Comparison of Climatological Balances for the Jhikhu Khola and Yarsha Khola Watersheds, Nepal

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Abstract

Water availability for agricultural production has become a major issue in many areas of the middle mountains in Nepal. While water retention may be modified and water use may be regulated, the amount of water that is potentially available depends on the climatic conditions and cannot be changed.

This paper discusses the climatological parameters of the two PARDYP watersheds in Nepal, the Yarsha Khola and the Jhikhu Khola. Climatological water balances were derived and compared between the two watersheds. Water availability was shown to be a major problem for winter crops; water has become the major limiting factor for agricultural production. A distinct difference was identified between the two watersheds. Possible improvements to the current situation are suggested.

Introduction

Degradation of natural resources has been a concern in the Hindu Kush-Himalayas for many years. The People and Resource Dynamics Project (PARDYP) is trying to improve the understanding of the processes associated with this degradation (ICIMOD 1997).

Water is only one of the resources that is endangered. The agricultural and domestic demand for water is growing with intensifying agriculture and increasing population. However, the potential availability of water within the system of a watershed is limited and cannot be changed.

This study attempts to assess the potential water availability within the two PARDYP watersheds in Nepal, the Jhikhu Khola and Yarsha Khola watersheds (hereinafter referred to as Jhikhu and Yarsha), on the basis of the climatological parameters, rainfall and temperature. Only one year's data is available for the Yarsha watershed at present so that a comparison of the two watersheds is only possible for 1998. This is insufficient for conclusive remarks about the water availability, but indicates where further research needs to be focused.

The Study Area

The watersheds are both located in the middle mountains of Nepal. The Jhikhu watershed is situated about 45 km east of Kathmandu on the Arniko Highway (Figure 53) and covers 111.4 sq.km.The Yarsha watershed is located about 190 km east of Kathmandu on the Lamosangu-Jiri Road in Dholaka District and has an area of 53.4 sq.km. The two watersheds differ not only in their altitudinal range (Jhikhu watershed 800 to 2200 masl, Yarsha watershed 990 to 3030 masl) and size, but also in their physiography. The Jhikhu watershed is a main valley with a large flat valley bottom of alluvial origin, where the major land use is irrigated agriculture. Short and steep slopes confine it on the southern and northern sides. There are many pocket-like valleys on the flanks, which make the watershed very heterogeneous. The general aspect of the watershed is south-east. The Yarsha watershed has a general south-west aspect, and a south and north facing slope with a small middle ridge in between. There is no extensive flat valley bottom of alluvial origin and irrigated areas are limited, especially in comparison with the Jhikhu watershed. The Yarsha watershed appears more homogenous than the Jhikhu watershed.

A dense network of meteorological stations has been established in both watersheds (Figure 53). A total of 10 stations in the Jhikhu Khola and 11 stations in the Yarsha Khola are used for climatological measurements, in particular rainfall and temperature. The characteristics of the stations are given in Table 55. Missing station numbers indicate hydrological stations and erosion plots. In the Yarsha watershed a good spatial coverage was chosen with the aim of obtaining data sets with good horizontal and vertical distribution. The meteorological measurements in the Jhikhu watershed focus on some sub-catchments of interest.

Measurements were started in the Jhikhu watershed in 1992, but in the Yarsha watershed only in 1997. Thus the first complete year data set for the Yarsha watershed is that for 1998 and the two watersheds can only be compared on the basis of the data for that year.

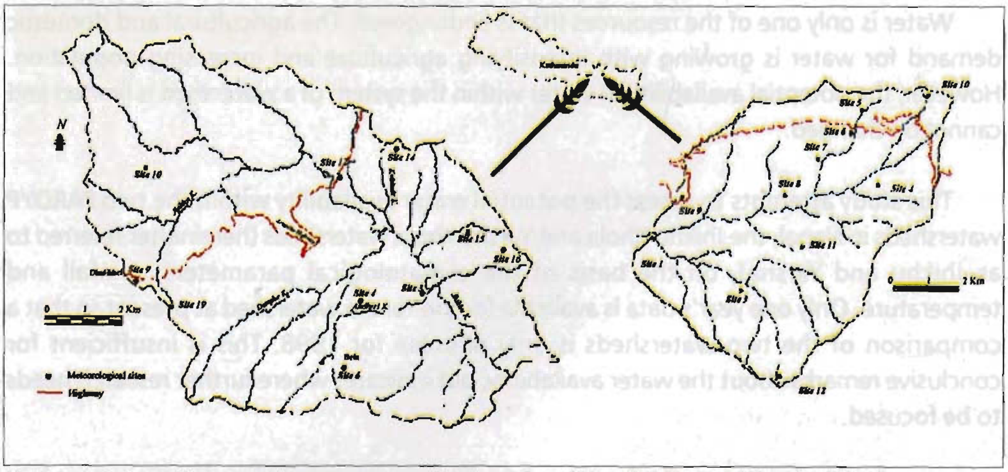


Figure 53: **Location and Measurement Networks of the Jhikhu and Yarsha Khola Watersheds**

Table 55: **Station Characteristics of Meteorological Stations in the Jhikhu and Yarsha Khola Watersheds**

