Synopsis 4: Impact of Future Scenarios

Hydrological models were used to document the potential impact of three scenarios based on global climate change, population growth coupled with increased water demand to meet basic requirements, and local land-use change with expansion to marginal lands or abandoning of marginal fields. The preliminary results for the Jhikhu Khola catchment have revealed that:

- **during the dry season water is becoming more scarce due to decreased precipitation, increased evapotranspiration, and decreased runoff;**
- **flood events during the wet season are becoming more frequent and are of marginally higher magnitude;and**
- **dependency of lower lying administrative units in a catchment on upper administrative units is increasing due to the increase of water demand in these lower areas, which are generally more accessible and productive. This calls for the introduction of catchment-based management of water resources.**

These results suggest that more attention should be paid to the storage of surplus water in the wet season to be used during the dry season, as seasonality will probably become even more pronounced in future. While domestic water use is presently below basic water requirements according to Gleick (1996), water supply should take into consideration both a change in population as well as in terms of daily water demands. This suggests that water management options of the future are to tap all available resources, minimise losses and inefficiencies, and improve considerably the quality of the water.

Chapter 5: Synthesis – What is the State of the Water Resources in the PARDYP Catchments?

"Indexes are important because they force decision-making"
(Canadian finance Minister Paul Martin)[1]

This chapter first summarises the preceding chapters with two conceptual frameworks before the application of indexes for the assessment of water scarcity, flood generation, and water-induced land degradation in mountainous catchments of the HKH region are discussed. The proposed indexes are applied to the data of the Yarsha Khola and Jhikhu Khola catchments and discussed in view of a later application of the indexes in the other PARDYP catchments in Pakistan, India, China, and other catchments of the region. These indexes are by no means a final product, but serve more to inspire further studies towards the objective comparison of catchments. The data are not only synthesised across catchments, but also within catchments according to spatial and temporal considerations.

"What is the state of the water resources in the PARDYP catchments and how will they be affected in the future?" This question has guided this study on key water-related issues in the PARDYP catchments in the middle mountains of the HKH. The studied catchments all belong to a very fragile region with an important ecological function in a greater river basin context. It is this altitudinal and physiographic zone where rainfall is greatest and the highest specific runoffs are expected (Alford 1992). It is this zone where weak geology and high uplift are prevalent. At the same time, population density and population pressure on natural resources are largest in this altitudinal zone of the HKH region (see also Chapter 2). The function of these catchments is illustrated in Figure 5.1 by Andersson and Quinn (1999), which shows the water availability in a theoretical catchment.

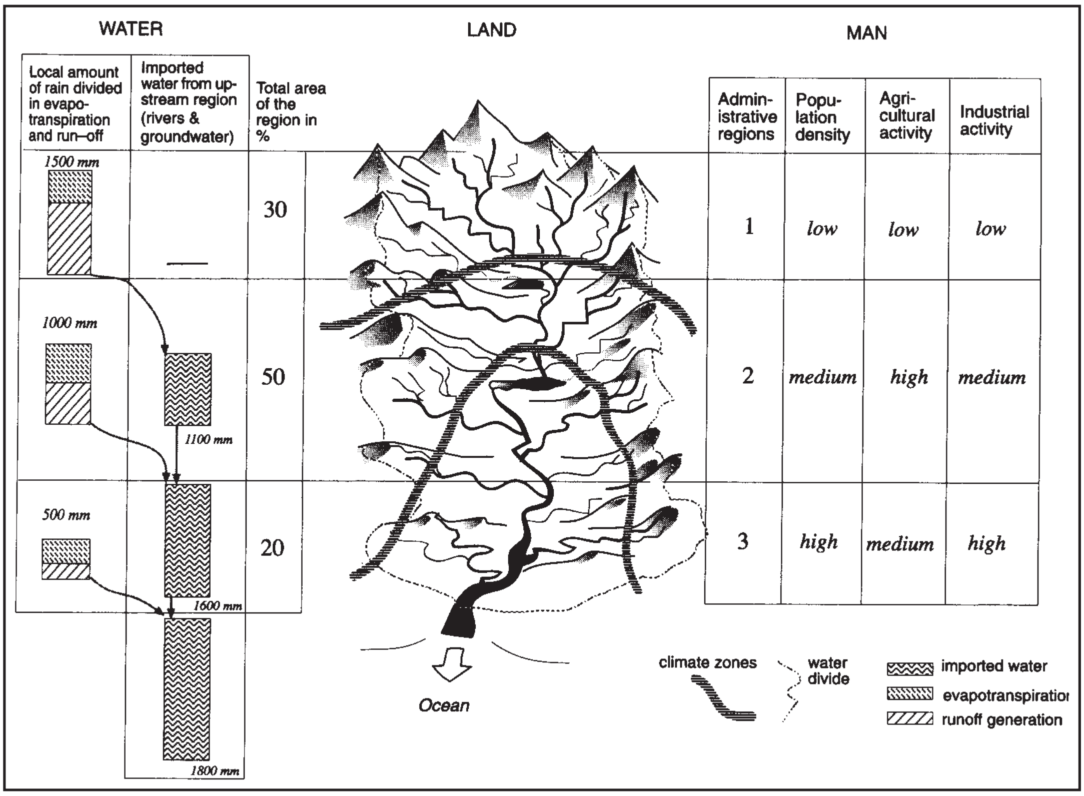

Figure 5.1: **Water availability in a theoretical catchment** (from Andersson and Quinn 1999)

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[1] Newcomb (2001)

7This figure demonstrates, in addition to the changed water availability, the changes in potential water need and the potential for water pollution downstream due to increased population as well as agricultural and industrial activities. The PARDYP catchments belong to the middle catchments and are indicative of administrative units in region 2. In the context of the middle mountains of the HKH region, the population density is high and industrial activities are generally low with the exception of some main valleys such as the Kathmandu or the Doon valleys. Agricultural intensity is often high as is also indicated in this figure. In this context, the studied catchments not only play an important role in the livelihoods of the residents, but also for people further downstream and signs of eutrophication are omnipresent. In terms of water, the PARDYP catchments are headwater catchments and therefore have no inflow from the regions above. All water resources in the catchments are from precipitation only, feeding the surface and groundwater resources.

Below, a summary of the main findings and discussions in the preceding chapters is given through the assessment of the three main susceptibilities related to water in the region — flood generation, land degradation, and water scarcity. The assessment is guided by three indexes based on a number of indicators identified during the course of this study. These indexes should provide a basis for further studies in the region by applying the methodology to other catchments of different size, location, and socio-political context.

The inter-catchment comparison is followed by an intra-catchment synthesis, which will be important for the development of a decision support system as planned for Phase 3. This intra-catchment synthesis focuses on the spatial dimension with particular stress on the topographic dimension, as well as the temporal dimension with particular focus on intra-annual variability.

5.1 CONCEPTUAL FRAMEWORKS

The results of the preceding chapters with particular reference to the key water issues of water availability, floods, and sediment transport are presented in two conceptual frameworks in Figure 5.2 and Figure 5.3.

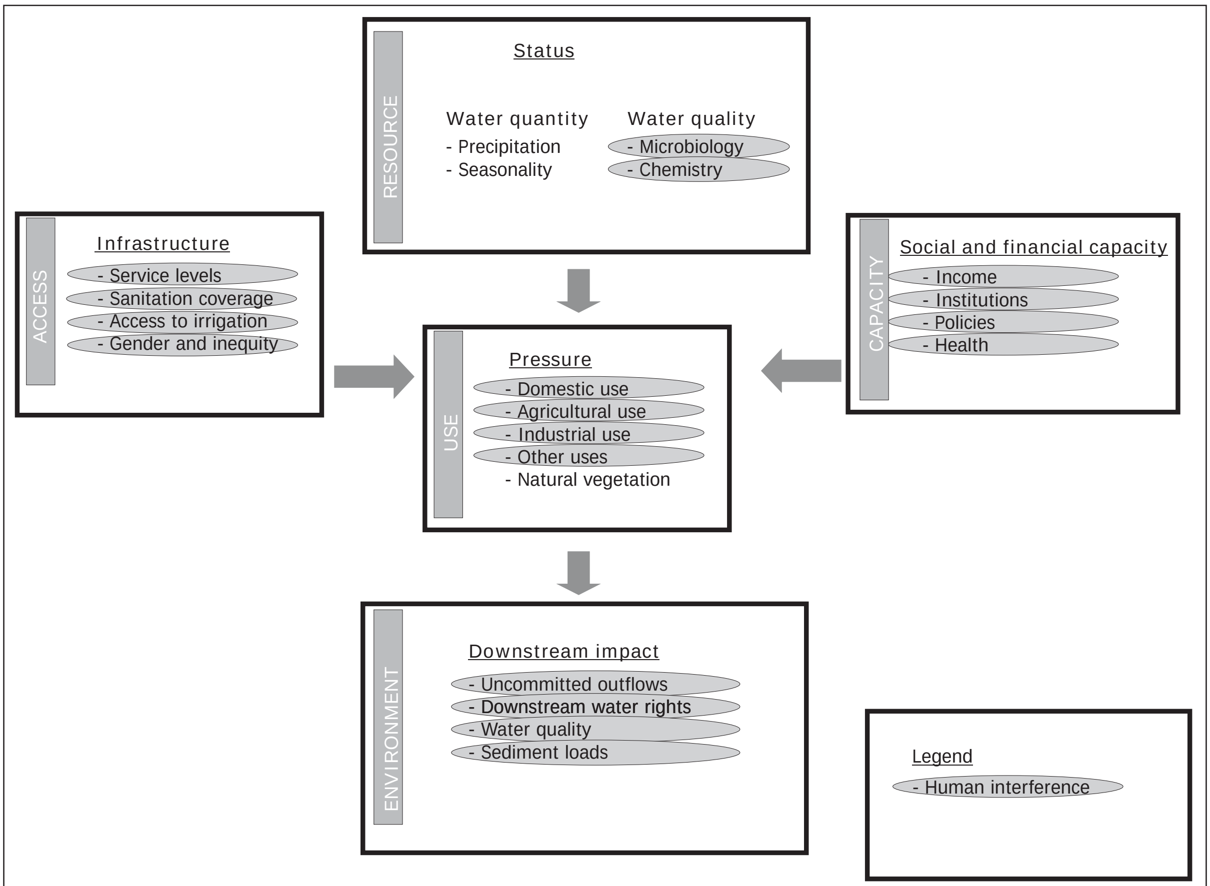

Figure 5.2: **Conceptual framework of water availability in middle mountain catchments of the HKH**

These frameworks are later translated to indexes in the next section. The conceptual framework describing the water availability generally follows a state-pressure-impact approach with the hydro-meteorological and water quality characteristics being the status, the use of water the pressure, and the downstream water availability and quality being the impact. The pressure component is additionally influenced by the infrastructure, which describes the overall access to water resources, and the social and financial capacity of the catchment's residents to cope with the current status and pressure. It is important to note that most of the components in the framework are heavily influenced by human impact with the exception of rainfall and its seasonality.

Flood generation and water-induced land degradation show a different picture in terms of human influence (Figure 5.3). Both processes are directly dependent on the potential hazard, which is mainly a function of hydro-meteorological characteristics. As shown in Section 3.4, there is a significant difference between major events and small to medium events. While the land condition (here also described as base condition) plays a role in the generation of small to medium events, for major events these land conditions can be neglected in the case of flood generation. The hazard coupled with the land conditions produces a certain flood magnitude as a consequence. Given that there is a risk within or immediately downstream of the catchment, potentially a loss has to be expected. The risk, by definition, is completely influenced by humans.

