Zeitschrift: Asiatische Studien : Zeitschrift der Schweizerischen Asiengesellschaft = Études asiatiques : revue de la Société Suisse-Asie

Herausgeber: Schweizerische Asiengesellschaft

Band: 61 (2007)

Heft: 4

Artikel: Changes in water availability in the Hilkot catchment, Pakistan : a case study illustrating the water situation in the Lesser Hindu Kush-Himalayas

Autor: Hänggi, Pascal / Weingartner, Rolf

DOI: https://doi.org/10.5169/seals-147767

Nutzungsbedingungen

Die ETH-Bibliothek ist die Anbieterin der digitalisierten Zeitschriften auf E-Periodica. Sie besitzt keine Urheberrechte an den Zeitschriften und ist nicht verantwortlich für deren Inhalte. Die Rechte liegen in der Regel bei den Herausgebern beziehungsweise den externen Rechteinhabern. Das Veröffentlichen von Bildern in Print- und Online-Publikationen sowie auf Social Media-Kanälen oder Webseiten ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Mehr erfahren

Conditions d'utilisation

L'ETH Library est le fournisseur des revues numérisées. Elle ne détient aucun droit d'auteur sur les revues et n'est pas responsable de leur contenu. En règle générale, les droits sont détenus par les éditeurs ou les détenteurs de droits externes. La reproduction d'images dans des publications imprimées ou en ligne ainsi que sur des canaux de médias sociaux ou des sites web n'est autorisée qu'avec l'accord préalable des détenteurs des droits. En savoir plus

Terms of use

The ETH Library is the provider of the digitised journals. It does not own any copyrights to the journals and is not responsible for their content. The rights usually lie with the publishers or the external rights holders. Publishing images in print and online publications, as well as on social media channels or websites, is only permitted with the prior consent of the rights holders. Find out more

Download PDF: 05.07.2025

ETH-Bibliothek Zürich, E-Periodica, https://www.e-periodica.ch

CHANGES IN WATER AVAILABILITY IN THE HILKOT CATCHMENT, PAKISTAN[1]
A case study illustrating the water situation in the Lesser Hindu Kush-Himalayas

Pascal Hänggi and Rolf Weingartner, Berne

Abstract

The main aim of this study is to analyse the natural availability of water in the Hilkot catchment, a typical area of the Hindu Kush-Himalayas in Pakistan. In the first part, the water balance and its components (precipitation, discharge and evaporation) will be analysed. In the second part, the results of the hydrological investigations will be compared with the high population density to examine the situation regarding water availability. The study is based on data collected between 2000 and 2003.

Introduction

From 1996 to 2005 the Swiss Agency for Development and Cooperation (SDC), the International Development Research Centre (IDRC) and the International Centre for Integrated Mountain Development (ICIMOD) supported the research-for-development project PARDYP (People and Resources Dynamics in Mountain Watersheds of the Hindu Kush-Himalayas Project). The project undertook investigations of five catchments: one each in China, India, Pakistan and two in Nepal. The aim was to obtain a basic understanding of the processes concerned with natural resources degradation and to recommend proven strategies for community and farm-based rehabilitation of natural resources in the Hindu Kush-Himalayas region.

To reach this aim, a hydrological and meteorological network was established in each watershed. The network in the Hilkot catchment in Pakistan (Figure 1) is operated by the Pakistan Forest Institute (PFI). It was designed and maintained with support from the Hydrology Group of the University of Bern. The first measurements were taken in 1996; by the end of the project in 2005,

1 This article was peer reviewed in a double blind process. It was accepted May 7th 2007.

some gauging stations had consecutive data recordings of at least five years at their disposal. For this study data collected between 2000 and 2003 were available.

In the last few years, the villages in the Hilkot watershed have developed rapidly. Today the area is densely populated, with more than 443 people per square kilometre (for comparison Pakistan has a density of population of 200 people per square kilometre). Most of the people base their livelihoods on agriculture and therefore fully depend on natural resources. In this context it is worth mentioning that the climatic variability is higher in this region than in other parts of the Hindu Kush-Himalayas due to the complex interaction between the subtropical high pressure belt and the Indian monsoon.

This present study aims not only to discuss the consequences of this climatic variability but also to evaluate the availability of water for domestic and agricultural purposes in the Hilkot area. Therefore the focus is mainly on the quantitative analysis of the meteorological and hydrological situation. The following questions will be discussed in particular: What are the meteorological and hydrological characteristics of the Hilkot catchment? Is there evidence of water shortage in the Hilkot catchment?

Research area

The Hilkot catchment is located in the northern part of Pakistan on 34°36'N and 73°10'E, within the Lesser Hindu Kush-Himalayas (Figure 1). The main river of the catchment is the Hilkot Khoar. It belongs to the basin of the Siran River, which drains directly into the Tarbela reservoir. Table 1 provides basic information on the Hilkot catchment.

Table 1: Basic features of the Hilkot catchment.

Coordinates (Hilkot village)	34°36'45.0''N/73°10'01.0''E
Area of the watershed [km^2]	14.9
Lowest elevation [m asl]	1485
Highest elevation [m asl]	2672
Population	6600
Population per km^2	443
Households	850
Ethnic group	Pashtuns

The Hilkot catchment politically forms part of Mansehra district of the North West Frontier Province. A livelihood survey has shown that approximately 6600 persons in around 850 households live in the Hilkot catchment (FLURY 2005). The population belongs to a patriarchal tribal group, the Pashtuns. Most of the residents of the watershed are *gujars*. They work as tenants on the lands of *khans*.

Agriculture is the main source of income. Rice during the summer season and maize are the main crops.

Figure 2 depicts rice terraces, which are irrigated by water from the Hilkot Khoar. It can also be seen that the slopes of the hills where rain fed agriculture dominates are mainly terraced as well. Growing maize is essential in this region as maize is the staple food and also fed to the livestock. The farmers use local varieties which are very tall and late-maturing, with low yields and susceptible to diseases. Higher yields are achieved where improved maize varieties, which have been introduced by PARDYP, are used. Another method to raise yields – and as a consequence to improve income – is to intercrop vegetables in the maize cultures. During the winter season, most fields are fallow or wheat is planted for fodder.