Station No.	Station Name	Elevation (m)	Parameters Measured
Jhikhu Khola			
3	Acharyatol -Baluwa	830	RA, AT, ST
4	Baghakhor	940	RA, RI
6	Bela	1,280	RA, RI, AT, ST
9	Dhulikhel	1,560	RA, AT
10	Bajrapare	1,100	RA
12	Tamaghat	850	RA, RI ,AT, ST
14	Kubindegaun	880	RA ,RI
15	Bhimsensthan	880	RA, RI, AT, ST
16	Bhetwalthok	1,200	RA, RI, AT, ST
19	Bhattidanda	1,640	RA, AT, ST
Yarsha Khola			
1	Main Hydro Station	1,005	RA, RI, AT, ST
3	Gairimudi	1,530	RA, RI, AT, ST, H
4	Yarsha Forest Site	1,990	RA, RI, AT, ST
5	Thulachaur	2,300	RA, RI, AT, ST, H
6	Jyamire	1,950	RA, RI, AT, ST
7	Bagar (NARC)	1,690	RA, RI, AT, ST, WS, WD, N, H
8	Nimkot	1,420	RA, RI, AT, ST
9	Namdu	1,400	RA, RI, AT, ST, H
10	Thuloban	2,640	RA, RI, AT, ST
11	Mrige	1,610	RA, RI, AT, ST
12	Pokhari	2,260	RA, RI, AT,

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

Both watersheds are represented by a main meteorological station: at Bagar (NARC) for Yarsha and at Tamaghat (Horticultural Farm) for Jhikhu. A variety of parameters are monitored at these stations. At normal stations, the rainfall amount, rainfall intensity, and air and soil temperatures are generally measured on a regular basis. Rainfall totals are measured in both watersheds with ordinary standard rain gauges of 8" diameter. Local readers read them daily at 08:45. The Department of Hydrology and Meteorology of Nepal (DHM) is using the same type of rain gauge and reads at the same time. Rainfall intensity information is derived from tipping bucket measurements. The tipping buckets are also of 8" diameter and can therefore be cross-checked with the data from the standard rain gauges. Two methods of recording are employed: some stations record rainfall by event, which allows the calculation of any intensity required; others record at regular time intervals of 2 minutes, which allows the calculation of two minute intensities. Both ordinary and tipping bucket rain gauges are installed with the receiving orifice 1m above ground level.

Temperature is measured with thermistors (temperature loggers) which are installed between 1.25 and 1.5m above ground level in a Stevenson screen.

Potential evapotranspiration (PET) was calculated by the Thornthwaite method as proposed by ICIMOD (1996). The method is explained in detail in Thornthwaite *et al.* (1955).

It requires mean monthly temperatures in order to determine tabulated monthly heat indices. These values are summed to give yearly heat indices. Unadjusted PET can be determined with the help of a value table. With information on the location (latitude) of the site, the PET can be adjusted to local conditions.

More recent installations include piche evaporimeters in the Yarsha watershed, and Chinese made evaporation pans and a piche evaporimeter at the main meteorological station in the Jhikhu watershed. In the future it will be possible to compare the results of the indirect method of determining evaporation with actual field measured evaporation.

Monthly climatological balances were calculated from the recorded rainfall, evapotranspiration, and field capacity values following the book-keeping procedure (Thornthwaite *et al.* 1955). Monthly field capacity values were taken from those reported in Upadhyay (1985), from Jiri (250 mm) for the Yarsha watershed balances and from Kathmandu (200 mm) for the Jhikhu watershed balances.

Calculation of the climatological water balance with this method is a first approximation of the conditions found in the two watersheds. Further investigation and verification of some of the parameters (e.g., field capacity, PET) are still needed.

Climatological Balances and Parameters in the Yarsha Khola Watershed

Although there are no long-term data available from within the Yarsha watershed, the DHM maintains stations in Jiri and Charikot, both of which are close by. The Yarsha meteorological main station at Bagar is considered to be representative for the whole catchment (Doppmann 1998). The annual mean rainfall at Bagar in 1998 is shown in Figure 54 together with the values for Jiri and Charikot from 1987 to 1994 (DHM 1992;

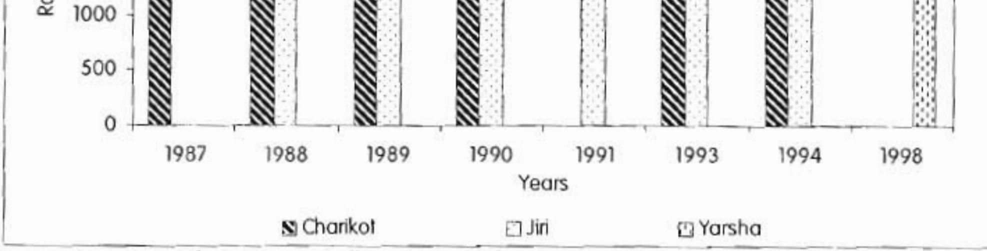


Figure 54: **Annual Mean Rainfall at Jiri and Charikot from 1987 to 1994 in Comparison with Annual Rainfall 1998 at Bagar (Data Source for Jiri and Charikot: DHM, 1992; DHM 1997a)**

DHM 1997a). Data for 1995 onwards are not yet available from DHM as they are still being checked. The overall mean annual rainfall at Jiri (2003 masl) from 1987 to 1994 was 2310 mm and at Charikot (1960 masl) 1909 mm. The annual mean rainfall for the whole region is 1800 to 2000 mm (ICIMOD 1996). The annual mean rainfall at Bagar (1690 masl) in 1998 was 2048 mm. The results indicate that 1998 was not an exceptional year in terms of annual mean rainfall although this cannot be finally confirmed until the 1998 data for Jiri and Charikot are available.