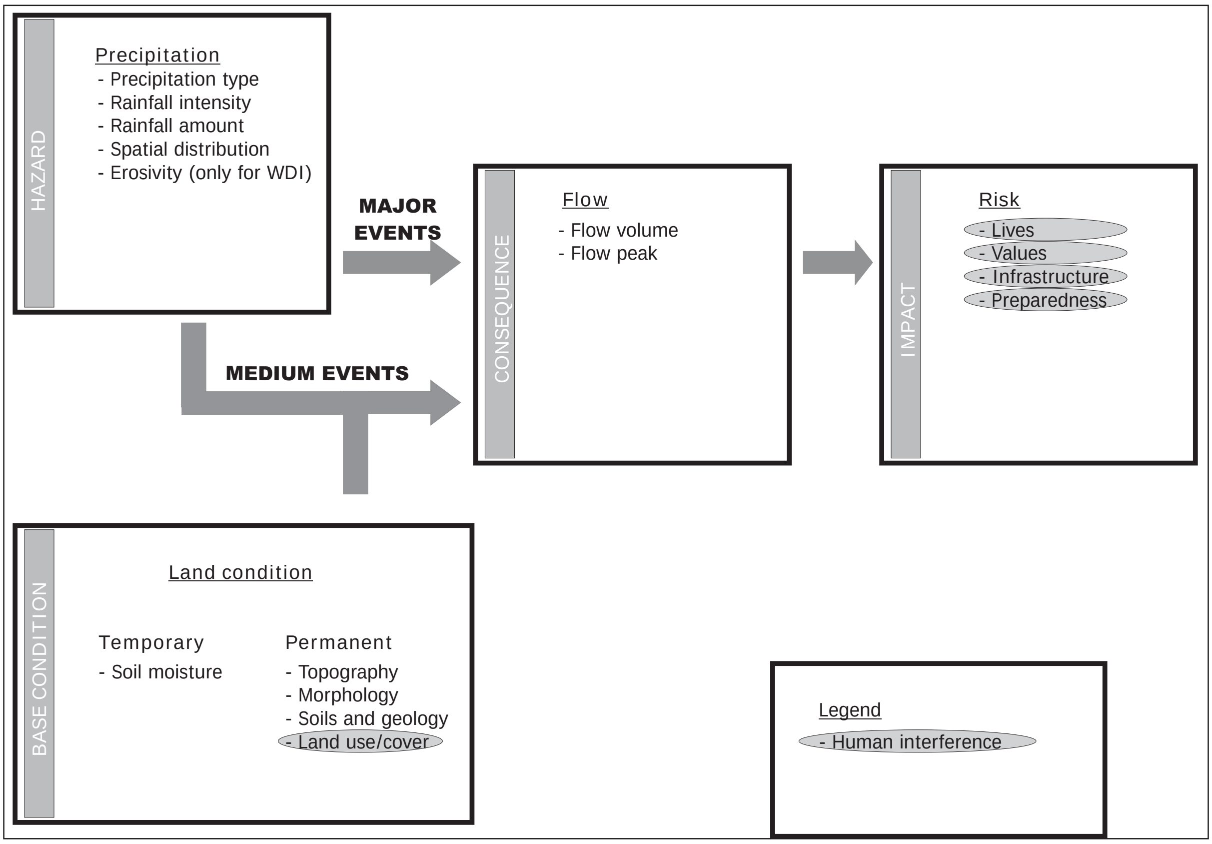

Figure 5.3: **Conceptual framework of flood generation and water-induced degradation in middle mountain catchments of the HKH**

5.2 ASSESSMENT OF DIFFERENT SUSCEPTIBILITIES FOR INTER-CATCHMENT SYNTHESIS

5.2.1 The use of indexes in environmental assessments

As briefly discussed in Chapter 1 the different susceptibilities can be expressed by a number of indicators and finally synthesised in an index for each susceptibility. These indexes can be compared between different catchments, and progress in terms of water resources development, soil conservation, and flood protection can be assessed.

The use of indexes is widespread in economic sciences for assessment and monitoring. The assessment and monitoring of gross domestic product (GDP) uses the WEF Current Competitiveness Index (WEF 2002); human development uses the Human Development Index HDI, the Human Poverty Index HPI, and the Gender Related Development Index GDI (all UNDP 2001); while environmental sustainability and sustainable development employ the Environmental Sustainability Index ESI (WEF 2002), and Indicators of Sustainable Development (CSD 2001). Environmental sustainability and sustainable development also use a number of other indexes mentioned in WEF (2002), as well as those from other fields such as the Living Planet Index (WWF 2002), or the Disability Adjusted Life Year DALY (WHO 2002). These indexes provide a holistic assessment of current conditions, including a set of predefined indicators. But, as Sullivan (2002) remarks, none of these indexes recognises the importance of water to all forms of life. A number of indexes incorporate indicators related to water, e.g., ESI, HDI, however they base the importance of water only on access to safe drinking water, overall water availability, sanitation, and a number of water quality parameters. Indicators such as workload for water fetching (which has a major impact on the amount of water used per household as well as the workload of women in particular; see Gleick 1996), water losses, livestock water demand, local perceptions, and others are generally missing.

In addition to the indexes mentioned, a number of global assessments of water-related issues without the target to determine an index have been presented with a set of interesting indicators (World Bank 1998; Seckler et al. 1998; Shiklamonov 2000; Gleick 2000; WSSCC 2000; OECD 2001; UNESCO-WWAP 2003).

In the literature a number of indexes are proposed for different applications related exclusively to water. Some examples are listed below.

- Sullivan (2002) proposes the Water Poverty Index as a tool to monitor progress towards development targets in water projects and improved satisfaction of the needs of the current generation while securing water availability for future generations (for more details about the WPI, see below).
- Yoffe and Ward (1999) propose an index related to water and conflicts with the aim of identifying river basins with conflict potential over water resources from both an intra-state and interstate perspective.
- Ohlsson (1999) proposes the Social Water Stress Index, which is calculated by dividing a water stress index such as the freshwater availability per capita by the HDI and dividing the result by two.
- Zandbergen (1998) discusses an approach to assessing the health of urban catchments using selected indicators such as imperviousness, riparian forest cover, water quality indexes and others.
- Salameh (2000) proposes another Water Poverty Index with a particular focus on the rainfed agricultural land and suitability in semi-arid and arid conditions.

5.2.2 The FGI, WDI and WPI

In order to capture the specificity of water as an important resource at the same time as a medium for destruction, three different indexes are proposed in the context of rural catchments in the mountainous areas of the HKH.

The proposed indexes with their respective indicators are suitable from the perspective of a middle mountain catchment in the HKH. From the major issues related to water within these catchments or under the direct influence of these catchments downstream it is important to note that water availability and land degradation have a direct impact on the livelihood of the local households and people. Floods, although in places a threat —as for example in the Kathmandu Valley — pose a risk mainly further downstream from these meso-scale mountain catchments. They also put infrastructure, such as bridges and roads, close to the rivers at risk.

In general, the three indexes have a score range from 0 to 100, showing the largest susceptibility with 0, i.e., the worst-case scenario. Each index consists of a number of components describing a general characteristic important for the calculation of the final index. Each component likewise has a score from 0 to 100 and can be weighted according to the user's requirements. The maximum scores of 100 are based on maxima mentioned in the literature, e.g., the potential evapotranspiration in the Tharr desert of 2000 mm according to Wyss (1993). In certain cases, maxima had to be assumed in the absence of any meaningful maxima in the literature. The indexes are calculated as shown in Equation 5.1:

$$I = (w_1 * C_1 + w_2 * C_2 + ... + w_i * C_i)/N$$ (adapted from Sullivan 2002) **Equation 5.1**

where

I = index
w_i = weight of the respective component
C_i = component
N = number of components

In Equation 5.1, weights are introduced, however, for the first use of the indexes below all weights were kept as 1.

The components consist of a number of measurable indicators. The most informative indicators and parameters for each index were identified in the course of this study and are discussed below for an assessment of the studied catchments and a comparison with other catchments of the region.

In terms of water availability, Sullivan (2002) proposes the Water Poverty Index (WPI-CEH) as discussed briefly in Chapter 1 and above, and this framework is adapted in this study. A first assessment of the nation-wide WPI-CEH assessment showed Finland at the top indicating it to be the most water-rich country, followed by Canada, Iceland, and Norway. The list ends with Eritrea, Ethiopia, Niger, and finally Haiti (WWC/CEH 2003). Nepal (ranked 90) shows an overall moderate score with a weak score for access and environment, a moderate score for capacity and resource, and a high score for water use. However, as the press release mentions, the final aim of the WPI is to provide a tool for monitoring progress in relation to development of water resources , mainly at the community or district level. The importance of indexes for this level of spatial aggregation and with particular focus on the mountain regions of the world was also stressed by Kreutzmann (2001). The above-mentioned indicators are generally based on national statistics. While this allows the use of regularly collected data and herewith decreasing amount of required funds, it does not cater for the specific conditions of the heterogeneous mountain conditions, and this was highlighted by Kreutzmann (2001) with examples from Nepal and Pakistan. The wide range of conditions amongst the different districts of Nepal in terms of development was also presented in Banskota et al. (1997).

The **Water Poverty Index (WPI)** in this study is a holistic measure of water supply conditions, including the availability of water resources adjusted for quality and reliability (*RESOURCE*); the water demand for different human purposes (*USE*); the effective access to water resources, e.g., in terms of distance and time (*ACCESS*); the human and financial capacity to manage the water supply system (*CAPACITY*); and finally the environmental demands and constraints related to water (*ENVIRONMENT*) (CEH, 2002). The WPI follows the conceptual model presented in Figure 5.2.

WPI = f(resource, capacity, use, access, environment)

- resource = f(hydro-meteorological characteristics, perception)
- capacity = f(income, social networks and user groups, health)
- use = f(water demand for different sectors)
- access = f(infrastructure, gender issues)
- environment = f(water quality, sediment)

In terms of flood generation, the main aim is to document the susceptibility that the catchment actively contributes in the generation of a flood and the threat that these floods pose to downstream areas. The latter is difficult to assess.

Duester (1994) and Weingartner (1999) propose the index ‘Hochwasser-Disposition’ (flood potential, also briefly discussed in Chapter 2), which indicates the susceptibility of a catchment to generating a flood. This index is based solely on the contributing area, which itself is based on the slope and the distance from the channel, and the total catchment area. Another index in this respect is the Topoindex, which relates the topography to the saturation potential of a catchment (Quinn et al. 1991; see also Chapter 2). This index is based on the slope of each cell and the area above draining into this cell. In certain studies, the soils have been included in the Topoindex framework to produce a soil topographic index (Schulla 1997). The two indexes above are purely based on topographical catchment characteristics (and soil characteristics), but they do not include any information about the potential hazard and the risk given in the catchments, hazard and risk being defined as in Chapter 1.