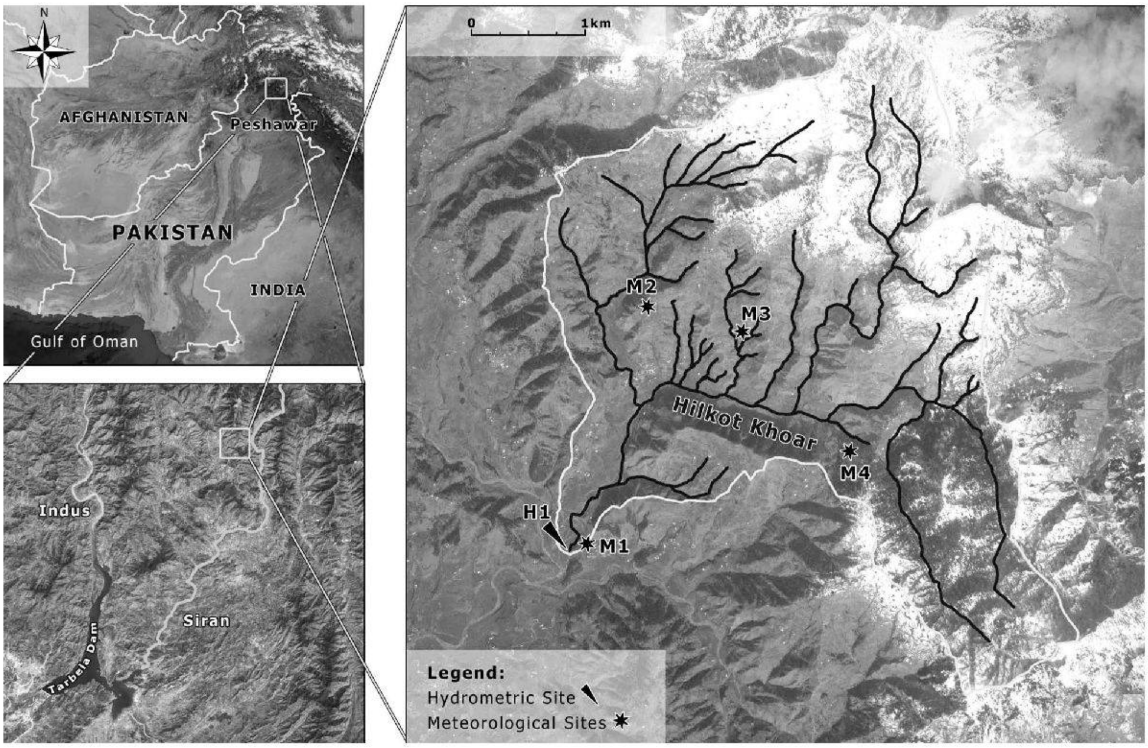


Figure 1: Location of the research area and its hydrological and meteorological network. Background: NASA WORLD WIND (left) and GOOGLE EARTH (right), 2006.

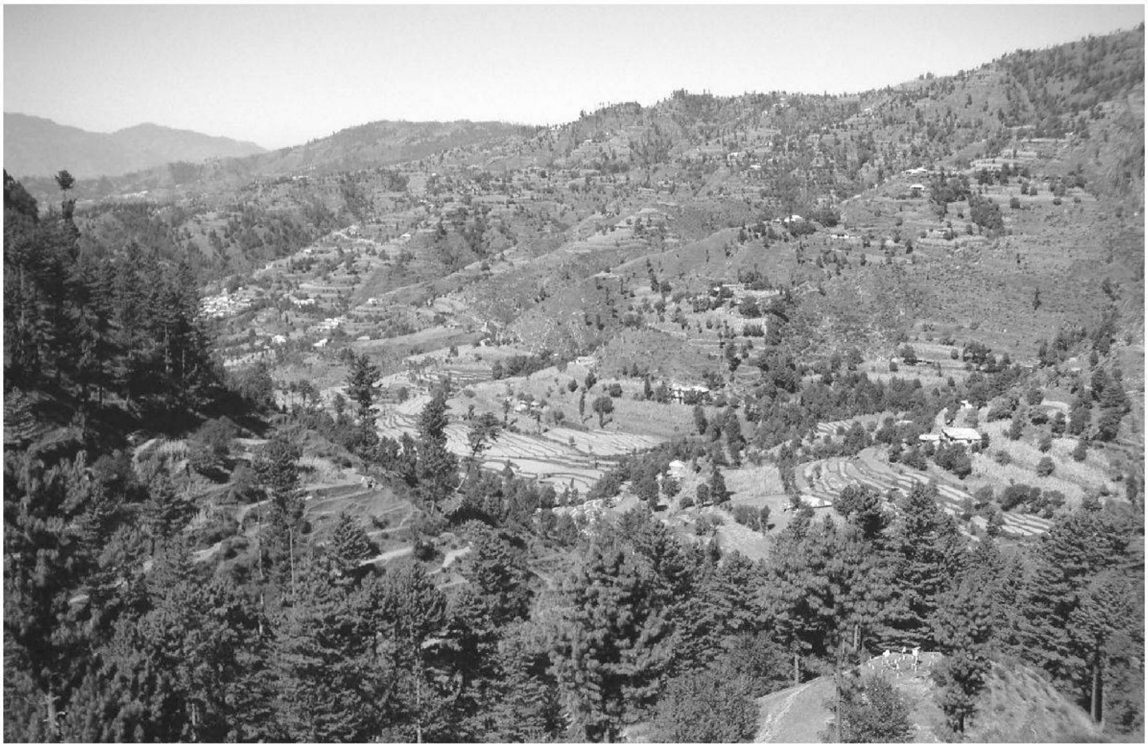


Figure 2: Rice and maize cultures in the Hilkot catchment. (Photo by Pascal HÄNGGI, 5 October 2004.)

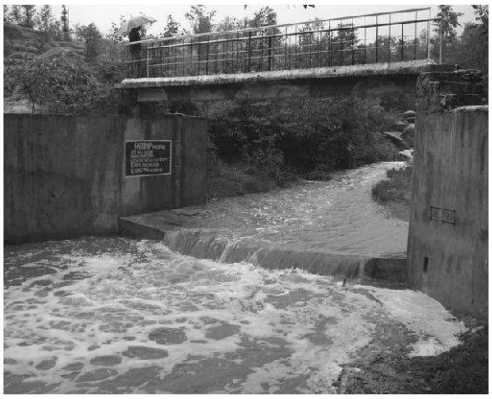
Fodder shortage is a problem even during the summer months. As a result, the slopes are over-grazed and forests are degraded. Trees such as oak and mulberry are used as fodder.

Forests grow mainly on the south-facing slopes. Poor forests can be found on the top of the hills in the northern part of the catchment, and especially in areas difficult to reach or cultivate. Pine prevails in the Hilkot catchment but there are also fir, spruce, oak, walnut and mulberry trees; they are mainly used as fuel and timber. The forests are used intensely and, as a consequence, wood is in short supply. To overcome this shortage there are plans to reforest some parts of the catchment. Plantation, however, is difficult to implement because nobody wants to lose grassland, which is more important for fodder than trees.

Part I: Water Balance

Hydrological and meteorological network

PARDYP has been running a hydrological and meteorological network in the Hilkot catchment since 1996. Runoff station H1 (Figure 3) is the main station at the outlet of the catchment. The total drainage area is about 14.9 km^2. The main station is equipped with an analogue floater continuously registering the water level. Additionally, members of the project staff record the water level twice a day.



Station no:	H1
Name:	Malkan
Name of stream:	Hilkot Khoar
Elevation [m asl]:	1485
Coordinates:	34°35'56.8''N/73°09'38.4''E
Running since:	July 1999
Reading times:	Daily 0900h and 1600h
Catchment area [ha]	1490
Equipment:	Floater, levelling staff

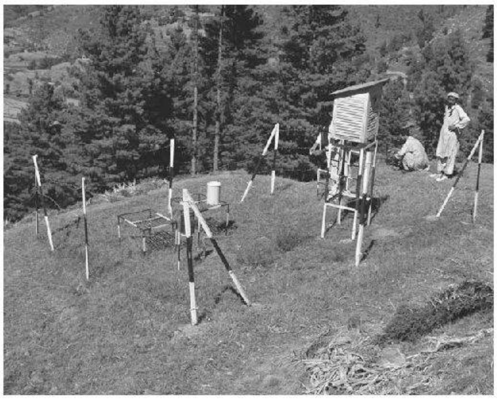
Figure 3: Hydrological station H1, Hilkot Khoar. (Photo by Gregor DOPPMANN, 11 October 2004.)

Precipitation is observed at sites M1 to M4, which are equipped with ordinary rain gauges and tipping buckets (Figure 4). The ordinary rain gauges measure daily precipitation amounts; they are read daily at 9 a.m. The tipping buckets record rainfall intensities instantaneously, with a resolution of 0.2 mm. Air temperature is registered at all sites. To determine (potential) evapotranspiration, site M2 additionally features two anemometers (measuring wind speed) installed at a height of 1.8 and 3 m above the ground, a sunshine recorder, plus a US class A pan evaporimeter.