The spatial variability of rainfall within the watershed is large (Figure 55). In 1998, the annual rainfall varied from from 1600 mm in the lower parts of the watershed, to 3300 mm in the upper parts. The altitudinal gradient varied from 114 mm rainfall/100m vertical distance on an annual basis to 97mm/100m during the monsoon. Similarly, the number of events increased with increasing altitude. An event was taken to be a total rainfall of more than 3 mm with less than two hours break between each recording (definition from Carver 1997). In Thulachaur (2300 masl), the highest station with a whole year rainfall record in the watershed, a total of 132 events were recorded for 1998; whereas the number of events at the lowest station, the Main Hydro Station (1005 masl), was only 52 (Table 55). These events mainly occurred during the monsoon (June-September; Hofer 1998), which reflects the high temporal variability in the annual rainfall. Eighty per cent of the total annual rainfall at all stations fell during the monsoon and an average of 16 per cent during the pre-monsoon season (March to May). The rest was distributed in the post-monsoon and winter periods. Thus there were two distinct seasons: wet and dry.

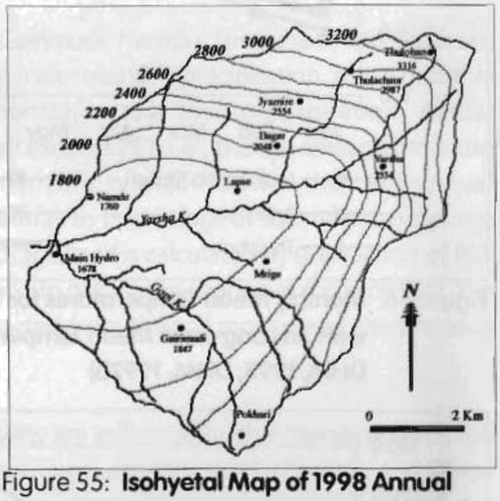


Figure 55: **Isohyetal Map of 1998 Annual Rainfall (mm) for the Yarsha Khola Watershed, 1998**

The Thornthwaite PET calculation is based on temperature, as explained above, and for 1998 this was the only parameter available to calculate the PET for several stations within the watershed. The variation in temperature over the year is shown in Figure 56. There was an altitude gradient of 0.65°C per 100m. Overall the mean monthly temperature ranged from 5.2°C in January at Thulachaur, to 26.6°C at the Main Hydro Station in June. June was the hottest month at all the stations in the Yarsha watershed. The mean monthly temperature for June at Bagar was 22.3°C, which matches well with the temperature of 21 to 24°C given by ICIMOD (1996) for this region. The 1998 temperatures also showed a good match with the long-term mean temperature of Jiri (Figure 56).

The calculated graph of PET is shown in Figure 57. It looks similar to the temperature curve as the calculations were based on temperature. The peak PET at all stations was

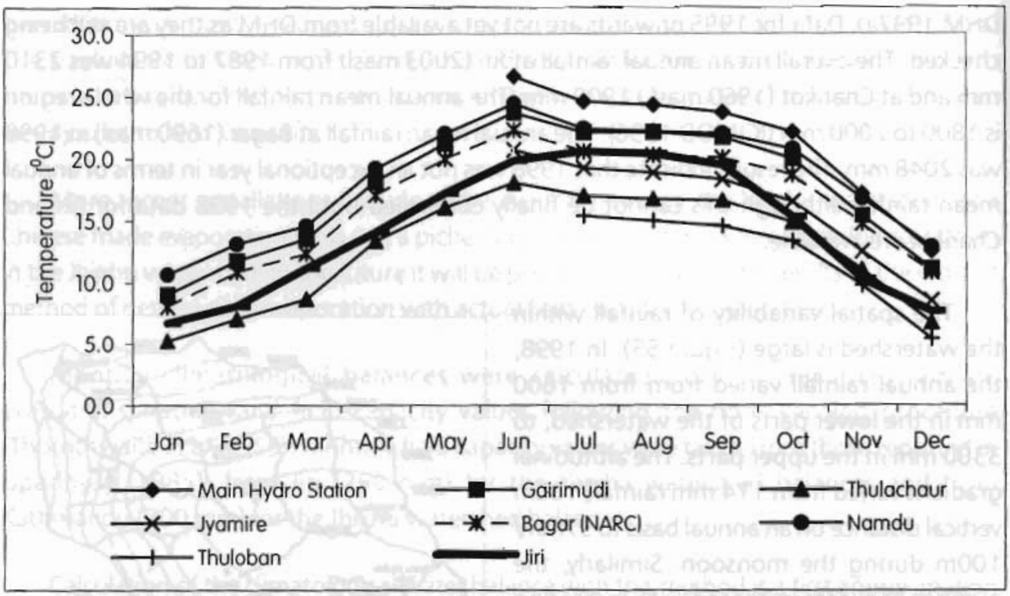


Figure 56: **Monthly Mean Temperatures for Yarsha Khola Watershed, 1998, in Comparison with Jiri Long-term Mean Temperature (1987 – 1994). (Data Sources for Jiri: DHM, 1995; DHM, 1997b)**