The proposed **Flood Generation Index (FGI)** is based on the inherent condition of a catchment and the channels towards generating a flood or becoming flooded (*BASE CONDITION*) as well as the related hydro-meteorological processes favouring flood generation (*HAZARD*); and the lives, values, or infrastructure at risk within the catchment or downstream within direct influence of the processes in the catchment (*RISK*). The risk in this context incorporates the people’s preparedness and strategy for protection of their lives and infrastructure. This aspect could also be separated as human, social, and financial capital, but in the context of mountain catchments where flooding is only a limited threat, it was deemed possible to lump them together. The conceptual model for flood generation and flood risk is presented in Figure 5.3.

FGI = f(base condition, hazard, risk)

- base condition = f(catchment characteristics)
- hazard = f(hydro-meteorological characteristics)
- risk = f(infrastructure, capacity, perception, preparedness)

Similarly, the **Water Induced Degradation Index (WDI)** describes the condition of a catchment in terms of vulnerability to land degradation caused by water taking into consideration human activities as well as natural conditions. The inherent condition of the catchment favouring sediment mobilisation and transport (*BASE CONDITION*) is based on catchment characteristics. Hydro-meteorological characteristics describe the potentially hazardous processes (*HAZARD*). The people’s preparedness to cope with the defined hazards as well as potential losses in terms of infrastructure and livelihoods are described in the sub-index *RISK*.

WDI = f(base condition, hazard, risk)

- base condition = f(catchment characteristics)
- hazard = f(hydro-meteorological conditions)
- risk = f(soil conservation, capacity, perception)

The parameters relevant to certain issues and indexes may change over time and therefore pose a new base for the relevant susceptibilities. With changed conditions the catchment has a new vulnerability to certain processes and therefore possesses a new susceptibility, shown by a new index value. The impact of project activities at the catchment or sub-catchment scale can also be assessed through examining changes in conditions and vulnerabilities and calculating a new index value. Other changes may be due to changes in driving forces, here understood as scenarios, e.g., climate change or policy change. These may impact on the status as well as the processes relevant to a key issue. This leads to an overall change in the respective susceptibility. With the understanding of a certain impact on susceptibility, adverse effects can be averted by employing the appropriate measures. This study will provide recommendations on the basis of the selected datasets and scenarios. However, solutions will not be discussed in this study as further investigation is still required, and is the main thrust of PARDYP’s Phase 3.

For the interpretation of the indexes refer to Table 5.1. In general terms, it can be said that an index value of 100 indicates favourable conditions with adequate water supply, no flood, and no degradation threat. An index value of 0 indicates considerable water supply issues, a high likelihood of flooding, and land degradation through water. The values in Table 5.1 are theoretical, as these values are not likely to be achieved in any situation, but they should indicate the given trends towards maximum or minimum extremes.

Table 5.1: **Explanations for theoretical index extremes**

Score	WPI	FGI	WDI
100 **=‘good’**	Water supply is ample and the local demand can be met without impact on the environment; low susceptibility	Floods are not likely to be generated and flooding poses no risk; low susceptibility	There is no reason to believe that land degradation through water is occurring and no risk identified; low susceptibility
0 **= ‘bad’**	Water poses a major problem and neither the population’s demands can be met nor the demands of the environment; high susceptibility.	Flooding poses a high risk and flood events are likely to be generated; high susceptibility	Land degradation through water is likely to occur; high susceptibility

5.2.3 The indicators

On the basis of the analysis in the preceding chapters as summarised in Figures 5.2 and 5.3 and the literature, several indicators were identified that:

a) contribute relevant information towards the assessment of the respective susceptibility, and
b) can be easily measured, determined in a household survey, looked up in the literature, or in national, district or local statistics.

According to Yoffe and Ward (1999), when selecting the indicators it is important that they sufficiently simplify the target system characteristics and that they have adequate spatial and temporal coverage so they can be effectively represented and modelled. In addition, Zandbergen (1998) suggests that some of the indicators should be directly linked to human activities and management to provide an entry for possible intervention and improvement strategies. On the number of indicators he comments that “a fairly high level of integration using a small set of indicators is considered desirable”. Winograd et al. (1999) suggest the use of a small set of well-chosen indicators for the most effective results. Some of the indicators were used by Schreier et al. (2002) for a comparison of Himalayan and Andean catchments to identify those issues in eight catchments of the two mountain ranges that were common to both and those that were different. While this comparison was qualitative, here an attempt is made to provide a more ‘measurable’ and ‘objectively comparable’ means of assessment, but only focusing on the key issues of water resources. It is important to note that, according to Schreier et al. (2002), in all of the eight catchments either water availability, soil erosion, or both figure among the identified key issues. The same was shown by Merz et al. (2003d) in a preliminary and first comparison of the five PARDYP catchments. The selection of parameters and indicators is based on the catchment characteristics and process analyses of Chapters 2 and 3. Overall, 155 parameters are required to calculate the 95 indicators that describe the three indexes. These parameters, appended in Appendix A5.1, are preliminary and need to be tested on the basis of a number of catchments (see Chapter 6). The aim should then be to reduce the number of parameters and indicators.

5.2.3.1 Water Poverty Index (WPI)

As mentioned above, for the WPI, , five sub-index values are calculated: resource, access, use, capacity, and environment. These sub-indexes include the main parameters related to water scarcity and its causes. A complete list of indicators for the WPI is compiled in Table 5.2. In general, the naturally available water resources are assessed using precipitation input, evapotranspiration outputs, and general water quality. In terms of access to water resources, the service levels are assessed as discussed in Chapter 2. Sanitation coverage is also important. The water demand of different sectors gives a total of the overall water use in the catchment. The sub-index environment is mainly based on the integral response of the catchment at its outlet, including water quality, sediment loads, and downstream water availability. Altogether, 111 parameters are required to calculate the 45 indicators of the WPI. Twenty indicators are required for the sub-index resource, 4 indicators for access, 7 indicators for use, 7 indicators for capacity, and 7 for environment.

Table 5.2: **Indicators for the Water Poverty Index**

Indicators	Unit	Relation*	Min	Max	Description/Reference
		Resource			
Precipitation	Mm	direct	0	27000	world record line; WMO(1994)
Evapotranspiration	Mm	inverse	0	4000	2000 mm in the Tharr desert; Wyss (1993)
Runoff	Mm	direct	0	3000	Preliminary value
Seasonality precipitation		inverse	0	3.46	maximum based on 100 % rainfall in one month
Seasonality runoff		inverse	0	3.46	minimum based on equal rainfall distribution
Water deficit	No	inverse	0	12	no. of months per year
Rainfall variability-pre-monsoon season		inverse	0	2	assumed maximum
Rainfall variability-post-monsoon season		inverse	0	2	assumed maximum
Rainfall variability-winter season		inverse	0	2	assumed maximum
Annual dry spells	No	inverse	0	24	maximum no. of dry spells possible per year
Average length of dry spell	Days	inverse	0	365	no. of days per year
Longest observed dry spell	Days	inverse	0	365	no. of days per year
Days without rainfall (P < 1 mm)	Days	inverse	0	365	no. of days per year
Microbiological contamination		inverse	1	4	four classes according the WHO (1997)
Water treatment coverage	%	direct	0	100	
Waste-water treatment coverage	%	direct	0	100	
Perception on water quantity–Female	%	inverse	1	2	yes/no
Perception on water quality–female	%	inverse	1	2	yes/no
Perception on water quantity--male	%	inverse	1	2	yes/no
Perception on water quality–male	%	inverse	1	2	yes/no
		Access			
Service levels for drinking water supply		inverse	1	4	four classes according to RWSSSP (1994)
Access to sanitation facilities		direct	0	100	
Access to irrigation facilities		direct	0	100	
Percentage of women fetching water		inverse	0	100	
		Use			
Annual water demand for crop production	mm	inverse	0	5000	2 crops of rice + another crop
Cropping intensity on irrigated land	%	inverse	0	400	maximum of 4 crops
Cropping intensity on rainfed land	%	inverse	0	400	maximum of 4 crops
Annual water demand for domestic use	l/person*day	inverse	0	500	
Annual water demand for livestock	mm	inverse	0	25	10 TLU/ha*61l*365days*area
Annual water demand for industries	mm	inverse	0	1000	assumed maximum
Other water demands	mm	inverse	0	1000	assumed maximum
		Capacity			
Institutional organisation-irrigation	org./km^2	direct	0	5	preliminary value
Institutional organisation-drinking	org./km^2	direct	0	5	preliminary value
Patients with water related diseases	%	inverse	0	100	
Children under 5 with diarrhoea	%	inverse	0	100	
Infant mortality rate	per 1000	inverse	0	1000	
Household income	US$	direct	0	5000	preliminary value
Literacy rate	%	direct	0	100	
		Environment			
Sediment load	t/ha/y	inverse	0	200	80 t/ha/y; Lauterburg (1993)
Phosphate load (as P)	mg/l	inverse	0	10	7 mg/l in Bagmati river (CEMAT, 2000)
Nitrate load (as N)	mg/l	inverse	0	100	100 mg/l (measured in New Zealand); Close et al. (2001); 60 mg/l in Bagmati River (CEMAT, 2000)
Phosphorous fertiliser	kg/ha	inverse	0	500	
Nitrogen fertiliser	kg/ha	inverse	0	500	
Water demand natural vegetation	mm	inverse	0	2000	preliminary value
Committed outflows/Average runoff	%	direct	0	100	

* The relationship indicates whether the respective parameter is directly or inversely related to the index, e.g., the more rain, the better for the WPI = direct relation, the more evapotranspiration, the worse for the WPI = inverse relation.

An example of how the sub-index Access of the WPI is calculated is shown in Table 5.3. In total, eight parameters (A) are required to calculate the four indicators (B) of this sub-index. The overall service level for drinking water supply valid for the entire catchment (C) is based on the percentages for each class from 1 to 4. It calculates thus: (57.4*1+15.0*2+4.7*3+14.4*4)/(57.4+15.0+4.7+14.4) = 1.7. On a scale from 1 to 4 (i.e., service levels 1 to 4), 1.7 lies at 24.6 %. As the relationship between the index and the indicator is inverse, i.e., the higher the index the worse the conditions, the indicator is calculated as 100-24.6 = 75.4. In the case of access to sanitation facilities, where the relation between the indicator and the sub-index is direct, i.e., the higher the percentage of households with access to sanitation the better, the indicator value is directly obtained with 30 %. The total score of this sub-index is calculated according to equation 5.1. For further discussion of the calculation refer to the MSExcel macro (see below).

Table 5.3: **Example for the calculation of the sub-index access of the WPI**

Parameter (A)	Unit	Value	Source	Indicator (B)	Value		
Service levels of water supply							
Service level 1-good	**%**	57.4	Merz et al. (submitted_b)	--> **Service levels for drinking water supply (C)**	**75.4**	--> ***Total score for Access:***	***52.8***
Service level 2-intermittent	**%**	15					
Service level 3-poor	**%**	4.7					
Service level 4-very poor	**%**	14.4					
Not assessed	**%**	8.5					
Access to sanitation							
People with access to sanitation facilities	**%**	30	Estimate	--> **Access to sanitation facilities**	**30.0**		
Access to irrigation infrastructure							
People with access to irrigation water	%	70	Estimate	--> **Access to irrigation facilities**	**70.0**		
Women's workload							
Percentage of women exclusively fetching water	%	64	Merz et al. (2002)	--> **Women exclusively fetching water**	**36.0**		

5.2.3.2 Flood Generation Index (FGI)

The FGI is based on the sub-indexes of hazard, basic condition, and risk. While the hazards are mainly based on rainfall and discharge parameters describing the potentially destructive forces, the basic condition describes the current state of the catchments. The risk parameters are preliminary and need more detailed investigations. This is in terms of actual values in the catchments as well as the scores. The parameters' values, bridges, and population describe the potential losses; while the preparedness and the mitigation coverage, as well as the perception, describe the overall ability to cope with the potential hazard. A complete list of indicators for the FGI is appended in Table 5.4. The index is based on 25 indicators, including 9 indicators describing the hazard, 8 describing the basic condition, and another 8 representing the risk.