Station no:	M1
Name:	Malkan
Elevation [m asl]:	1499
Coordinates:	34°35’56.5’’N/73°09’39.4’’E
Running since:	September 1998
Reading times:	0900h, 1400h and 1800h
Equipment:	Onset temperature logger, max. and min. thermometer, wet and dry bulb thermometer, ordinary rain gauge, siphon rainfall recorder

Station no:	M2
Name:	Guldehri
Elevation [m asl]:	1829
Coordinates:	34°37’07.3’’N/73°10’05.0’’E
Running since:	September 1998
Reading times:	0900h, 1400h and 1800h
Equipment:	Onset temperature logger, max. and min. thermometer, wet and dry bulb thermometer, ordinary rain gauge, tipping bucket, US class A pan, anemometers at 1.8 and 3m height, sunshine recorder

Station no:	M3
Name:	Maira
Elevation [m asl]:	1755
Coordinates:	34°36’50.0’’N/73°10’30.1’’E
Running since:	September 1998
Reading times:	0900h, 1400h and 1800h
Equipment:	Onset temperature logger, max. and min. thermometer, wet and dry bulb thermometer, ordinary rain gauge, tipping bucket



Station no:	M4
Name:	Bojri/Forest
Elevation [m asl]:	1804
Coordinates:	34°36’23.3’’N/73°11’12.7’’E
Running since:	September 1998
Reading times:	0900h, 1400h and 1800h
Equipment:	Onset temperature logger, max. and min. thermometer, wet and dry bulb thermometer, ordinary rain gauge, tipping bucket

Figure 4: Meteorological sites M1, M2, M3 and M4. (Photos by Pascal HÄNGGI, 5 October 2004.)

Climatic conditions

The climate in the Hilkot catchment is predominately influenced by the subtropical high pressure belt and the Indian monsoon circulation. The Hilkot catchment receives a high amount of precipitation during summer but also in winter and early spring. Summer precipitation is mainly attributable to the monsoon circulation, whereas westerlies are responsible for precipitation in winter and early spring. Yearly precipitation averages 1164 mm, with an annual average temperature of 14.4 °C. The climatic conditions allow the spring, summer, autumn and winter seasons to be clearly distinguished, just as in Europe.

The surrounding mountains have a major influence on the climate, especially affecting the amounts of precipitation in the region. The climatic significance of mountains can be demonstrated by comparing different climate charts of northern Pakistan (Figure 5). The monsoonal influence on the amount of precipitation stands out in the eastern parts of this region: Islamabad, Murree and Balakot exhibit the highest amount of rainfalls during the monsoon months of July and August. This precipitation is carried by warm and humid easterlies crossing the Murree Hills. This high mountain barrier has an immense impact on the availability of water in the Hilkot catchment during these months: Compared to locations east of the barrier, the Hilkot catchment gets approximately half the precipitation.

The significant influence of the monsoon can also be seen in the temperature curve. The highest values are reached in June just before the monsoon is starting. Likewise, the decrease of temperature from July to September can be explained by the more intensive cloud cover during the monsoon.

Peshawar, which lies in the range of influence of the monsoon, shows the same pattern of temperature. The city, however, is located inside the Peshawar Basin where no mountains can force orographical precipitation. As a consequence rainfall amounts are very low.

Dir is located at an altitude of 1369 m asl at the northern edge of the Himalayan foreland. The largest amounts of precipitation are recorded in the months of February to April due to the westerlies. During the summer season, precipitation is quite low and equals that at Hilkot. Chitral, which is surrounded by high mountains, receives next to no precipitation in summer. Here the easterlies are not able to influence the climatic conditions at all. In general, the climate in the Hilkot catchment can be classified as Cfb, according to KÖPPEN (1923), which translates into a humid (f), warm (b) and moderate climate (C).

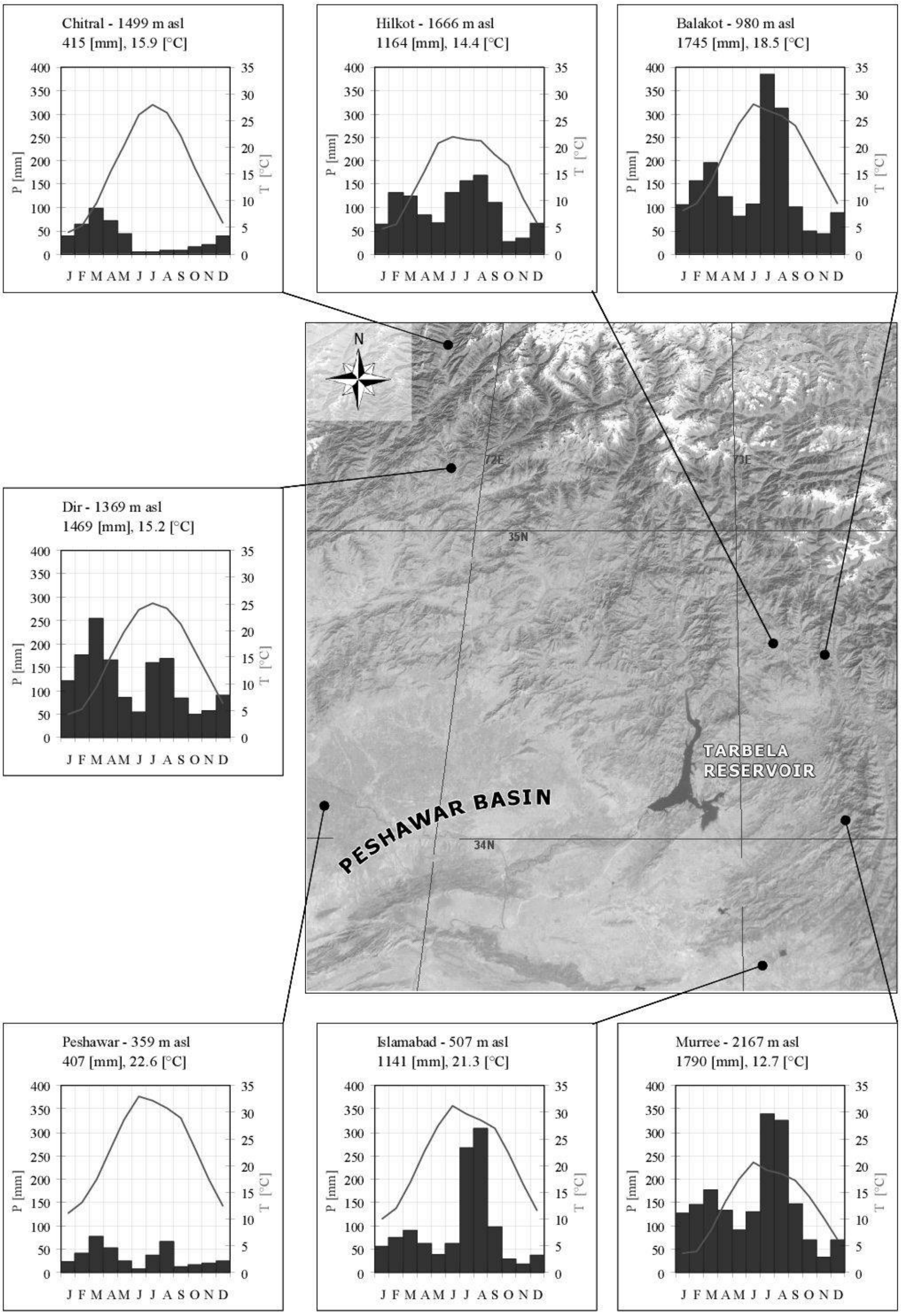


Figure 5: Climate charts showing monthly average precipitation sum [mm] and air temperature [°C]. The values are based on daily averages of 30 years (1961–1990), with the exception of the graph for Hilkot, where only values of the 2000–2003 period were available. The Landsat picture shows the Himalayan foreland in northern Pakistan, with the Tarbela reservoir. (Source: http://www.klimadiagramme.de; Background: NASA WORLD WIND 2006.)

Basis for the hydrological analyses

The water balance of a catchment is defined as follows:

$$P = R + E + \delta S - I$$

where P: precipitation [mm/dt], R: runoff [mm/dt], E: evapotranspiration [mm/dt], δS = storage change [mm/dt], I: inflow [mm/dt].