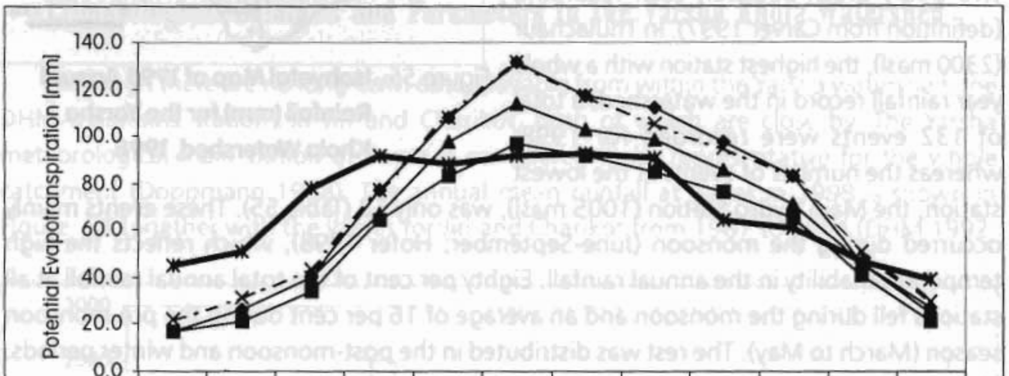


Figure 57: **Potential Evapotranspiration at Selected Stations in the Yarsha Kola Watershed 1998 in Comparison with Long-term PET Derived from Class A Pan Data for Jiri (Data Source for Jiri: DHM, 1995; DHM, 1997b)**

calculated to be in June, the hottest month of the year. The lowest PET was calculated to be in January with a rapid increase thereafter towards June. The calculated data for Bagar (NARC) were compared with the class A evaporation pan data for Jiri as a crosscheck (Figure 57). For this purpose, the class A pan data was converted to PET by applying a conversion factor of 0.8 (mid-summer), 0.7 (spring), and 0.6 (winter) (WECS).

The calculated values for Bagar and the measured values for Jiri agree fairly well for May to November; but during the winter and pre-monsoon months the PET appeared to be underestimated by the calculation method used. The low values during May and June in the Jiri data set were unexpected, however, as in the middle hills of Nepal, peak PET is normally expected during the May/June period. On the other hand, Thornthwaite's method is directly related to temperature, thus an overestimate during summer and an underestimate during winter is likely. In future, measured evaporation data will be compared directly with the calculated data .

The calculated climatological balances for Gairimudi, Namdu, Thulachaur, and Bagar are shown in Figure 6. The graphs show three lines: mean monthly precipitation, mean monthly potential evapotranspiration, and mean monthly actual evapotranspiration. Actual evapotranspiration is equal to PET when rainfall exceeds PET, i.e., there is enough moisture available to fulfill the atmospheric requirements. If rainfall is lower than PET, actual evapotranspiration is determined by adding rainfall to the change in soil moisture storage over the period of one month. Soil moisture storage itself is calculated by subtraction of PET from rainfall and with reference to field capacity. To obtain the change in soil moisture, the soil moisture of any particular month is subtracted from the soil moisture of the previous month.

Different stages of potential water availability are indicated by the intersections of the different graphs: water surplus, soil moisture recharge, soil moisture utilisation, and water deficiency (see legend to Figure 58). Soil moisture recharge occurs when rainfall exceeds the potential evapo-transpiration; this occurs mainly during the pre-monsoon and early monsoon. After full recharge of soil moisture, there is a water surplus during any subsequent times of excess rainfall . With the end of the monsoon, soil moisture utilisation and water deficiency begin. Water deficiency occurs when potential evapotranspiration exceeds soil moisture availability, i.e., the available soil moisture is fully utilised by high actual evapotranspiration.

The potential climatological water availability differs between different locations and at different times. Thulachaur, the highest station in the watershed for which a balance is available, only showed soil moisture utilisation during three months of 1998 (November, December, and January). In contrast, Namdu, representing lower watershed areas, faced water shortages during six months of the year (October to February and May). Gairimudi, the only station on a north-facing slope, also faced water shortages during five months of the year. The available soil moisture met the requirements of PET in all the calculated balances, which is indicated by the close or exact overlaying of the actual evapotranspiration and PET graphs. This shows that there are only minor periods of water deficiency within the Yarsha watershed. Soil moisture utilisation was most likely to occur during the winter months at all stations. Climatological water shortages (soil moisture utilisation and/or water deficiency) were most likely to occur during the post-monsoon and pre-monsoon periods at lower altitude stations.