5.2.3.3 Water-induced Degradation Index (WDI)

The WDI is calculated from 25 indicators made up of 10 indicators describing the hazard, 10 describing the basic condition, and 5 describing the risk. A complete list of indicators for the WDI is compiled in Table 5.5. This index consists basically of the same indicators as the FGI with the exception of erosivity and sediment load in the sub-index hazard. The basic condition additionally includes the population and livestock stocking densities. The risk sub-index of the WDI is described by the soil conservation coverage, showing the preparedness of the population as well as by the perception on soil erosion and the potential losses in case of severe soil erosion. This is described by the portion of the on-farm income in relation to the total income as well as the productivity of the land.

In order to simplify the calculation procedure, an MSExcel spreadsheet was prepared and appended as Appendix B8. This spreadsheet basically includes a navigation main sheet (Figure 5.4), data entry sheets, index calculation sheets, and summary sheets in both tabular and graphical forms. A brief

Table 5.4: **Indicators for the Flood Generation Index**

Indicators	Unit	Relation*	Min	Max	Description / Reference
Hazard					
Maximum 60 minute rainfall intensity	mm/h	inverse	0	401	world record line; WMO (1994)
20 year return period 60 minute rainfall intensity	mm/h	inverse	0	401	world record line; WMO (1994)
Maximum daily rainfall	mm	inverse	0	1825	world record line; WMO (1994)
Probable maximum precipitation (PMP)	mm	inverse	0	1825	world record line; WMO (1994)
20 year return period for daily rainfall	mm	inverse	0	1825	world record line; WMO (1994)
Daily discharge, maximum	$l/s*km^2$	inverse	0	1000	Preliminary value
Ratio maximum/average discharge	%	inverse	0	100	
Q5 (exc)	$l/s*km^2$	inverse	0	1000	Preliminary value
25 year return daily discharge	$l/s*km^2$	inverse	0	1000	Preliminary value
Basic condition					
Mean slope	deg	inverse	0	45	
Mean topoindex		inverse	0	30	
Elongation ratio (width/length)		direct	0	2	
Irrigated agricultural land	%	direct	0	100	
Ratio cultivated/uncultivated land	%	direct	0	100	
Grassland/pasture	%	inverse	0	100	
Degraded land	%	inverse	0	100	
Other land use/cover	%	inverse	0	100	
Risk					
Values [in % of total catchment income)	%	inverse	0	100	
Bridges	bridges/ km^2	inverse	0	5	Preliminary value
Livelihoods (houses and agricultural land)	%	inverse	0	100	
Lives	%	inverse	0	100	
Population density	people/km2	inverse	0	5000	
Perception	%	inverse	0	100	
Flood preparedness	%	direct	0	100	
Flood mitigation coverage	%	direct	0	100	

* The relationship indicates whether the respective parameter is directly or inversely related to the index, e.g., the more rain, the better for the WPI = direct relation, the more evapotranspiration, the worse for the WPI = inverse relation.

Table 5.5: **Indicators for Water Induced Degradation Index**

Parameter (A)	Unit	Value	Source	Indicator (B)	Value		
Service levels of water supply							
Service level 1-good	**%**	57.4	Merz et al. (submitted_ b)	--> **Service levels for drinking water supply (C)**	**75.4**	--> ***Total score for Access:***	***52.8***
Service level 2-intermittent	**%**	15					
Service level 3-poor	**%**	4.7					
Service level 4-very poor	**%**	14.4					
Not assessed	**%**	8.5					
Access to sanitation							
People with access to sanitation facilities	**%**	30	Estimate	--> **Access to sanitation facilities**	**30.0**		
Access to irrigation infrastructure							
People with access to irrigation water	%	70	Estimate	--> **Access to irrigation facilities**	**70.0**		
Women's workload							
Percentage of women exclusively fetching water	%	64	Merz et al. (2002)	--> **Women exclusively fetching water**	**36.0**		

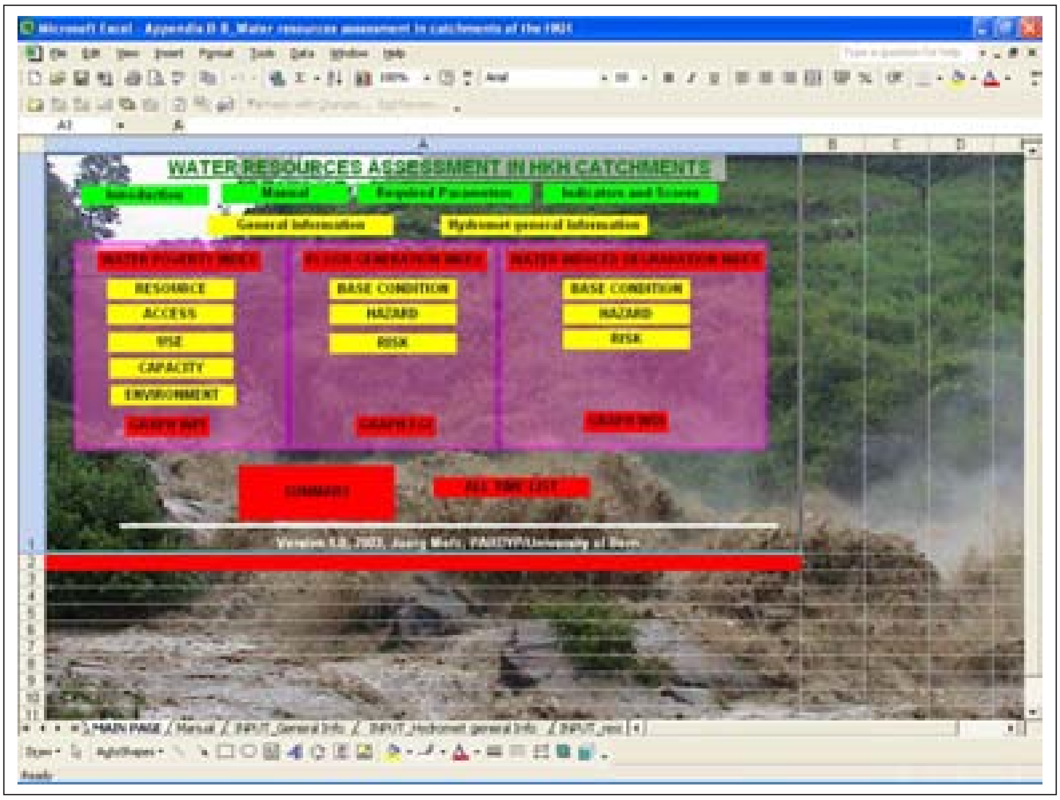

Figure 5.4: **Navigation main sheet for water resource assessment in HKH catchments**

manual explaining the colours used and the different functions is included as a separate sheet. The idea of this spreadsheet and the reason that it is coded in MSExcel is so that the project can test the approach in other catchments and develop it further for potential up-scaling.

5.2.4 Application of the proposed indexes

The three indexes were primarily applied to the two catchments in Nepal, the Jhikhu and Yarsha Khola catchments. For a first preliminary comparison they were also applied to the available information from the remaining PARDYP catchments. In addition the impact of two scenarios is assessed using the index approach and the WPI in particular.

5.2.4.1 Comparison of the indexes for the Jhikhu and the Yarsha Khola catchments

In the Jhikhu Khola catchment, the WPI assumed a value of 59.2 points with the following values for the sub-indexes: resource, 46.8 points; access, 52.8 points; use, 80.3 points; capacity, 49.9 points; and environment, 66.4 points. The complete file, including the input data and the score limits, is included as Appendix B.9. For the meaning of a high or low index value refer to Table 5.1; but it should however be remembered that the indexes are a relative measure and therefore show their best results in comparison with other catchments (see below).

The values of the sub-indexes show that in the Jhikhu Khola catchment a problem with water availability has to be expected, as indicated by the low resource value. The other values that are rather low are access and capacity. This is not surprising in the context of Nepal, with the often long distances to the water sources, the high burden on women's shoulders in terms of fetching water , generally poor access to sanitation and irrigation facilities, as well as low service levels for drinking water supply. The capacity is low due to low income, generally bad health, and low education status as shown with low literacy rates. Use shows a high value due to the low water demands for domestic, industrial, and other uses in the catchment. Agricultural demand is high in the catchment, although this is not shown by the index mainly because of the high maximum on the score board with two crops of rice and an additional crop. It is expected that this value will show low values in comparison with the other catchments.

The FGI assumed a value of 75.4 points with the following sub-index values: basic condition, 59.2 points; hazard, 81.2 points; and risk, 85.9 points. The hazard value results are quite low, although the rainfall characteristics on a first observation (see Section 3.1) indicate rather high rainfalls and high intensities. The WDI showed a value of 61.4 points with a basic condition of 74.8 points, a hazard value of 70.9 points, and a risk value of 38.6 points. For a graphical representation refer to Figure 5.5.

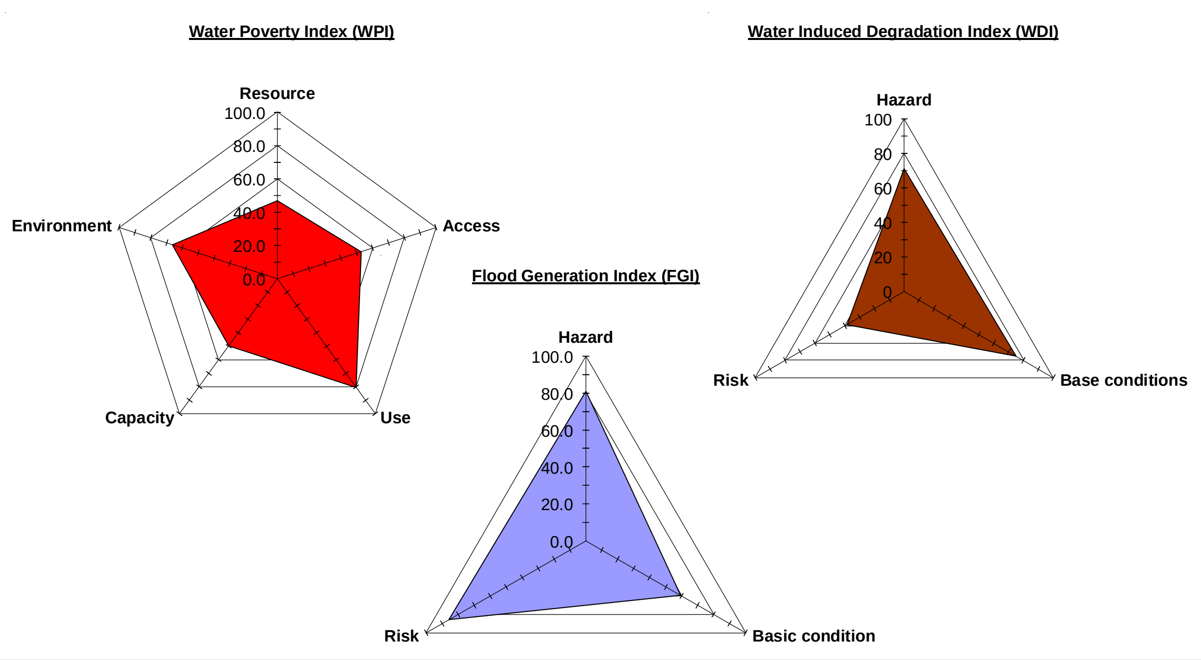

Figure 5.5: WPI, FGI, and WDI of the Jhikhu Khola catchment

In the Yarsha Khola catchment, the WPI assumed a value of 63.2 points with sub-index values of 54.5 points for resource, 55.6 points for access, 82.4 points for use, 47.6 points for capacity, and 76.1 points for environment (for the detailed file including the input data and the score board refer to Appendix B.10). A graphical comparison of the three indexes in the Yarsha Khola catchment is shown in Figure 5.6.

