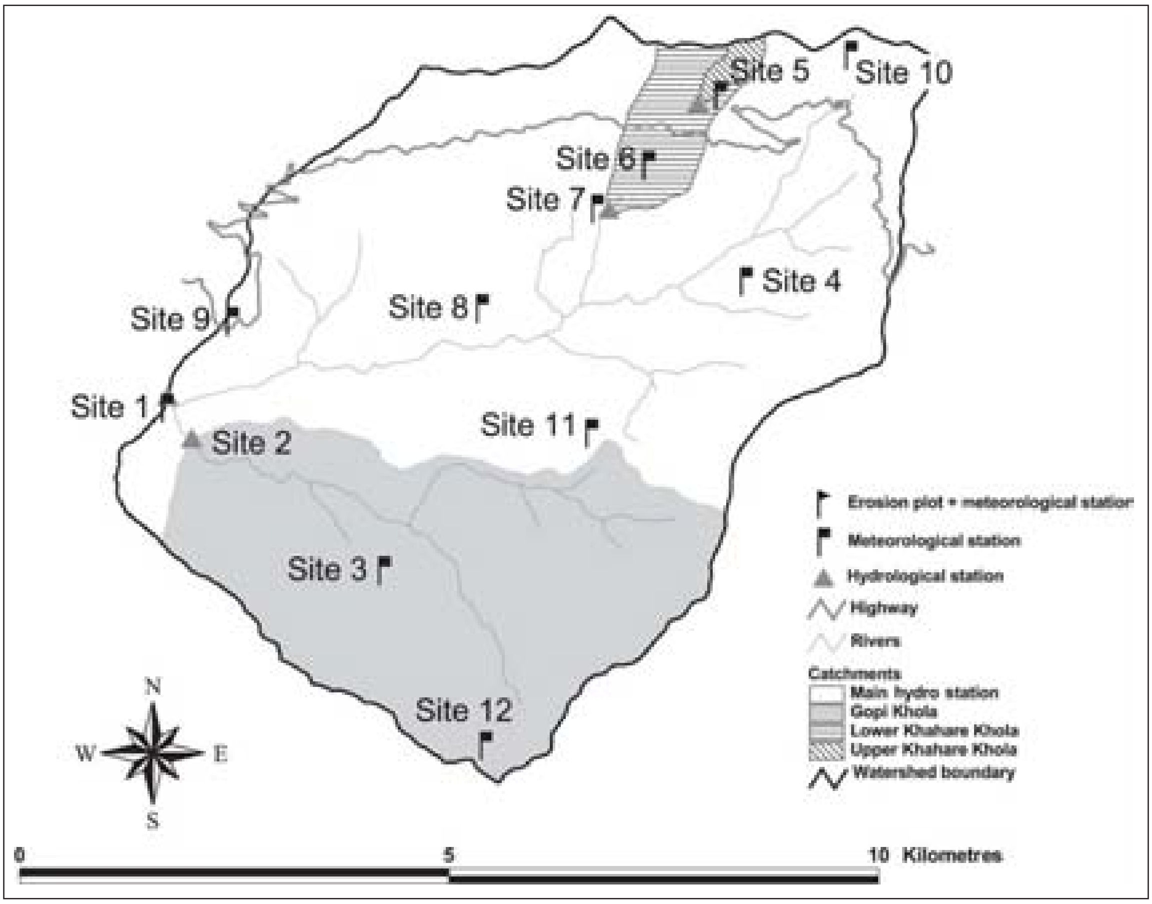

Figure 2.17: **Research monitoring network of the Yarsha Khola catchment**

2.4.3 Data management

All the data of the project is managed digitally. This means that all the data first has to be entered into digital form. All manual data, such as precipitation records, water levels, and discharge measurement results, are entered by field assistants and field hydro-meteorologists. The entered data and the data from the automatic stations are imported into HYMOS in original form and original time resolution by the project database manager. The HYMOS software developed by Delft Hydraulics in The Netherlands was introduced in 2000 at the beginning of Phase 2 with the aim of simplifying data exchange with the help of an identical data format.

In order to prevent any loss of data, the original files from the automatic recorders are kept and stored on digital media. The original recording sheets are filed and stored for later reference.

At least weekly, or whenever large amounts of data are imported, the database is backed-up on another project desktop computer and on two digital data carriers. The back-ups are kept in two different buildings to prevent data loss from fire or theft.
Data checking is a critical issue in hydro-meteorological data research. The data checking in PARDYP consists of four steps, as follow.