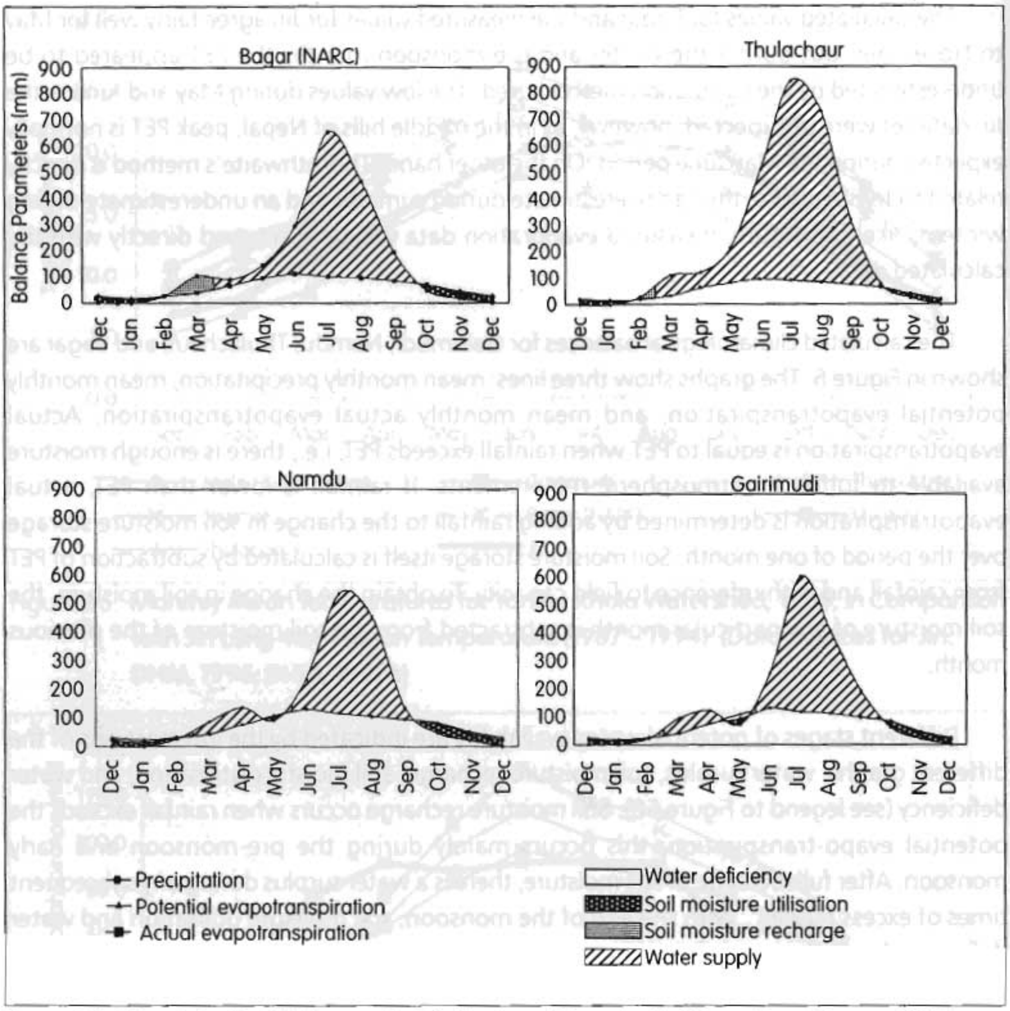


Figure 58: **Climatological Balances for Thulachaur, Namdu, Gairimudi and Bagar, 1998**

Climatological Balances and Parameters in the Jhikhu Khola Watershed

The station representative for the whole watershed is situated at Tamaghat (830 masl), which is part of the DHM meteorological network of Nepal. Data for this station since 1992 are available in the PARDYP database. The rainfall data for 1998 were compared with the data for 1992 to 1997 (Figure 59). The 1998 total of 1351 mm was somewhat higher than the long term mean of 1182 mm, and than the range of 1000–1200 mm given by ICIMOD (1996) for this region. The amount of rain in the 1998 pre-monsoon season, was more than double the long-term mean (297 mm in 1998 compared with 143 mm in the period 1992–1998) and this explains in part the excess in annual rainfall. The 1998 monsoon rainfall was also slightly higher than the long-term mean (990 mm in 1998 compared with 942 mm in the period 199–1998), but the winter of 1998 was exceptionally dry with less than half the average rain of other years.

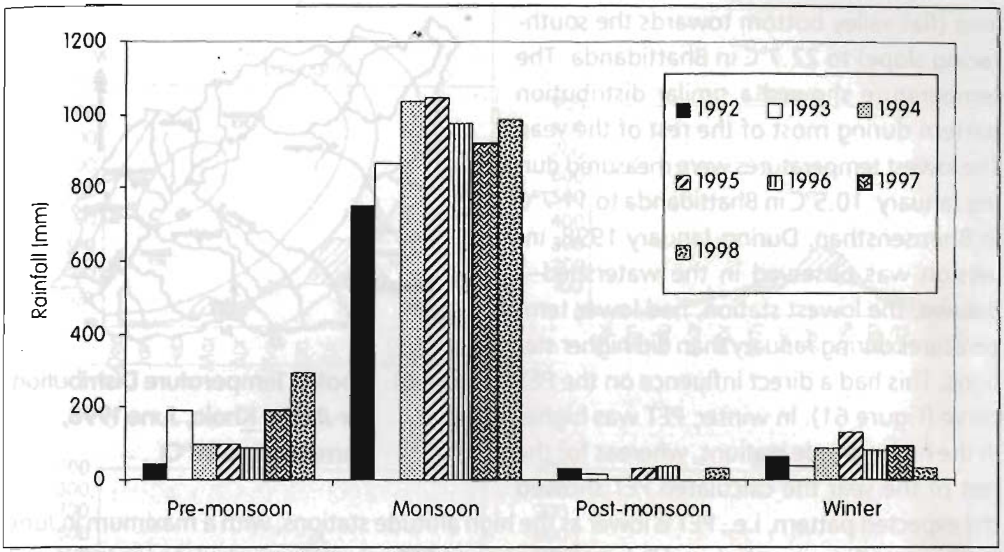


Figure 59: **Seasonal Rainfall at Tamaghat in 1992 - 1998**

The Jhikhu watershed is very heterogeneous, and with the existing monitoring network, it is difficult to assess the spatial distribution of rainfall within the watershed properly. The results of the best attempt are shown in Figure 60. In 1998, the rainfall varied from 1100 mm around the main hydrological station in the east of the watershed to more than 1700 mm in Bhattidanda and Dhulikhel. The valley bottom, where agricultural intensity is high, is the driest part of the watershed. It wasn't possible to measure changes in the number of events with altitude as there is no tipping bucket at Bhattidanda or Dhulikhel. In 1998, 81 events were measured at Tamaghat, the lowest station with a tipping bucket, and 82 in Bela.