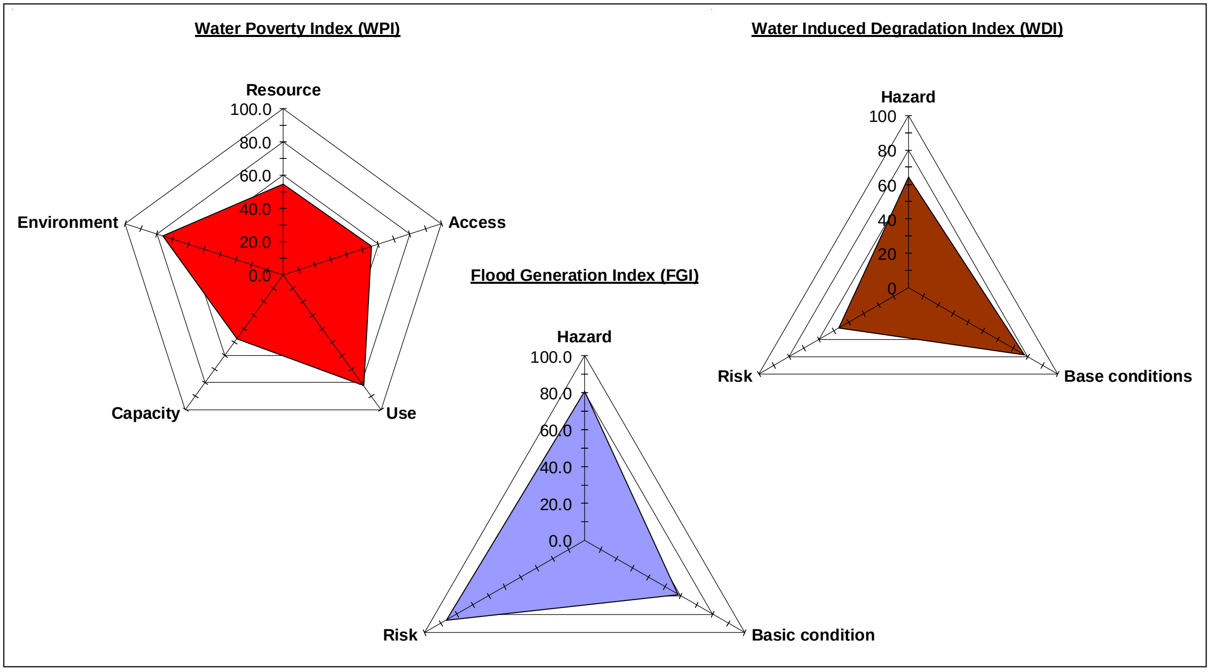

Figure 5.6: WPI, FGI, and WDI of the Yarsha Khola catchment

Water availability is an issue, particularly due to the high seasonal differences and the intra-annual variabilities. Access to water resources likewise shows a rather low value, mainly due to the low access to sanitation and irrigation facilities. The drinking water supply service levels are quite good in this catchment since most of the households depend on tap systems. Water demand is very low in the catchment. This is true for all sectors, including agriculture, as the farming systems in this catchment are not very intense. The low values for capacity are mainly due to the small number of irrigation and drinking water supply associations in the catchment, which may have an impact on the strength of the water supply organisation. The environmental flow conditions and the water demand and supply situation for the natural environment in this catchment are satisfactory.

The FGI assumed a value of 75.2 with the sub-indexes of 58.5 points for base conditions, 80.7 points for hazard, and 86.3 points for risk. The WDI assumed 62.8 points, with 77.7 points for base condition, 64.3 points for hazard, and 46.5 points for risk.

Comparing the two catchments in Nepal (Figure 5.7), the following is evident.

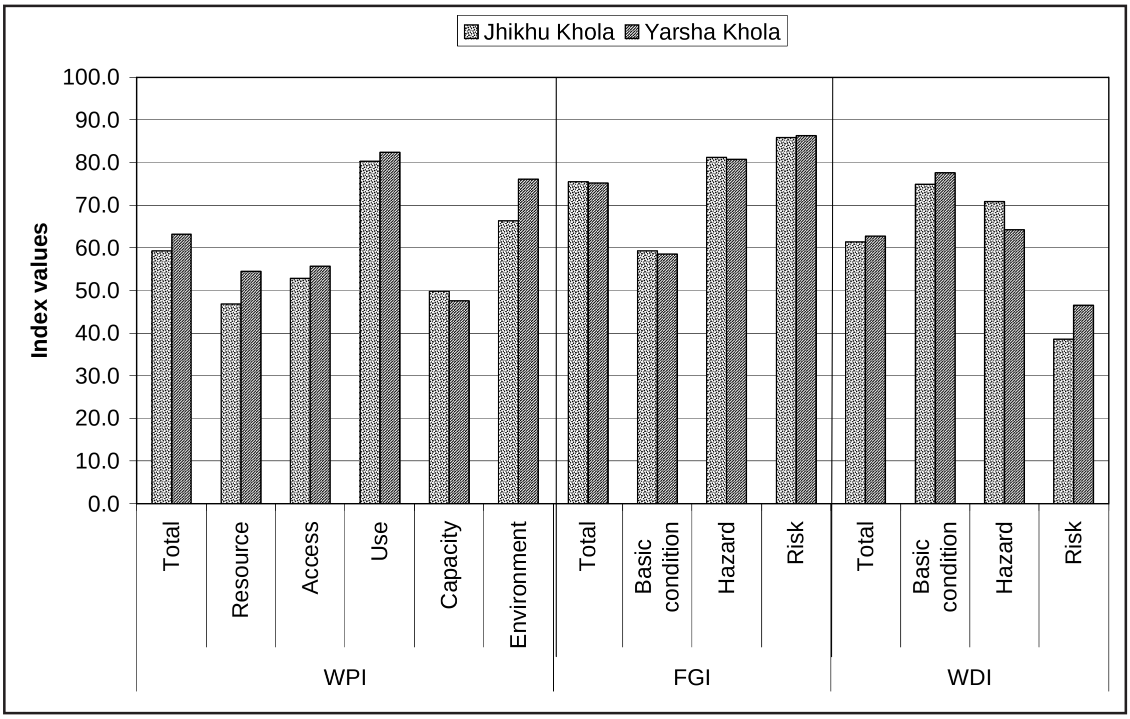

Figure 5.7: **The WPI, FGI, and WDI in the Jhikhu and Yarsha Khola catchments**

a) *The Jhikku Khola catchment is more prone to water scarcity than the Yarsha Khola catchment*
The Jhikhu Khola catchment shows, with 59.2 points, a slightly lower WPI than the Yarsha Khola catchment with 63.2 points. This shows that water scarcity susceptibility is higher in the Jhikhu Khola catchment than in the Yarsha Khola catchment.

The Yarsha Khola shows the higher resource score, which is mainly due to the higher rainfall in this catchment, the lower evapotranspiration rates, and the more pristine water quality. In addition, the water use is lower in the Yarsha Khola catchment than in the Jhikhu Khola catchment, mainly based on the lower agricultural water demands. The capacity to cope with these water issues is higher in the Jhikhu Khola catchment based not only on higher incomes, but also based on higher literacy rates. The sub-index values for environment are higher in the Yarsha Khola based on the lower fertiliser use and the lower water demand by natural vegetation.

The worse natural conditions in the Jhikhu Khola catchment are met with better social conditions such as higher education and better economic status than in the Yarsha Khola catchment.

b) *The Jhikku Khola catchment is about equally prone to flood generation as the Yarsha Khola catchment*
The lower hazard values in the Yarsha Khola due to more intense rainstorms, more rain in general, and the lower basic condition values are balanced by the higher risk sub-index due to lower values, population, and infrastructure at risk in the Yarsha Khola catchment. Basically, the Yarsha Khola flows continuously in a gorge, where only few people live and generally no infrastructure is found. In the Jhikhu Khola catchment, on the other hand, large areas of agricultural land and a number of houses and their owners are potentially affected by a flood.

c) *The Jhikku Khola catchment is more prone to land degradation than the Yarsha Khola catchment*
The Jhikhu Khola catchment shows a lower WDI than the Yarsha Khola catchment. This is based on the lower values for the sub-index risk as well as the basic condition. The hazard sub-index assumes lower values in the Yarsha Khola catchment than in the Jhikhu Khola catchment.

5.2.4.2 Assessment of scenario impacts

The two examples below should show how the impact of a change in a driving force such as climate change, a development project, or a policy could be monitored using the indicator approach. The first example shows the tremendous impact of a rural development project which aimed to improve the water supply situation in the Jhikhu Khola catchment. The changes of parameters are hypothetical and not based on a real situation. The second example shows the impact of climate change using the scenario by Lal (2002) as predicted by the PREVAH model (for more details about the modelling refer to Chapter 4). The parameters that changed in the two examples are compiled in Table 5.6.

Table 5.6: **Parameter values before and after the selected impact**
($^{\#}$ rural development project, $^{\&}$ climate change)

	pre-project	**post project**
Resource		
Public water sources below guideline value (no risk)	5$^{\#}$	15
Public water sources below guideline value (low risk; 1-10)	4$^{\#}$	33
Public water sources below guideline value (intermediate risk; 10-100)	10$^{\#}$	10
Public water sources below guideline value (high risk; 100-1000)	39$^{\#}$	0
Water treatment coverage	10$^{\#}$	50
Waste-water treatment coverage	5$^{\#}$	20
Water quantity adequate (female/male)	41/24$^{\#}$	75
Water inadequate (female/male)	59/76$^{\#}$	25
Water quality good (female/male)	56/75$^{\#}$	75
Water quality bad (female/male)	44/25$^{\#}$	25
Average annual areal reference evapotranspiration	1175$^{\&}$	1536
Average annual areal precipitation	1295$^{\&}$	1236
Average annual runoff at the outlet	411$^{\&}$	506
Annual dry spells	4$^{\&}$	6
Average length of dry spell	44$^{\&}$	60
Longest observed dry spell	113$^{\&}$	130
Days without rainfall ($P < 1$mm)	250$^{\&}$	280
Coefficient of variation for pre-monsoon season	0.5$^{\&}$	0.9
Coefficient of variation for post-monsoon season	1.2$^{\&}$	1.3
Coefficient of variation for winter season	0.9$^{\&}$	1.1
Access		
Service level 1-good	57.4$^{\#}$	80
Service level 2-intermittent	15$^{\#}$	20
Service level 3-poor	4.7$^{\#}$	0
Service level 4-very poor	14.4$^{\#}$	0
Not assessed	8.5$^{\#}$	0
People with access to sanitation facilities	30$^{\#}$	80
People with access to irrigation water	70$^{\#}$	90
Percentage of women exclusively fetching water	64$^{\#}$	10
Capacity		
Patients in health facilities with water related diseases	25$^{\#}$	5
Children under 5 with diarrhoea within 2 weeks before survey	15$^{\#}$	2
Infant mortality rate	64$^{\#}$	30

The hypothetical and highly successful rural development project achieved a total change of the WPI of 10.3 points, from 59.2 to 69.5 points, and overall conditions were improved. The main change was observed in the case of the sub-index access to 88.3 points, a change of 35.5 points. The sub-index resource changed to 57.5 points, a change of 10.7 points, while capacity became 55.1 points, a change of 5.2 points. Use and environment remained the same. A graphical representation of the changes is shown in Figure 5.8a.