1. *Field check*
Upon receipt of the manual recording sheets, the readability, the plausibility of the numbers, and the digits are checked by the field assistants or the field hydro-meteorologists. In case anything is unclear, the reader can be asked for support immediately.

2. *Preliminary office check*
As soon as the data are entered into digital form, a graph is drawn for the identification of implausible values such as impossible extremes, breaks, steps, and the like.

3. *Consistency check*
When all the data are clean of outliers, the time series are checked for consistency by means of crosschecking where possible. The first check is done by comparing the same variables measured by different instruments (such as tipping bucket vs. ordinary rain gauge). A second check is performed between the same parameters of different stations.

4. *Homogeneity check*
For the homogeneity check, two methods were applied, that is, the visual double mass curve analysis (Dyck 1980) and the statistical U-test of Wilcoxon, Mann, and Whitney (Dyck 1980). The results of these analyses are presented in Appendices A3.2 to A3.5.

2.4.4 Data dissemination

At this stage, the data from PARDYP Nepal are published in the form of a yearbook in daily time series (ICIMOD 2002d; ICIMOD 2002e). The yearbook is published on a CD-ROM and is therefore very flexible. Any mistakes identified at a later stage can be eliminated for the next release of the yearbook. The yearbooks are usually updated annually. For the use of local line agencies, a summary yearbook in Nepali has been published (ICIMOD 2002f; ICIMOD 2002g).

Box 2.2: **Yearbooks**
Yearbooks are published by the government agencies collecting hydrological and meteorological data to enable access to data holdings by consultants, planners, researchers, and others who are interested. A yearbook consists primarily of checked, but still unanalysed, data. Often, simple overviews in the form of an annual graph and descriptive statistics are added.In PARDYP, the yearbook mainly aimed at two things:the publication of a yearbook forces the teams to check their datasets and compile them into readable form;andthe yearbooks can be exchanged between the different country teams.The yearbooks are by no means the final product, but act much more as a support for the data analyses at a later stage.

2.4.5 Data used for this study

This study primarily relies on data generated by the project itself. In general, daily data were used for all parameters. In the case of intensity analyses and event analyses, 10- min rainfall data and 30-min discharge were used. Appendices A3.6 (Jhikhu Khola catchment) and A3.7 (Yarsha Khola catchment) give an overview of the stations and data availability for all parameters. Secondary data and data from other sources substantiate the project's own data to put the study into the perspective of the larger area. Their sources are duly acknowledged. Unpublished data sets (received from the people who collected them) used in this study include the following.

- Godavari ICIMOD Test and Demonstration (T&D) site: meteorological data (received from Gopal Nakarmi/PARDYP Nepal)
- Dug well water levels in Shree Ram Pati and Dhuganabesi (received from Bhawani S. Dongol/ PARDYP Nepal and Monika Schaffner/PARDYP UoB)
- Community forestry areas in the Jhikhu Khola catchment (received from Bhuban Shrestha/ PARDYP Nepal)

In addition, the daily data from the PARDYP Nepal network used for this study can be found in ICIMOD (2002d) and ICIMOD (2002e).

2.4.6 Summary

PARDYP provides a unique database in the region in terms of temporal and spatial resolution. The rainfall and temperature parameters in particular are unique, providing insight into the high temporal resolution of these parameters. The discharge data are unique in their own sense, but are not uniformly of the quality one would wish. The sediment data from both the erosion plots as well as from the streams may support a number of studies into these important processes. The project team has done a lot within the framework of the project to improve data quality. However, mistakes cannot always be excluded.

In general, the measurement network is arranged in a nested approach, monitoring erosion plots, meteorological stations, and hydrological stations at different spatial levels. The set-up is such that a good spatial coverage is guaranteed and the most representative areas of the catchments are included in the measurement programme.

Data are available from 1993 to 2000 in the case of the Jhikhu Khola catchment and from 1997 to 2000 for the Yarsha Khola catchment. However, not all the sites cover the complete duration of the study period in the respective catchment. Data are continuously published in the form of a yearbook.

2.5 SUMMARY AND SYNTHESIS OF CHAPTER 2

This chapter was based on the assumption that biophysical and socioeconomic catchment characteristics influence water-related parameters, as was shown in many studies over time. A first fingerprint and assessment on whether a catchment is inherently conditioned to low water availability or is susceptible to flood generation and land degradation should therefore be possible just by looking at the catchments themselves without further monitoring of hydro-meteorological parameters. In Chapter 1, the key issues to be studied further were identified as water availability, flood generation, and land degradation induced by water. The ways in which catchment characteristics influence these key issues were highlighted throughout Chapter 2, and the main indicators will be discussed below according to each key issue after an overall summary of the chapter. The indicators will be taken up again in Chapter 5 to discuss an overall assessment, including the indicators identified from the remaining chapters along with the relevant processes.