Precipitation P, which is the input parameter of the water balance, is very important for questions concerning agriculture and water management. In addition to this, height, seasonality, variability and intensity have to be known. Precipitation data of different time resolutions from January 2000 to December 2003 were available for our study. Daily precipitation data from sites M1 to M4 were used to calculate areal precipitation, seasonal distribution and year-to-year variability. In-depth analyses showed that all sites of the network exhibited very similar precipitation conditions. Therefore areal precipitation was computed by taking the average of the recordings of the four sites. Tipping bucket recordings from M2 and M3 were evaluated to determine rainfall intensities.

Water level (stage) data from H1 were available for the period between January 2000 and December 2003, and were used to characterise runoff R. The existing stage-discharge curve had to be adapted because discharge measurements to set the stage-discharge relation had mainly been made in the summer months and at similar stages. Accordingly the hydraulic approach of MANNING-STRICKLER was employed to improve the stage-discharge curve:

$$Q = M \cdot C^{\frac{2}{3}} \cdot I^{\frac{1}{2}} \cdot A_F$$

where Q: discharge [m^3 s^{-1}], M: roughness factor [$m^{1/3}$ s^{-1}], C: hydraulic radius [m], I: slope of energy line [‰], A_F: area of cross-section [m^2].

Analysing maps, the construction drawings of hydrometric station H1, pictures and movies helped to identify the requisite parameters of the formula. This resulted in enhancing the accuracy of discharge data at both low and high levels. Another difficulty was the fact that runoff is influenced by humans: A large amount of water is used for irrigation purposes, mainly in spring. This influence had to be taken into account when interpreting runoff data.

Potential evaporation was measured using a US Class A pan at meteorological site M2. This measuring device is well known to overrate potential evaporation because of the so-called oasis effect. Therefore monthly coefficients had to be calculated to correct this overestimation. This was done by comparing the measured pan evaporation with potential evaporation values calculated according to PENMAN (1948) and HAUDE (1955). The requisite data regarding wind speed, air temperature, relative humidity and sunshine were provided by recordings at site M2. Those data were available for the 2000–2003 period. Additionally actual evapotranspiration was calculated according to TURC (1954):

$$E_{act} = \frac{P_{year}}{\sqrt{0.9 + \left(\frac{P_{year}}{300 + (25 \cdot T_{year}) + (0.05 \cdot T_{year}^3)} \right)^2}}$$

where E_{act}: actual evapotranspiration [mm/a], P_{year}: yearly amount of precipitation [mm/a], T_{year}: yearly mean air temperature [°C].

The monthly E_{act} values were calculated on the basis of the pan evaporation values.

The second part of this study addresses water demand and water availability in the Hilkot catchment. For this purpose, the calculated amount of available water was compared with demand, employing the definition of FALKENMARK & WIDSTRAND (1992). Additionally a drought analysis following the method of MAURER (1975) was carried out. This analysis furnishes information about the monthly average duration, the intensities and the yearly number of droughts.

Meteorological and hydrological characteristics of the Hilkot catchment

a) Precipitation

The long-term monthly means of areal precipitation as well as the maximum and minimum values of the 2000–2003 period are depicted in Figure 6. Besides, the coefficient of variation (COV) is plotted for each month. Two distinct precipitation peaks in early spring and in summer are discernible. October is the month with the lowest amount of precipitation.

In the monsoon season the variability of rainfall is quite low, which means that the year-to-year changes in monthly rainfall are small. On the other hand, the highest precipitation variability occurs between November and February. This variability is of particular importance in January and February when westerlies are dominating. It is interesting to note that the rainfall amounts in February and March are similar to the monthly values recorded during the monsoon seasons. This phenomenon is quite different from anything observed in other regions of the Himalayas and underlines the major impact of the westerlies on the Hilkot region.

The variation of annual rainfall is quite low (Figure 7). The mean annual precipitation is 1164 mm/a (2000–2003). The values recorded by tipping buckets at sites M2 and M3 were analysed to determine the precipitation intensities of the Hilkot catchment (Figure 8). The highest precipitation intensity was recorded at site M3 on 12 August 2001, when 24 mm of rain were registered in 3 minutes and 43 seconds. This corresponds to an intensity of 360 mm/h.

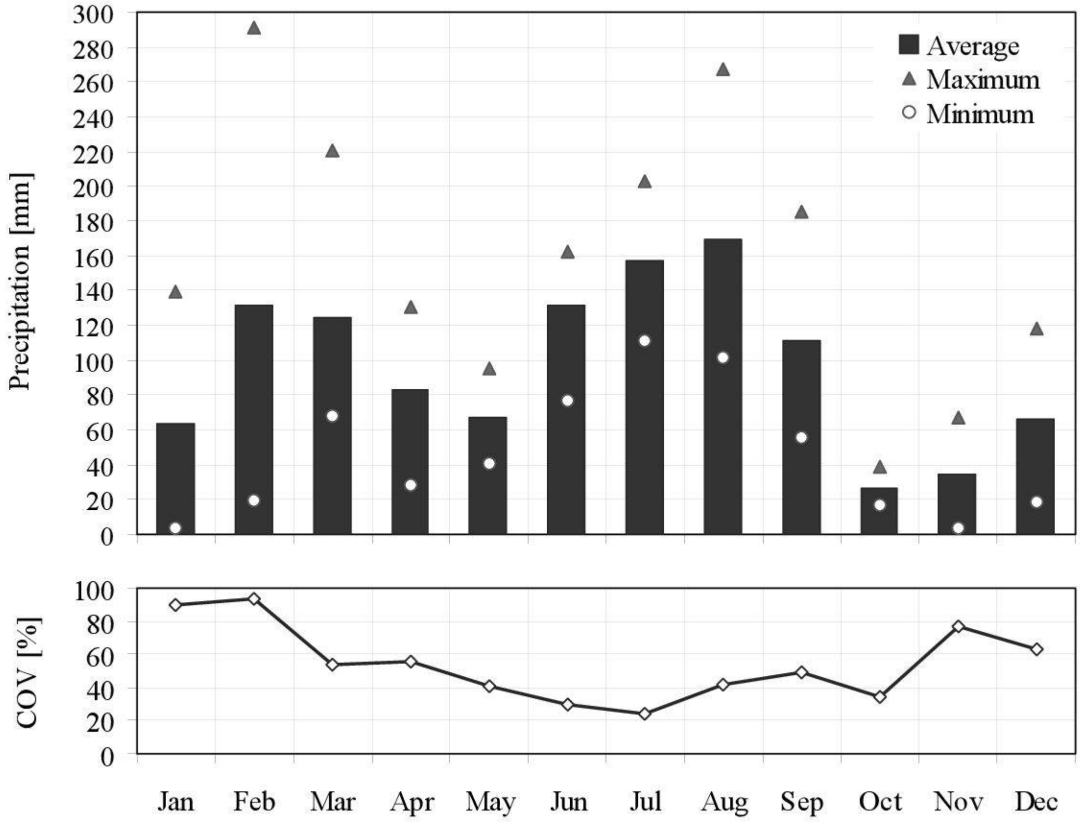


Figure 6: Statistical characteristics of monthly areal precipitation in the Hilkot catchment (2000–2003). COV: Coefficient of variation.