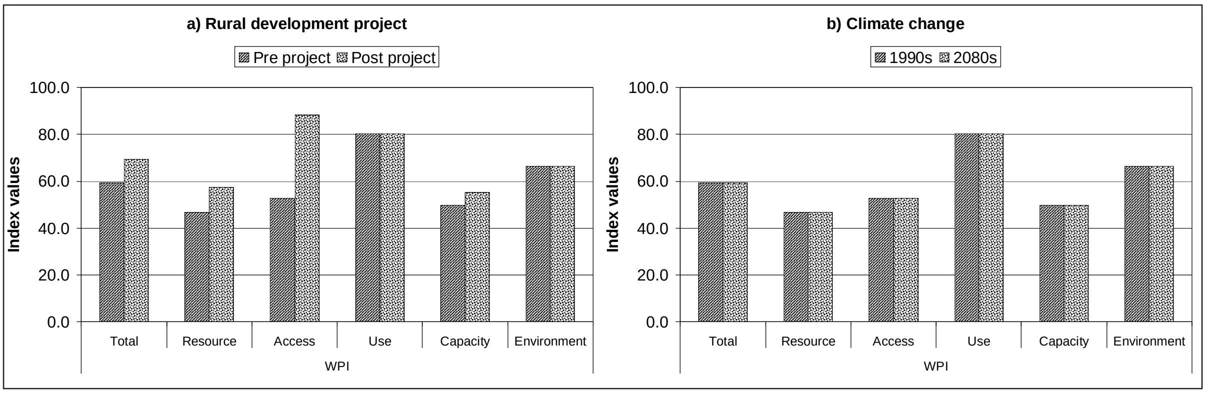

Figure 5.8: **Impact of the rural development project (a) and climate change (b) on the WPI in the Jhikhu Khola catchment**

The global climate change scenario was simplified to the extent that only resource parameters were changed. Other parameters such as demands for water for agriculture or for natural vegetation are presumably also subject to changes in case of higher evapotranspiration rates. In the case of this simplified version of global climate change impact, the total WPI changed by –0.7 points, from 59.2 to 58.6 points with all the changes that occurred in the sub-index resource. This sub-index changed to 43.3 points by –3.4 points.

This suggests that with a global climate change scenario as suggested by Lal (2002), availability of water resources would decrease and worsen the overall water supply conditions in the catchment. The same result was also obtained on the basis of the modelling results in Chapter 4.

5.2.4.3 Comparison of PARDYP catchments

The main benefit of these indexes is believed to be the objective comparison of catchments and the assessment of required action in the water resources' sector. A first preliminary comparison of the WPI was carried out in the four PARDYP catchments of India (data source: PARDYP India, pers. communication), Nepal, and Pakistan (data source: PARDYP Pakistan, pers. communication). The PARDYP China team unfortunately did not respond in time to include their data in this preliminary analysis. The FGI and the WDI could not be included as no estimates could be provided for the sub-index risk. The comparison showed clearly that the Jhikhu Khola catchment has the lowest resources of the four catchments, both based on the quality as well as quantity (Figure 5.9). In terms of access, the catchments in Nepal show much better values than the other two catchments, mainly because the percentage of households where water is exclusively brought by women is lower in these catchments than in India and Pakistan. The capacity is identified to be lowest in the Indian catchment mainly due to the low economic status in the catchment. The best conditions in terms of environment are given in the Hilkot catchment, followed by the Yarsha Khola catchment, and finally the two catchments of the Jhikhu Khola and Bhetagad.

5.2.5 Discussion

The proposed indexes are by no means believed to be a final product without any possibility of improvement. The introduction of these indexes is meant mainly to provoke thought about the PARDYP project and point a possible way forward in the discussion of the upscaling of project experiences and the objective comparison of catchments.

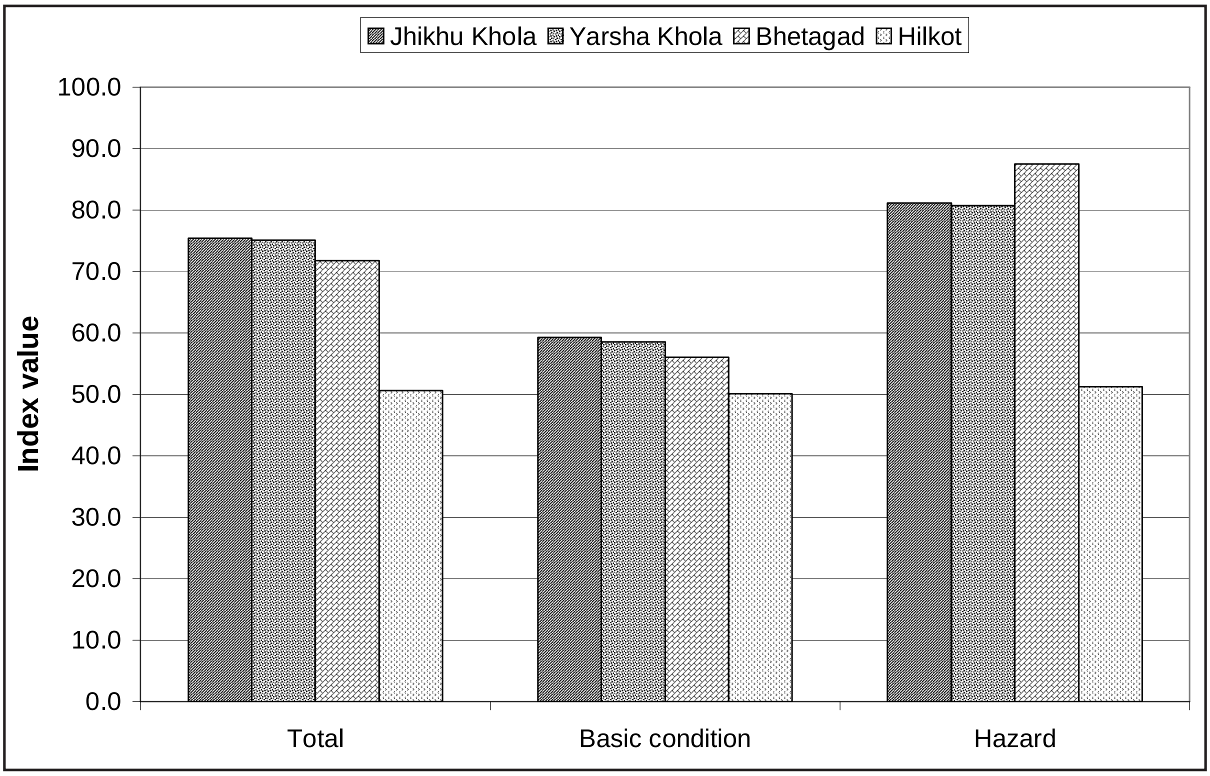

Figure 5.9: **The preliminary WPI in four PARDYP catchments (note: missing parameters in the Bhetagad and Hilkot datasets were also removed from the Jhikhu and Yarsha Khola datasets)**

At present, the sensitivity of the indexes is very low, i.e., the values of the Yarsha Khola and the Jhikhu Khola catchments are very close and similar. The reason for this is the choice of score maxima. For example, the use of the world record line of rainfall according to WMO (1994) showing a maximum of 27,000 mm annual rainfall is 25,705 mm more than the annual average rainfall in the Jhikhu Khola, and 24,794 mm more than in the Yarsha Khola catchment. This results in a score of 4.8 % for the Jhikhu Khola catchment and 8.2 % for the Yarsha Khola catchment. The difference between the Jhikhu and the Yarsha Khola catchments is therefore just 3.4 %, with an absolute difference of 911 mm. The use of this maximum figure is justified, as this value was observed in Cherrapunjee in the Meghalaya Hills and is therefore part of the HKH region, for which this method was prepared. However, for the choice of score maxima and minima, other rules could be used, such as the highest value amongst the catchments being automatically the score maximum. This would, however, reduce the applicability of that particular score board to other regions.

In terms of data requirements, it is important to note that the Indian and Pakistani data were compiled in just a few days. However, the indicators as well as the number of these will have to be further scrutinised in Phase 3 of the PARDYP project (also see Chapter 6). In order to successfully use the indicator approach, the most sensitive and the most easily collected indicators have to be included in the method.

The chosen equation for the calculation of the indexes shown in equation 5.1 is based on additions. This leads to an averaging of the conditions in the case of extremely high values on one hand and extremely low values on the other. In order to identify these extremes it is important not only to compare the final indexes, but also their sub-indexes.

The index approach has shown an interesting way forward where PARDYP could provide a useful method and show its comparative advantage as a project of a regional nature. In order to provide a final method, further activities and a firm commitment are required (also see Chapter 6).

5.3 SPATIAL AND TEMPORAL INTRA-CATCHMENT SYNTHESIS

5.3.1 Spatial synthesis

For all PARDYP activities and the activities of other watershed management projects, the unit of catchments is used. A method for the objective comparison of the catchments was discussed above. However, the catchments are of considerable spatial heterogeneity. This was discussed in Chapter 2 on the basis of catchment characteristics as well as in Chapter 4 in terms of modelling. The processes likewise differ spatially, which was discussed in Chapter 3. For the development of a decision support system (DSS), this heterogeneity has to be described and the necessary steps taken.

As shown in Chapter 3, there is often a good relationship between elevation and many water resources' related parameters. In the case of the two catchments in Nepal, this includes annual rainfall, erosivity, evapotranspiration, and others. However, these relationships tend to change from location to location as shown with a comparison of the relationships for the Jhikhu and Yarsha Khola catchments in Chapter 3. Merz and Nakarmi (2001) therefore propose the use of general topography and landforms for the DSS base, and the inclusion of rainfall and temperature from a simple measurement network of two to three sites or a locally available dataset. The reason for using the topography is based on the fact that different water sources are present at different locations in a catchment (Figure 5.10). Precipitation is the only conveniently located source of water along the divide and close to middle ridges. This zone is followed by a zone where natural springs can be found in addition to the precipitation. Simultaneously, rivulets start to form but they generally have low flows and often dry up during the late dry season. A next zone, on the foot slopes of the valleys, includes rivers that have reached a considerable size and can be harvested for various purposes. The last zone also includes groundwater. Keeping Figure 5.1 in mind, water quality changes along the way from precipitation to streamflow and groundwater. Precipitation has the best quality status (as shown by a few samples of Schaffner 2003), followed by springs. In the case of good aquifers, the groundwater is qualitatively better than the river water to a considerable degree.