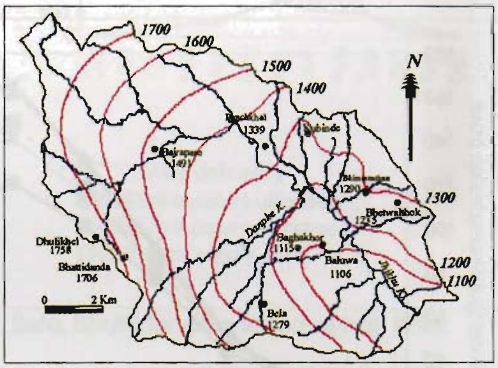


Figure 60: **Annual Rainfall Distribution in the Jhikhu Khola Watershed, 1998 (rainfall in mm)**

There was a high temporal variability in the rainfall amount. The monsoon rainfall is closely related to altitude and varied between 768 mm at the lowest meteorological station in Baluwa (69 % of the annual rainfall), to 1414 mm at Dhulikhel (80 % of the annual rainfall). On average, 74 per cent of the annual rainfall in Jhikhu fell during the monsoon in 1998, compared with a long-term mean of 80 per cent for the period 1992 to 1998. The pre-monsoon rainfall was particularly extensive in 1998; at Tamaghat 22 per cent of the annual rainfall fell during this season, compared with a long-term mean of 12 per cent.

The temperature distribution within the watershed during the hottest month, June, is shown for 1998 in Figure 61. The temperature varied from a mean of 27.7°C in the warmest area (flat valley bottom towards the south-facing slope) to 22.7°C in Bhattidanda. The temperature showed a similar distribution pattern during most of the rest of the year. The lowest temperatures were measured during January: 10.5°C in Bhattidanda to 11.7°C in Bhimsensthan. During January 1998, inversion was observed in the watershed—Baluwa, the lowest station, had lower temperatures during January than did higher stations. This had a direct influence on the PET curve (Figure 61). In winter, PET was higher in the high altitude stations, whereas for the rest of the year the calculated PET showed the expected pattern, i.e., PET is lower at the high altitude stations, with a maximum in June (165 mm at Bhimsensthan and Baluwa). The lowest PET values were calculated in January at Baluwa and Tamaghat.

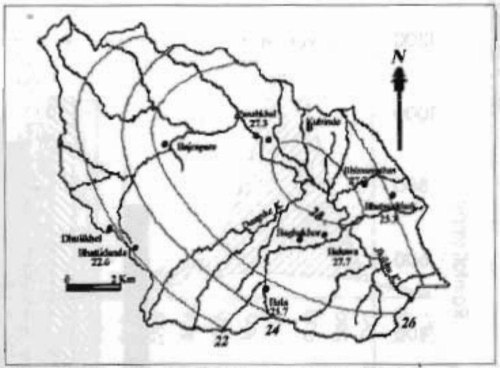


Figure 61: **Spatial Temperature Distribution for Jhikhu Khola, June 1998, (temperature in °C)**

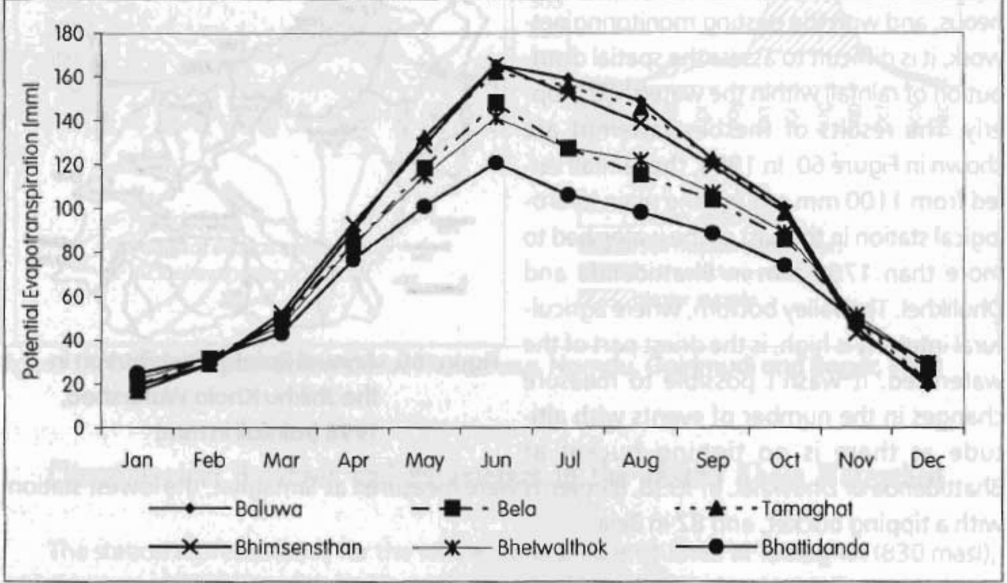


Figure 62: **Potential Evapotranspiration for Jhikhu Khola, 1998**

Climatological balances were calculated on the basis of rainfall and evapotranspiration and are shown for Baluwa, Bela, Bhattidanda, and Tamaghat in Figure 63. The comparatively low rainfall values associated with relatively high temperatures suggest that there are strong possibilities for water deficiency in many places in the Jhikhu watershed. In 1998, even the highest station situated at Bhattidanda was likely to have had six months of water deficiency or at least soil moisture utilisation. The lowest station in Baluwa faced