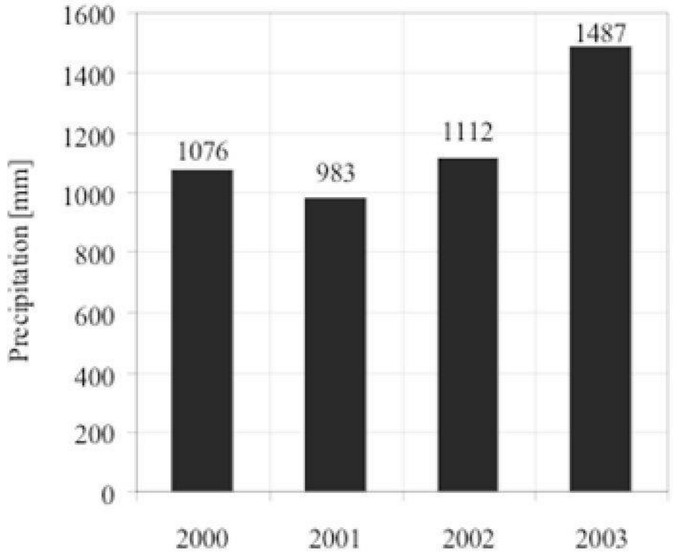


Figure 7: Annual areal precipitation (2000–2003).

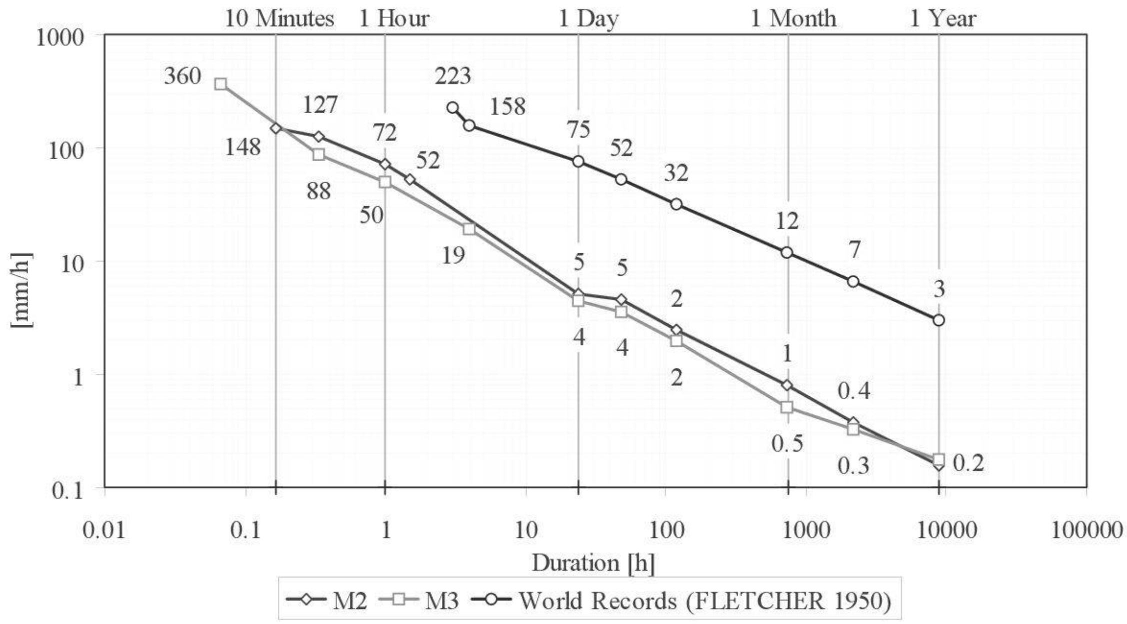


Figure 8: Diagram of precipitation intensity for sites M2 and M3. The graphs are based on the highest measured intensities [mm/h] of the 2000–2003 period. For purposes of comparison, the curve of world records by FLETCHER (1950) is also depicted.

b) Discharge

The basic runoff characteristics for the 2000–2003 period at station H1 are compiled in Table 2. The mean annual discharge (MQ) of that period is 218 l/s; this corresponds to a specific discharge of 15 l per second and square kilometre, or 460 mm/a respectively.

Table 2: Runoff characteristics at station H1 (2000–2003).

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Period*
NNQ	0	0	3	1	1	1	1	7	15	19	7	7	0
MNQ	9	7	107	45	22	4	15	20	44	36	15	11	28
MQ	33	224	440	204	98	234	275	513	362	128	51	50	218
MHQ	242	1599	1895	850	837	4026	2635	5345	3678	1132	348	440	1919
HHQ	620	4623	5218	2601	1731	10044	3975	9839	12422	3200	882	792	12422

NNQ: lowest discharge [l/s], MNQ: mean lowest discharge [l/s], MQ: mean discharge [l/s], MHQ: mean highest discharge [l/s], HHQ: highest discharge [l/s].

The lowest annual discharge (NNQ) is 0 l/s; it occurred twice during the observation period. It is remarkable that the lowest discharge in October was 19 l/s. As already mentioned, October is the month with the smallest amount of precipitation. Therefore, we may assume that the other monthly NNQ values, which are smaller than that for October, are influenced by withdrawals of water for irrigation, especially in the months from April to June.

PARDÉ coefficients were calculated for each month in order to highlight the discharge regime. The PARDÉ coefficients express the long-term mean monthly discharge in relation to the long-term mean annual discharge. The runoff regime of a river characterises its seasonal pattern; it is influenced both by characteristics of the catchment (climate, relief, vegetation and geology) and by human activities (WEINGARTNER & ASCHWANDEN 1985). The runoff regimes for the Hilkot Khoar and the Siran River are plotted in Figure 9.

The runoff regime of the Hilkot Khoar exhibits two significant peaks, one in March and one in August. The steep rise of the curve to these two peaks implies that this regime is mainly influenced by the seasonal pattern of rainfall, but the influence of snowmelt in spring has to be acknowledged, too. The low values in winter are a result of small amounts of precipitation in early winter on the one hand (Figure 6), and of the conservation of precipitation as snow on the other hand. In contrast, the low value for May is attributable to high evapotranspiration rates due to extensively growing vegetation. Furthermore, the river is tapped for irrigation purposes at that time of the year, again on account of the high water need of the vegetation (crops). According to WEINGARTNER & ASCHWANDEN (1985) this type of regime, in which the influence of rain is dominant and that of snowmelt marginal, is called “pluvio-nival”.

The runoff regime of the superordinate Siran River (Figure 9) was calculated so as to put the regime of the Hilkot Khoar in a regional context. It also shows two peaks, the higher of which occurs in April. This peak in April is clearly attributable to snowmelt and precipitation. The combination of these two factors results in a higher value than that of the August peak, which is only governed by monsoon precipitation. Between the two peaks are low values in June and from September to January. It follows that the Siran River, too, has a pluvio-nival runoff regime. The characteristics of its two peaks, however, constitute the main difference to the Hilkot Khoar regime. It demonstrates that snowmelt is of lesser importance in the Hilkot catchment.

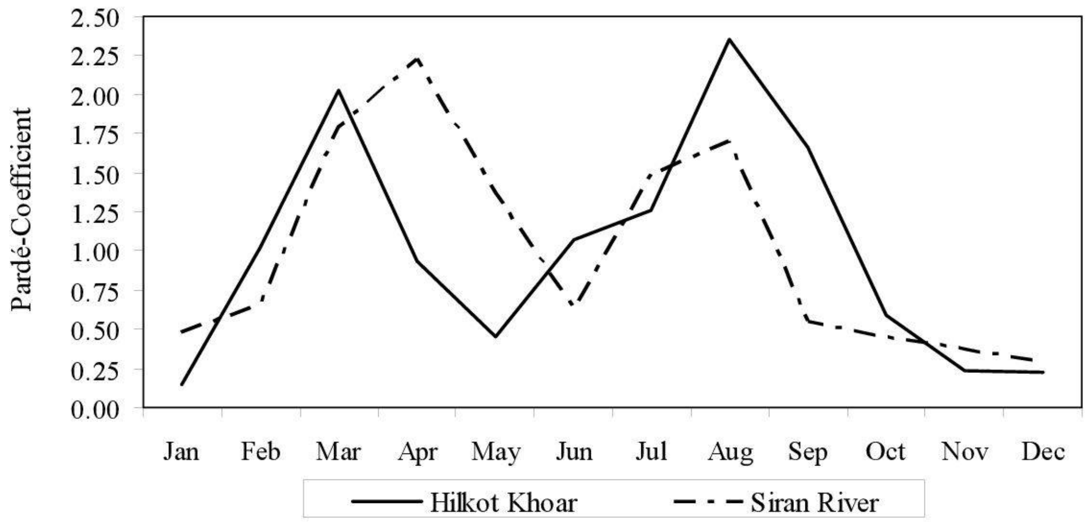


Figure 9: Runoff regimes of Hilkot Khoar (2000–2003) and Siran River (1978–1981). (Source for Siran River: GRDC 2005)

Figure 10 illustrates the variability of monthly runoff. This variability is particularly large in January and February, as well as in June and July. These are the months before runoff peaks (Figure 9). The low flow values from April to June are attributable to water losses due to irrigation in the catchment. For October, when there is hardly any irrigation, the values plotted in the graph are not influenced by human acitivities.