Aspect was shown to play a minor role in terms of rainfall in the upper areas of the catchment; in the lower stretches or the foot slopes of the valley, on the other hand, a distinct difference was observed. Annual temperature extreme values (i.e., annual minimum and maximum) tend to differ according to aspect on the lower foot slopes with higher minimum and maximum temperatures on the south-facing slopes. The same as in the case of precipitation was shown for the upper slopes where temperature does not differ distinctly between the slopes.

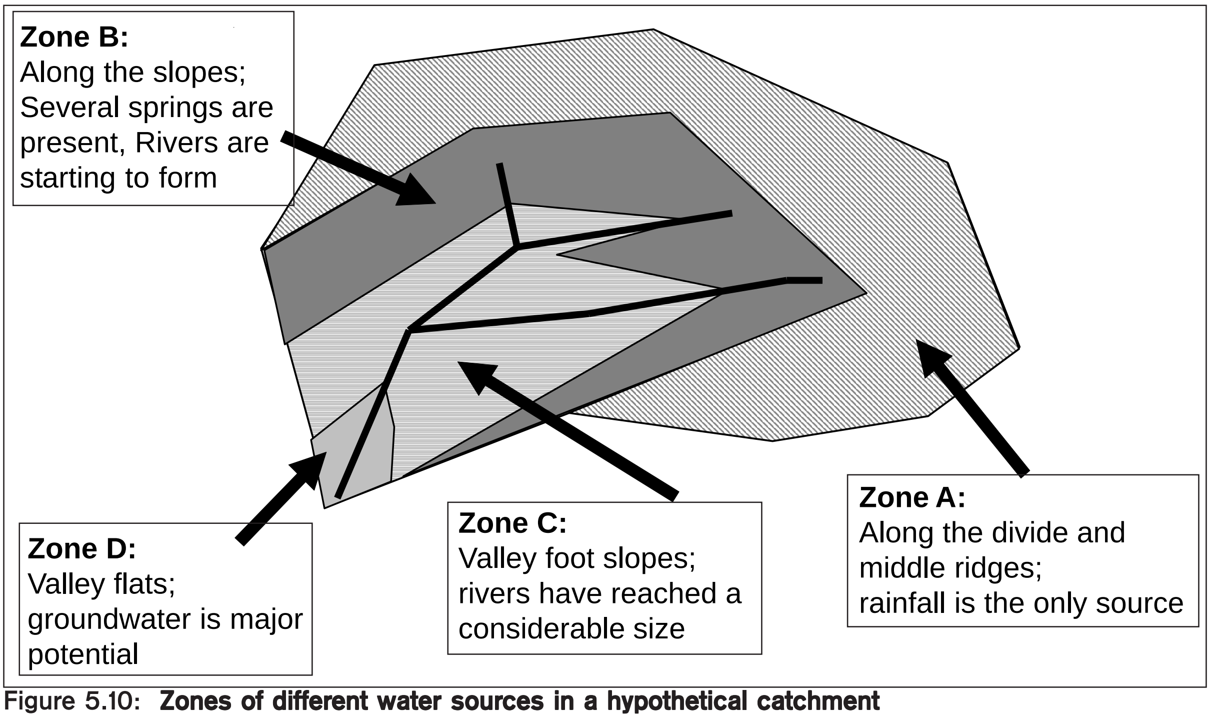

Figure 5.10: **Zones of different water sources in a hypothetical catchment**

The approach above suggests that different water management solutions have to be sought and proposed for each zone. Methods appropriate in a mainly rainfed zone may not be appropriate in a zone where groundwater is available. In the DSS this should be kept in mind and used to suggest the appropriate solutions as well as for upscaling the method.

5.3.2 Temporal synthesis

The processes vary not only spatially as shown above, but also temporally. The inter-annual variabilities of different water resource parameters are limited due to the stable macro-climatic conditions of the monsoon and the westerlies, which are primarily responsible for the summer and winter rains respectively. A note of caution has to be mentioned here as the impact of global climate change is being discussed and different scenarios have been identified (e.g., see Chapter 4 or IPCC 1998). The intra-annual temporal variability or seasonality of water resources, however, is a major constraint in the region, in catchments that depend entirely on precipitation in particular. Most of the hardship related to water availability can be attributed to this highly seasonal behaviour. The main question is, therefore, when is the most critical time of the year?

The critical times in a year are based firstly on natural conditions, and secondly on the farmer's expectations according to traditional farming practices. For considerations about the availability of water, the greatest risk of very dry conditions in the Jhikhu Khola catchment is during the early pre-monsoon season, in April and May (Figure 5.11a). During this time, rainfall is low and often variable and evapotranspiration is high. This results in the lowest runoff during the year and the highest water deficits. During the monsoon season the risk is low, as there is ample and secure rainfall resulting in a water surplus. The post-monsoon and winter seasons are dry from the point of precipitation. Due to the low evapotranspiration during this time of the year, soil moisture availability is high, resulting in low to medium water deficits and risk. Comparing the observed deficit (i.e., as determined from scientific data for precipitation and evapotranspiration) with the deficit perceived by the local residents, a nearly perfect match could be determined.

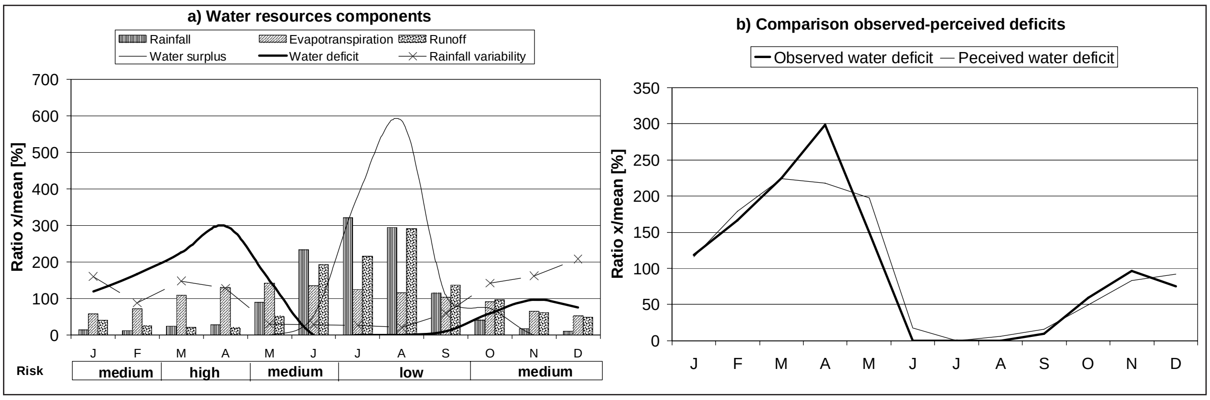

Figure 5.11: Temporal distribution of selected water resource components (a), and comparison with perceived water shortages (b)[2]

Linking the availability of water resources with the cropping calendar for the Jhikhu Khola catchment, it is evident, that the calendar is very well adapted to local water availability (Figure 5.12). On the irrigated land (Figure 5.12a) the pre-monsoon season crops of tomato and maize are only grown if adequate water is available to allow enough irrigation during the time of highest risk of water scarcity. The rainfed agricultural land (Figure 5.12b) during this time is fallow and ready for planting maize after the first good seasonal rains. From the point of view of agronomic interventions, it is this time period that allows changes. While the remaining seasons are important for the staple food production, these few months during the dry season could be used for an additional cash crop.

2 The perceived water deficits are based on the answers of 178 male farmers in the Jhikhu Khola catchment to the question "In which months do you face water deficits for irrigation purposes?" (Merz et al. 2002)

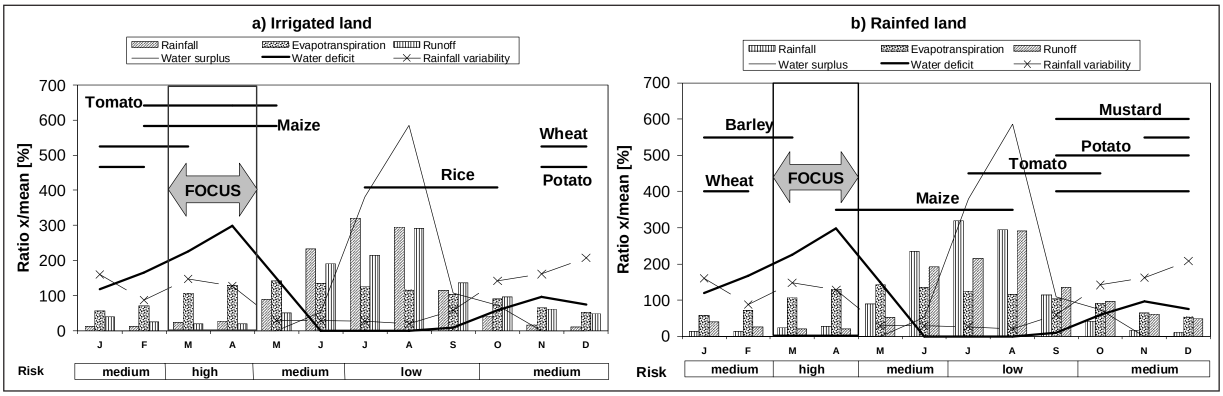

Figure 5.12: Comparison of temporal distribution of selected water resource components with crops on a) irrigated land and b) rainfed agricultural land

As water availability is the main concern, vegetables that can be grown with low cost drip irrigation (Polak et al. 1997) would be most suitable.

On the irrigated land on the valley floor, Prajapati-Merz et al. (2003) selected bitter gourd for a trial and suggested other cucurbits such as cucumber or other different gourds for this season. This crop is sown in February after the wheat or potato crop and is harvested in mid-May to July before transplanting the rice crop. For a plot of 12 m by 12 m Prajapati-Merz et al. (2003) planted a total of 96 bitter gourd plants. This produced a total of 612.1 kg of marketable fruit (excluding 2.7 kg of damaged fruit) which, at a price of 15 NRs (~0.2 US$), resulted in a total income of NRs 9182. Subtracting the total expenditure, including drip irrigation set, labour cost, seedlings, and fertiliser amounting to NRs 2712, a net benefit of NRs 6470 was realised.

On rainfed agricultural land where only a two- to three-month time slot is available between the wheat or potato and the maize crops, three months' cole crops are suggested. Adhikari et al. (2003) and Von Westarp (2002) made successful trials with cauliflower, though slightly earlier in the season, from October to January instead of the suggested February to April period.

Water for these off-season cash crops during the time of highest water scarcity risk could be provided from springs, rivers with very low flows, or water harvested in an underground cistern as proposed by Nakarmi and Neupane (2000). The bitter gourd trial by Prajapati-Merz et al. (2003) used a total of 2240 litres for a plot of 12 m by 12 m. Von Westarp's (2002) trial indicated that an additional cauliflower crop on a field size of 180 m^2 required about 11,000 litres of water. Under deficit irrigation, i.e., deliberate under irrigation of a crop for efficient use of water (Von Westarp 2002), this amount of water could be reduced to 6000 litres at similar yields. The link between water harvesting and drip irrigation will be further pursued by the project.