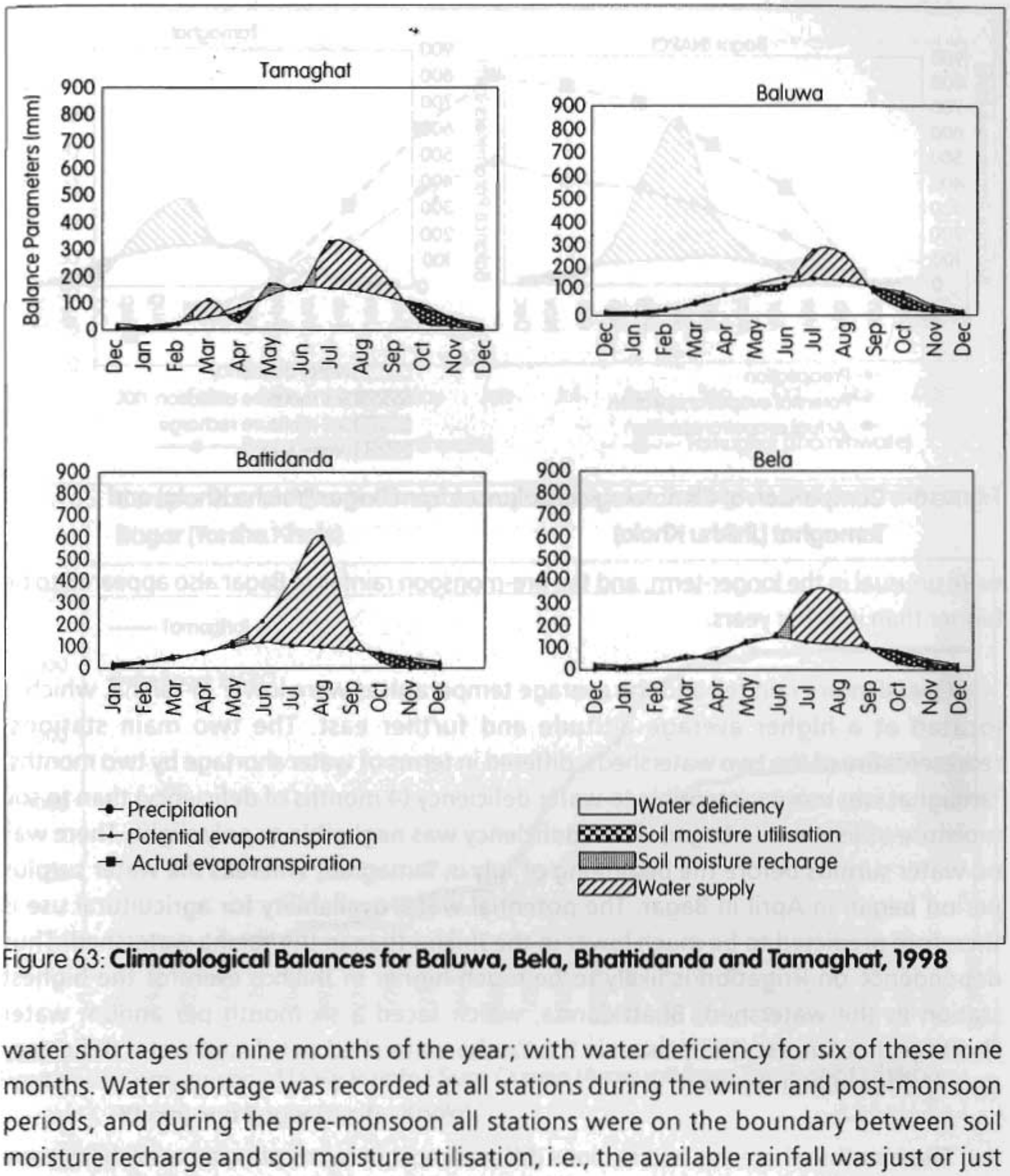


Figure 63: **Climatological Balances for Baluwa, Bela, Bhattidanda and Tamaghat, 1998**

water shortages for nine months of the year; with water deficiency for six of these nine months. Water shortage was recorded at all stations during the winter and post-monsoon periods, and during the pre-monsoon all stations were on the boundary between soil moisture recharge and soil moisture utilisation, i.e., the available rainfall was just or just not able to fulfil the requirements of PET.

Comparison Between the Yarsha Khola and Jhikhu Khola Watersheds

The climatological balances, calculated from rainfall and evapotranspiration data, provide an indication of potential water availability at different locations. Figure 64 shows the balances at the two main stations Tamaghat (Jhikhu) and Bagar (Yarsha) together to facilitate comparison (from Figures 58 and 63). The extent to which the 1998 climatological balances represent the long-term conditions in the watersheds can be assessed from the comparisons with the long-term data sets. 1998 does not appear to be an exceptional year, although the high pre-monsoon rainfall values in Tamaghat (Figure 59)

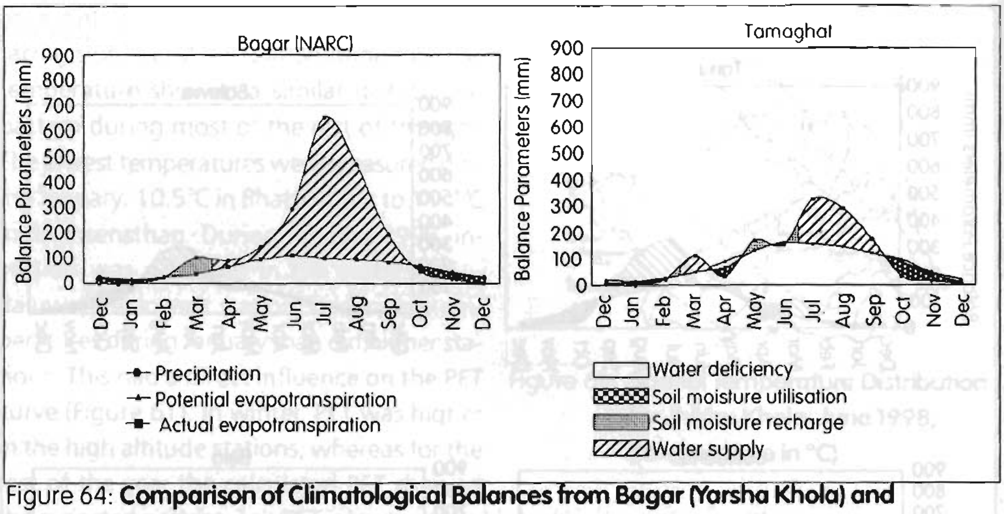


Figure 64: **Comparison of Climatological Balances from Bagar (Yarsha Khola) and Tamaghat (Jhikhu Khola)**

were unusual in the longer-term, and the pre-monsoon rainfall in Bagar also appeared to be higher than in other years.