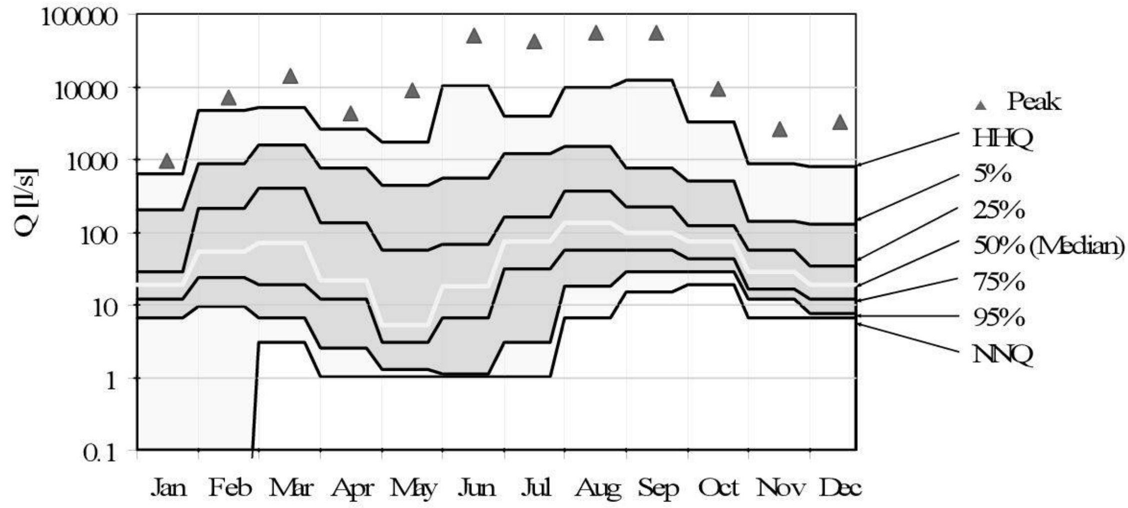


Figure 10: Monthly distribution of the daily discharge averages [l/s] (2000–2003).

c) Evaporation

Different methods were applied to estimate potential evaporation (cf. Table 4). The mean annual potential evaporation for the 2000–2003 period was 940 mm/a. The A pan recordings at site M2 were compared with the calculated values according to PENMAN (1948) and HAUDE (1955) to adjust the measured values. The correction factors are listed in Table 3.

Table 5 gives the actual annual evaporation rates calculated according to both TURC (1954) and the water balance method. Actual evaporation (687 mm/a, mean of the two methods) amounts to about 72 % of potential pan evaporation.

Table 3: Monthly correction factors to calculate the potential evaporation from original US Class A pan measurements.

Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
0.74	1.08	1.00	0.98	0.98	0.94	1.13	1.09	0.78	0.62	0.35	0.35

Table 4: Annual corrected and uncorrected potential evaporation at M2 (2000–2003).

	2000	*2001*	*2002*	*2003*	*Average*
Pan Evaporation [mm/a] (uncorrected)	965	991	1194	1152	1075
Pan Evaporation [mm/a] (corrected)	862	873	1065	1020	955
PENMAN [mm/a]	–	943	966	894	935
HAUDE [mm/a]	979	925	873	939	929

Table 5: Yearly actual evaporation according to TURC and the water balance method (2000–2003).

	2000	*2001*	*2002*	*2003*	*Average*
E_{act} [mm/a] TURC	657	651	675	691	669
E_{act} [mm/a] Water Balance	577	762	721	756	704

d) Water balance

The monthly water balances are based on monthly areal precipitation, mean monthly discharge and monthly corrected potential pan evaporation multiplied by 0.72. From the water balance, a remainder term (*RT*) can be calculated:

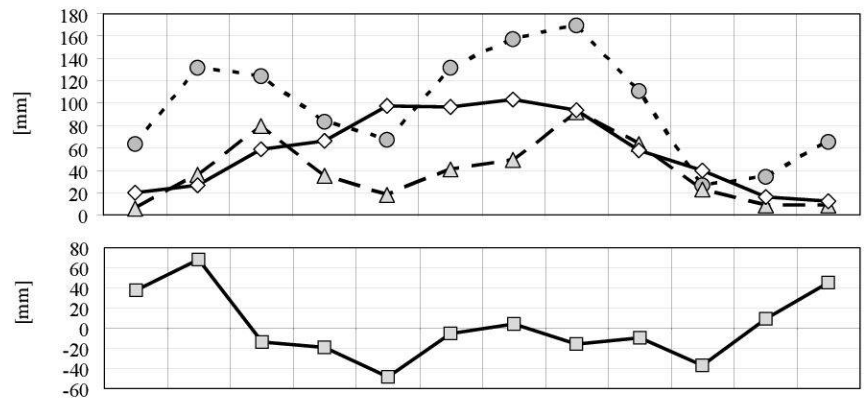
$$RT = P - R - E$$

where P: precipitation [mm/dt], R: runoff [mm/dt], E: evaporation [mm/dt].

RT includes the storage change (δS) but also all errors incurred in the calculation of P, R and E. Although RT has to be interpreted with caution, it provides some general information about the seasonal pattern of storage change.

The months from November to February feature a surplus of water (i.e. δS is positive; Figure 11). This is the time when precipitation is stored as snow or in the groundwater for hours, days or even weeks. This surplus is, however, not directly available for the inhabitants. Furthermore, no agricultural activity is possible during these months and thus there is no need for any irrigation water. The negative values of RT (or of δS, respectively) from March to May indicate that the temporary storages are depleted. In June and July, the water balance suggests that there is neither any filling nor any emptying of storages. It becomes slightly negative in August and September due to high evaporation and runoff rates. The low amount of precipitation in October results in a negative water balance.

The average annual water balance for the 2000–2003 period was calculated as follows: 1164 (P) [mm/a] = 460 (R) + 688 (E) + 16 (RT).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
P [mm]	63	131	124	83	67	132	157	170	111	26	34	66	1164
R [mm]	6	36	79	35	18	41	49	92	63	23	9	9	460
E Pan [mm] (corrected) · 0.72	19	27	58	66	98	97	103	94	58	40	16	12	688
RT = P - R - E [mm]	38	68	-13	-19	-48	-6	4	-16	-10	-37	9	45	16

Figure 11: Monthly water balances [mm] for the Hilkot catchment (2000–2003).

Part II: Water Shortage

Evidence of water shortage in the Hilkot catchment?