To reduce the risk to crops in the post-monsoon season , improved recharge of late monsoon showers with resulting increased soil moisture levels, water harvesting in connection with drip irrigation for cash crops, as well as the use of sprinklers for the post-monsoon potato crop are suggested.

For domestic water supply, no distinct temporal differences are expected from the requirements side. The supply, however, seems to decrease towards the end of the dry season on the basis of the perceived water deficit for domestic purposes (Figure 5.13). The same was reported during the public water sources' survey, according to which the yield in all sources tends to decline towards the end of the dry season in the months of April/May (Merz et al. submitted_b). The highest risk for water scarcity from a quantity point of view is therefore the pre-monsoon season during the months from March to May.

From the point of view of water quality, this period in the pre-monsoon poses a medium risk with the highest risk observed during the monsoon season where the highest coliform, turbidity, and nitrate levels were observed in the 33 public water sources investigated (KU/ICIMOD 2001).

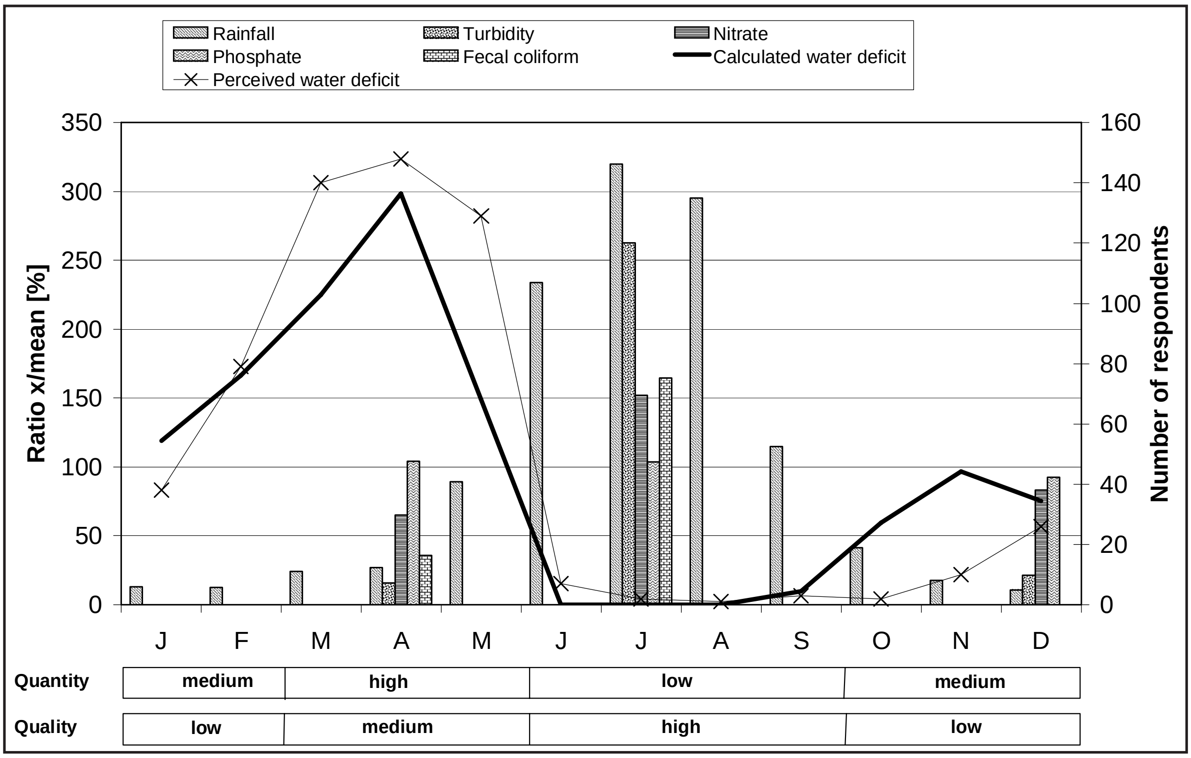

Figure 5.13: **Temporal distribution of selected water resource components related to domestic water supply[3] (note: right axis for perceived water deficit)**

In order to improve the water quantity and quality situation in these catchments, an integrated water supply, water demand, and water quality management approach is necessary. Different approaches are discussed in Merz et al. (2003c). While during the dry season supply has to be ensured — for example through improved catchment management or water harvesting — water quality during the monsoon season when the risk is highest could be improved through simple treatment methods.

From an erosion risk perspective, two different aspects have to be distinguished: surface erosion that mainly depends on the rainfall and vegetation characteristics (see Section 3.5) and streambank erosion and mass wasting that largely depends on major flood events as well as high soil moisture contents. In this context, the late pre-monsoon and the early monsoon season show the highest surface erosion risk (Figure 5.14). This is the time with generally the biggest rainfall events, intensities, and erosivities. At the same time, this is also the initial crop development stage for the maize crop with only little ground cover. In addition, farmers tend to weed their maize fields to reduce competition between the weed species and the maize plants. From a mass wasting and streambank erosion point of view, it is the late monsoon season that shows the highest risk. Flooding depends largely on rainfall characteristics, rainfall volume, and intensity in particular and therefore can occur anytime during the year. Most frequently the largest flood events occur during the monsoon season with some isolated events either in the pre-monsoon or monsoon season (for more detail refer to Chapter 3).

5.3.3 Summary

Three indexes, the WPI, the FGI, and the WDI were proposed to assess water availability, flood generation, and land degradation susceptibilities respectively in a middle mountain catchment. These indexes can be used for the comparison of catchments, for the assessment of impact by changes in driving forces, or changes induced by project activities. The parameters to calculate the indicators of the indexes are based on the analyses in the previous chapters.

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[3] **The perceived water deficits are based on the answers of 178 female farmers in the Jhikhu Khola catchment to the question "In which months do you face water deficits for domestic purposes?" (Merz et al., 2002)**

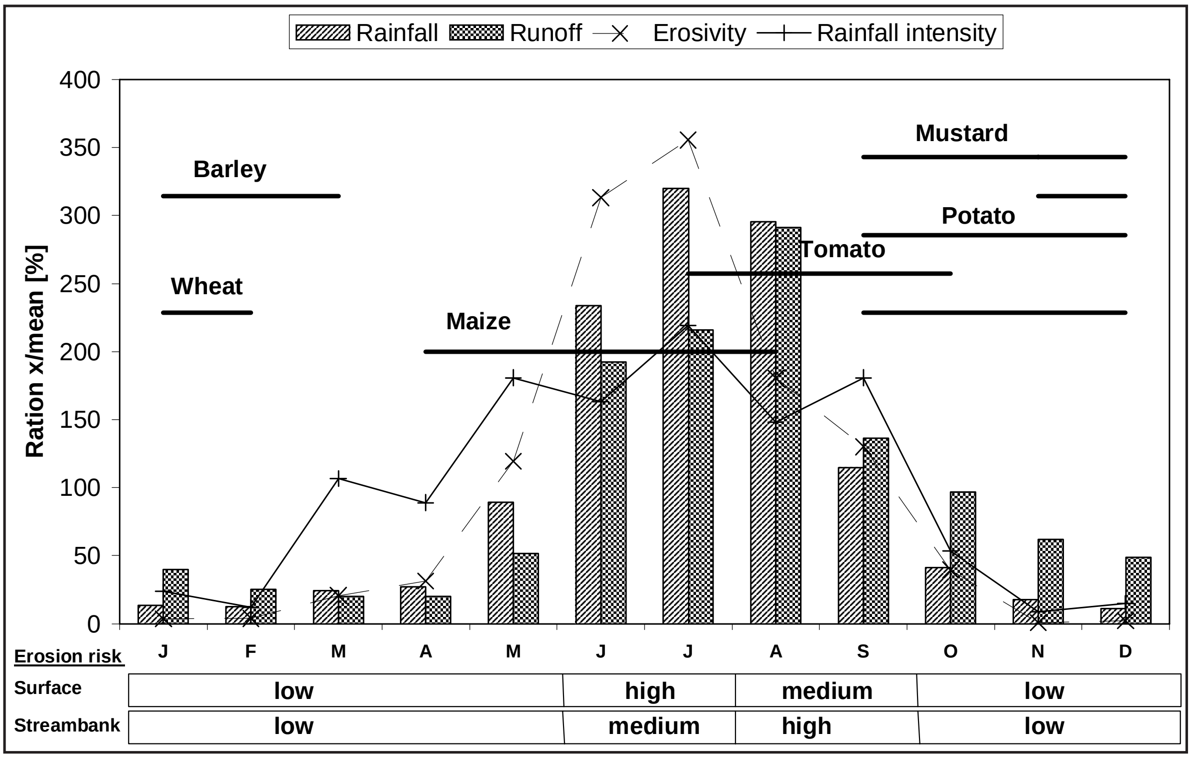

Figure 5.14: **Temporal distribution of selected water resource components relevant to soil loss**

A first assessment of the three indexes has shown that they present a plausible picture when comparing the Yarsha and Jhikhu Khola catchments. The Jhikhu Khola shows a higher water scarcity and higher degradation susceptibility, while the flood susceptibility in both catchments is similar. The indexes were also successfully applied to a climate change scenario and the impact assessment of a hypothetical development project. While the development project led to an increase in the WPI, the climate change reduced the WPI, mainly due to lower availability of water resources as modelled by the PREVAH model in Chapter 4.

Comparing the preliminary data from four PARDYP catchments, it was demonstrated that the Bhetagad catchment shows the lowest WPI score, followed by the Jhikhu, the Hilkot, and the Yarsha Khola catchments. It has to be noted, however, that the input data has to be reviewed and certain, currently missing parameters have to be included.

This index approach could further be useful in the up-scaling of the PARDYP results. At this point the indexes, however, have to be further tested on larger datasets and the indicator selection has to be verified and fine tuned on the basis of each parameter's sensitivity. For suggestions for this, refer to Chapter 6.

In terms of spatial and temporal intra-catchment synthesis in view of a DSS, it was found that the topographic location is of main importance, as it is here that the potential water sources are determined. Both elevation and aspect do not give conclusive answers at a regional scale, as their relationships with water resource parameters differ from location to location. Temporally, it is shown that the late dry season months are most susceptible to water scarcity. This led to a well-adapted cropping calendar in the Jhikhu Khola catchment. For an improved livelihood for local farmers, it is, however, noted that just the months of March and April could provide a chance for improved conditions through the application of water saved or harvested in the previous season.

It was learned that, for the development of a DSS for improved water management, particular focus should be given to the topographic location and the time of the year as well as the use of the water. Actual volumes of available water will additionally play a role but only after the consideration of the other aforesaid parameters.

Synopsis 5: Synthesis

In order to assess water resource issues in a more objective and holistic way, three indexes are proposed. The Water Poverty Index (WPI), the Flood Generation Index (FGI), and the Water Induced Degradation Index (WID) are suggested to assess water scarcity, flood generation, and land degradation susceptibilities. This approach has shown some promising first results, but will have to be further tested in other catchments of the region. The approach was successfully used to compare catchments in the region as well as to assess the impact of changes as a driving force mechanism.

For future reference in the PARDYP project and the development of a decision support system, topographic location with reference to the location of water sources and the temporal distribution of water availability and demand will be decisive. A potential model for this purpose was proposed.