2.5.1 Water availability

The key issue regarding water availability is governed by two base conditions:

a) the naturally available water resources in the catchment; and
b) the water demand in the catchment.

For a single household, both conditions have an impact on their water availability. If ample water is naturally available, the demand can be high and still adequate water is available. In the case of scarce water resources, a small water demand can lead to scarcity of water for the single household.

None of the above catchment characteristics indicates conclusively whether water can be assumed to be plentiful or scarce. Elevation could be used within physiographic regions, but, as Chyurlia (1984) and others showed, the relationship between elevation and rainfall changes over the boundary of different physiographic regions. While rainfall amount increases with altitude in the middle mountains, it decreases on the boundary of the Tibetan plateau. The elevation, however, plays a major role in the estimation of the snowline within the catchment (WECS 1990). The demand for water is largely governed by the catchment characteristics, mainly the areas of irrigated and rainfed cultivation. The forest areas are also believed to have a major impact on evaporation values. High population densities, particularly in the Nepal catchments, put a major stress on water quantity and quality. The current population growth rates of about 2.5 to 3% will aggravate these issues, with higher demand for increased food production and drinking water supplies.

The greater proportion and importance of agricultural land in the Jhikhu Khola catchment are accompanied by high overall agricultural intensity from the point of view of intensity, productivity, agrochemical inputs, and animal stocking density. The agricultural intensity in the Yarsha Khola catchment is of medium intensity. Agricultural intensity probably has a major impact on water resources in the catchments, in terms of both quality as well as quantity.

From a geology and soils point of view, soil acidification is a major issue for soil fertility in areas with non-limestone bedrock geology. In addition to this, phosphorous deficiency poses a risk. With the high fertiliser inputs mentioned above, phosphorous has recently become excessive in the Jhikhu Khola catchment. The same can be observed in the local drinking water supply.

A list of indicators relevant for water availability and based on catchment characteristics is presented in Table 5.1, Chapter 5 p. 291, this volume.

2.5.2 Flood generation

Duester (1994) presented a model for the estimation of extreme floods on the basis of catchment characteristics. The indicators proposed by him: elongation factor, sealed catchment area, mean slope, waste and grassland, and relative contributing areas, were partly adapted to the local conditions (Table 5.2) Chapter 5, p292, this volume. Any parameters based on the drainage network, such as the elongation factor and the relative contributing areas, should be avoided due to the large differences in mapping of this feature across the region. These indicators were therefore replaced by the Topoindex and the width/elongation ratio that basically presented the same information. The mean slope was substantiated with the slope ratio of the flat areas with the steep catchment areas. This was done to adjust for the topographic differences between the catchments with or without extended valley floors.

2.5.3 Land degradation

Degradation susceptibility is the basic condition of a catchment favouring water-caused degradation. In terms of sediment yield, Shen and Julien (1998) propose that the parameters of drainage density, catchment slope, and catchment area affect sediment yield the most. While the catchment slope and the area are incorporated, the drainage density had to be excluded due to the different details in stream network mapping in the two catchments and in comparison with other maps. Population and stocking density reportedly have a major impact on degradation and are, therefore, included, as well as a number of land-use/cover parameters. The high proportion of red soils makes the Jhikhu Khola catchment particularly vulnerable to surface erosion and land degradation. See Table 5.3, Chapter 5, p. 293, this volume for a complete list of the indicators.

SYNOPSIS 2: SPATIAL CONTEXT OF THE STUDY

The PARDYP catchments are located in a region that is naturally very dynamic and fragile. From a development point of view, the region is very static, in certain cases even moving backwards. For water resource development this poses a major challenge as:

- **the vulnerabilities are high,**
- **the financial resources are low, and**
- **the number of dependents on subsistence agriculture is high,**

From a catchment characteristics' point of view, the catchments studied have high potential for flood generation and surface erosion. Water availability is not limited due to catchment characteristics per se. However, their combination with relevant processes could lead to water shortages.

Limited data availability is a major issue for improved understanding. Data of high spatial and high temporal resolution in particular are in short supply in addition to long time series' data. Efforts by PARDYP in this direction deserve support both from official institutions and the government as well as from the donor community.