Water shortage occurs when demand is higher than the availability of water. "Per capita total renewable water availability" is a widely used basic indicator to assess the water situation (FALKENMARK & WIDSTRAND 1992). It is calculated on the basis of the ratio of annual runoff volume (so-called "blue water") and the number of inhabitants. FALKENMARK & WIDSTRAND (1992) differentiate between "periodic", "chronic" and "absolute shortage". Periodic shortage is defined as the availability, per capita and per year, of less than 1700 m^3 water, while the threshold for chronic shortage is 1000 m^3 and that for absolute shortage 500 m^3. At first glance, these threshold values seem to be arbitrary. They are, however, based on the following assumptions: 50 litres of water per day and person are the minimum requirements of a household, 70 times as much is needed to meet the consumptive water use for producing a projected human diet for one person based on a kcal consumption of 3000 kcal/d (SIWI 2005). These results in a water need of approximatively 3.5 m^3/d, 1300 m^3/a respectively.

A comparison between the thresholds mentioned above and the water situation in the Hilkot catchment is presented in Table 6.

Table 6: Water availability in the Hilkot watershed; population 2005: 6600 (MQ: mean annual runoff).

Situation	*Water availability [m^3]*	
	Per capita and per year	*Per capita and per day*
No critical situation (e.g. 2003, MQ = 345 l/s)	1648	4.5
Critical situation (e.g. 2001, MQ = 104 l/s)	497	1.4
Mean situation (2000–2003, MQ = 218 l/s)	1042	2.9

It can be seen that, in general, the water situation in the Hilkot catchment is close to chronic shortage. It is remarkable that there is a shortage of water even in years when the annual rainfall amount is above average, as it was the case in 2003. In relatively dry years, e.g. 2001 (Figure 7), the water situation becomes very critical.

As it has already been discussed, these assessments are based on "blue water". "Green water", however, i.e. the fraction of rainfall that is stored in the soil and available for the growth of plants through transpiration (cf. Figure 12) has to be considered as well since it is of great importance for both rain fed crop production and biomass production. According to the water balance, 60 % of the rainfall are transformed into "green water" (P = 1164 mm/a, E = 688 mm/a, E/P = 0.6) and 40 % into "blue water" (R = 460 mm/a) which underlines the significance of the "green water" and indicates that values shown in Table 6 which are only based on "blue water" probably overestimate the water crisis in the Hilkot catchment.

Water availability is especially affected by dry periods. The longer these periods last, the greater the impact on soil water storage and on river flow. That is why a meteorological drought analysis was conducted according to MAURER (1975). The results are presented in Figure 13.

The charts suggest that meteorological drought periods may occur every month, but there are significant differences from month to month with regard to the duration and intensity of droughts as well as the number of drought periods. In October, the likelihood of long and intensive drought periods is highest. From October to January, the average duration of drought periods is longest, whereas the intensity of drought peaks in September and October as well as in June and July. All in all, drought periods in June, July and September (monsoon season) are infrequent and short but in general very intensive due to high evapotranspiration rates. Table 7 shows the meteorological drought characteristics for every year from 2000 to 2003. It is interesting to note that the number of drought periods hardly changes from year to year.

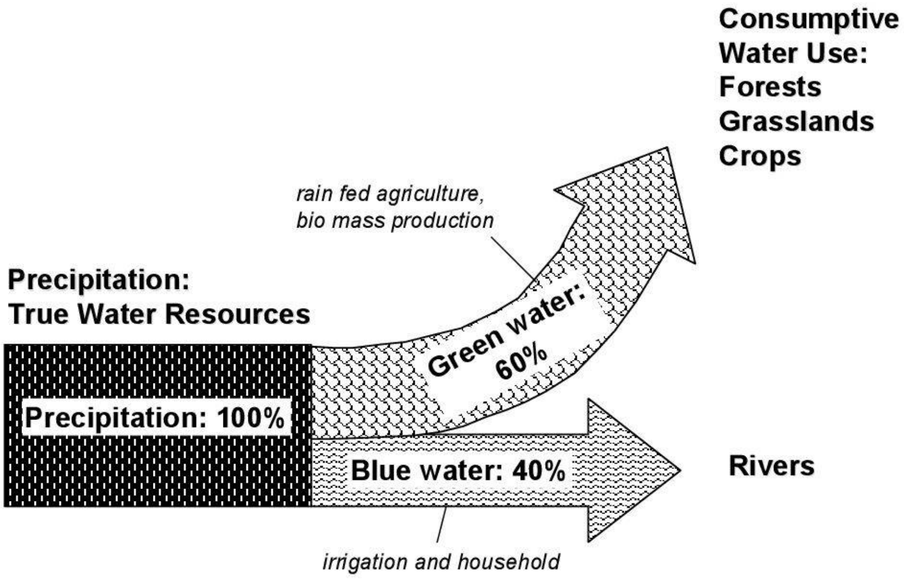


Figure 12: Fraction of blue and green water in the Hilkot catchment.

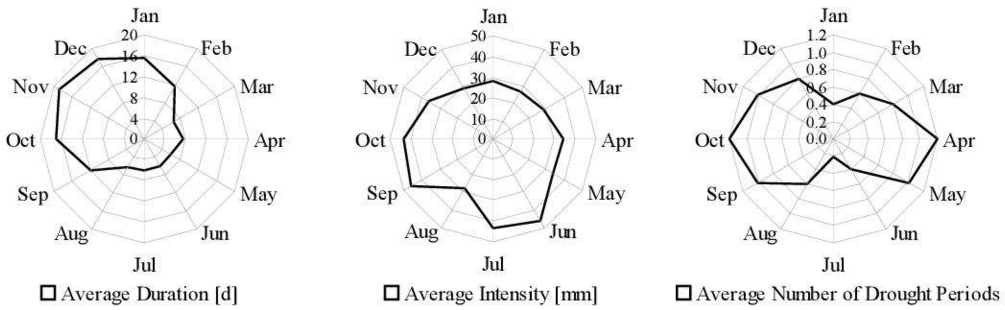


Figure 13: Monthly average drought duration, intensity and number of drought periods (2000–2003).

Table 7: Meteorological drought characteristics (2000–2003).

	2000	*2001*	*2002*	*2003*	*Average*
Number of drought periods	12	12	12	10	11.5
Total duration [d]	150	151	128	101	133
Total intensity [mm]	384	394	439	405	406
Average duration [d]	13	13	11	10	11
Average intensity [mm]	32	33	37	41	35

Final remarks

The data analysed provide evidence that the availability of water in the Hilkot catchment varies strongly from year to year. Although there is a certain bias in the data which makes it difficult to assess the situation precisely, there are clear signs of water shortage especially in years with below-average amounts of precipitation. In these years, river flow is low and also rain fed agriculture is affected.

Water shortages are aggravated by the rapid growth of the population in the Hilkot region. It is therefore a prerequisite for a successful water policy that population growth will be reduced, which would, in turn, reduce the pressure of water demand.

There are several options to stabilise or even increase the food production. FALKENMARK (2007) has given an overview of these options (Figure 14).

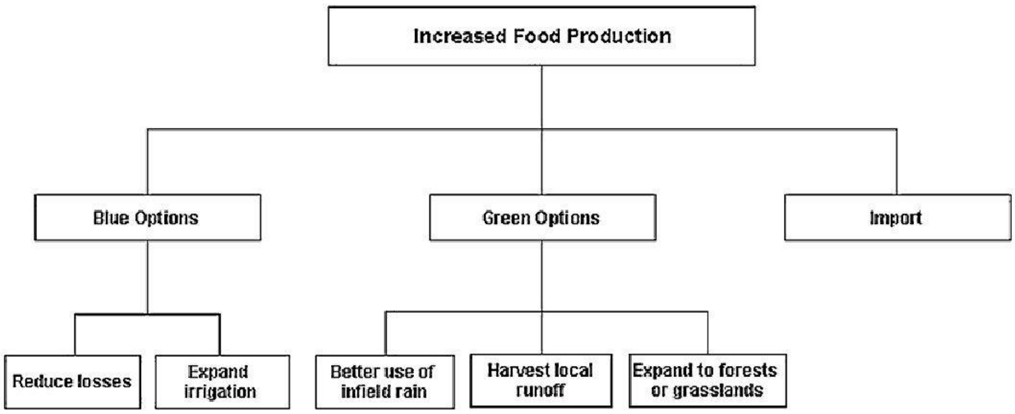


Figure 14: Three basic ways to capture the additional water needed to meet consumptive water use of increased food production: blue water options, green water options, and import/virtual water option (according to FALKENMARK 2007).

It can be concluded from Figure 14 that an improved water management is very important for an efficient use of the available water resources.

As it has been mentioned in the very beginning of this paper, the Hilkot catchment is part of five PARDYP test catchments located in the Himalayas. An in-depth survey of the socio-economical aspects of water has been made in the two Nepalese catchments Yarsha Khola and Jkikhu Khola (MERZ et al. 2003): On the one hand, this study pinpoints the fact that water availability is the main problem perceived by the inhabitants (Figure 15) and therefore emphasises the findings of the present paper which is mainly based on hydrological data. The shortage of water for agricultural and domestic purposes during the dry months of the year is of particular concern in the two Nepalese watersheds. People perceive that the water supply for agricultural production is decreasing. The main reason for this is an agricultural intensification that followed developmental efforts targeted at increasing marketable agricultural and horticultural products. Microbiological water quality data show that fecal contamination is a problem in most water sources. Intensive agriculture aggravate the quality problems; shallow groundwater wells and surface water courses are contaminated and have elevated levels of nitrate and phosphate that often exceed health standards.

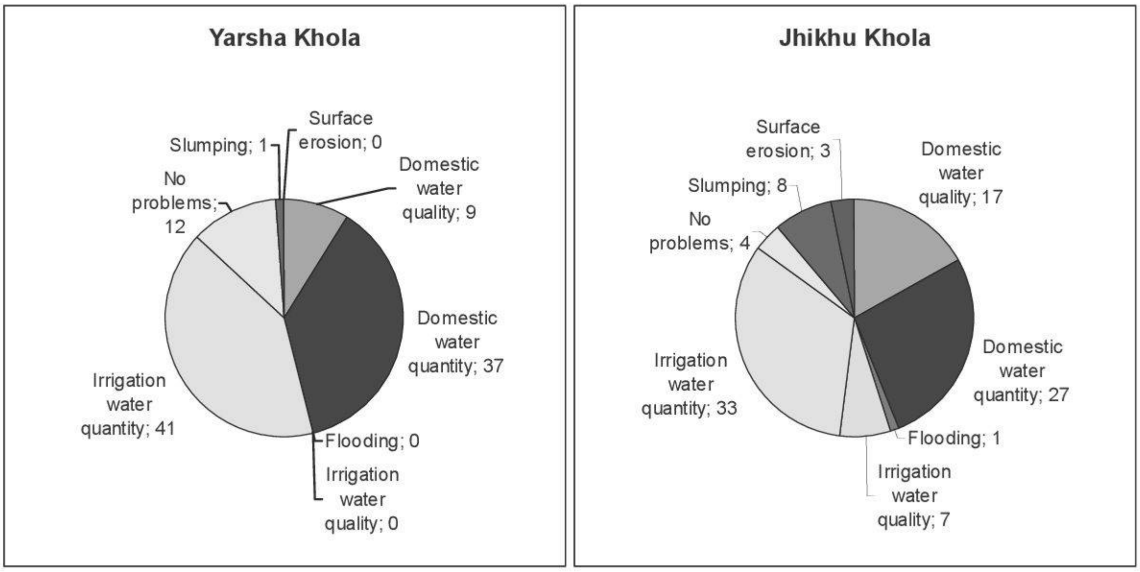


Figure 15: Responses of inhabitants on water related problems in Yarsha Khola (YK) and Jhikhu Khola (JK) [%], n = 436 in YK and n = 356 in JK. YK has an altitudinal range of 990–3030 m asl, JK of 800–2200 m asl (according to MERZ et al. 2003).

On the other hand, the study of MERZ et al. (2003) concludes that with the increasing pressure on available water resources, new forms of water resources management at watershed scale have to be introduced. They have to be based on the social background of the area and on the technical possibilities. Without evaluating water balances, it is increasingly difficult to determine the carrying capacity of water, and without knowing the social setting, it is impossible to address water equity issues. Furthermore, participation of households and communities in the development of new and adapted institutional and technical options is a prerequisite.

The comparison with Nepal watersheds clarifies that the findings for the Hilkot catchment are quite typical for the situation in many regions of the Hindu Kush-Himalayas.

Acknowledgement

The data used for this study were kindly made available by PARDYP Pakistan and the Pakistan Forest Institute (PFI). The authors wish to express their special thanks and gratitude to the team of PARDYP Pakistan.

References

FALKENMARK, M.

2007 "Shift in thinking to address the 21st century hunger gap – Moving focus from blue to green water management". In: *Water Resources Management* 21:3–18.

FALKENMARK, M.; WIDSTRAND, C.

1992 "Population and water resources: a delicate balance". In: *Population Bulletin*. Washington, DC: Population Reference Bureau.

FLETCHER, R. D.

1950 "A relation between maximum observed point and areal rainfall values". In: *Transactions of the American Geophysical Union*, No. 31:344–348.

FLURY, B.

2005 *Water-related results of the PARDYP-livelihood survey 2004/2005, Hilkot watershed, Pakistan.* Zurich, Switzerland: Geographical Institute of the University of Zurich.

GDRC

Web page of Hindu-Kush Himalayan Friend. Discharge data from the Global Runoff Data Centre (GRDC). Accessed in July 2005. http://www.hkh-friend.net.np/rhdc/data.html.

GOOGLE EARTH SOFTWARE

As at October 2006. http://earth.google.com/.

HAUDE, W.

1955 *Zur Bestimmung der Verdunstung auf möglichst einfache Weise.* Mitteilung des Deutschen Wetterdienstes 2 (11), Bad Kissingen.

KLIMADIAGRAMME
Web page with climate charts from different parts of the world. Accessed in October 2006. http://www.klimadiagramme.de.

KÖPPEN, W. P.
1923 *Die Klimate der Erde. Grundriss der Klimakunde.* Mit 8 Tafeln und 19 Textfiguren. Berlin and Leipzig, Germany: De Gruyter.

MAURER, H.
1975 *Niederschlagsarme Perioden und Trockenperioden in der Bundesrepublik Deutschland.* Dissertation. Freiburg, Germany: University of Freiburg im *Breisgau.*

MERZ, J.; NAKARMI, G.; SHRESTA, S. K.; DAHAL, B. M.; DANGOL, P. M.; DHAKAL, M. P.; DONGOL, B. S.; SHARMA, S.; SHAH, P. B.; WEINGARTNER, R.
2003 "Water: A scarce resource in rural watersheds of Nepal's Middle Mountains". In: *Mountain Research and Development*, Vol. 23 (1):41–49.

NASA WORLD WIND SOFTWARE
As at October 2006. http://worldwind.arc.nasa.gov/.

PARDYP synthesis CD-ROM.
2004 *International Centre for Integrated Mountain Development (ICIMOD).* Kathmandu, Nepal: ICIMOD.

PENMAN, H. L.
1948 "Natural evaporation from open water, bare soil and grass". In: *Proceedings of the Royal Society of London*, No. 193:120–145.

SIWI, IFPRI, IUCN, IWMI.
2005 *Let it reign: the new water paradigm for global food security. Final report to CDS-13.* Stockholm: International Water Institute, Stockholm.

TURC, L.
1954 "Le bilan d'eau des sols, relations entre les précipitations, l'évaporation et l'écoulement". In: *Ann. Agronomique,* No. 12:36–43.

WEINGARTNER, R.; ASCHWANDEN, H.
1985 *Die Abflussregimes der Schweiz.* Geographisches Institut der Universität Bern, Abt. Physikalische Geographie-Gewässerkunde. Publikation Gewässerkunde Nr. 65.