Overall more rain fell and the average temperatures were lower in Yarsha, which is located at a higher average altitude and further east. The two main stations, representative of the two watersheds, differed in terms of water shortage by two months. Tamaghat was more susceptible to water deficiency (4 months of deficiency) than to soil moisture utilisation. In Bagar, water deficiency was negligible or only slight. There was no water surplus before the beginning of July in Tamaghat, whereas the water surplus period began in April in Bagar. The potential water availability for agricultural use is therefore predicted to be much lower in the Jhikhu than in the Yarsha watershed. Thus dependence on irrigation is likely to be much higher in Jhikhu, even for the highest station in the watershed, Bhattidanda, which faced a six month per annum water shortage. In contrast, Thulachaur in the Yarsha watershed only faced water deficiency during three winter months.

The months where the two stations differed most in terms of water availability were April and June, and the reason for this can be seen from Figures 65 and 66. While in late April, at the time of increasing evapotranspiration rainfall was already increasing in Bagar, rainfall and therefore adequate moisture did not start in Tamaghat until mid-May. The monsoon rainfall started somewhat later in Jhikhu than in Yarsha, which resulted in a one-month water deficiency in the watershed at the time that PET reached a peak (June).

A comparison of the water availability with the crop calendar reveals some interesting issues (Figure 67). Both main stations lie roughly on the boundary between zones of dominantly rainfed and dominantly irrigated agricultural land. Monsoon rice is planted in about June in the Jhikhu watershed which is still a time of soil moisture utilisation; thus a

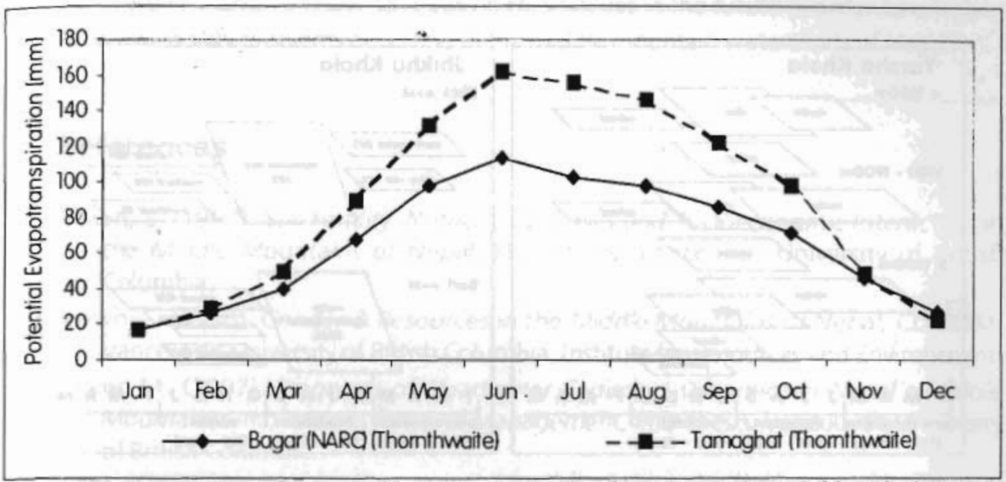


Figure 65: **Comparison of Potential Evapotranspiration from Tamaghat (Jhikhu Khola) and Bagar (Yarsha Khola)**

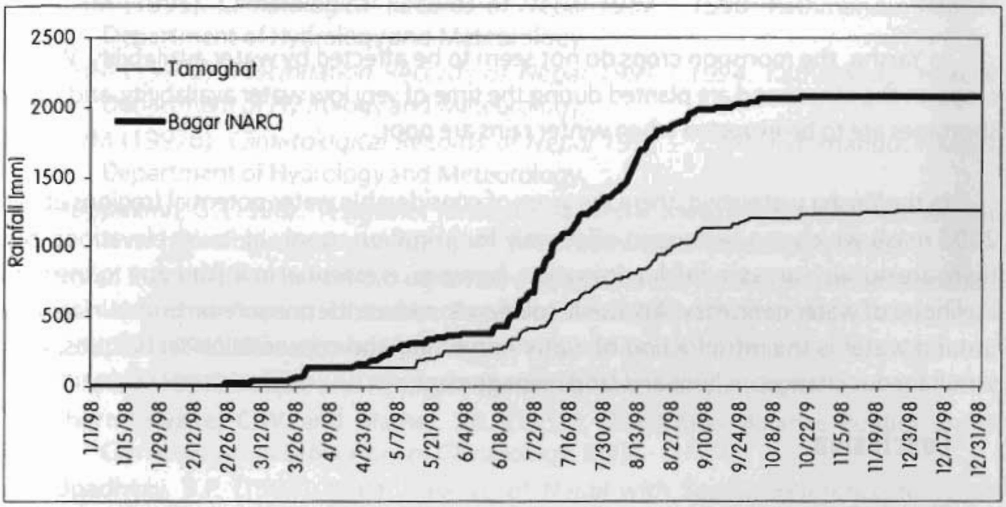
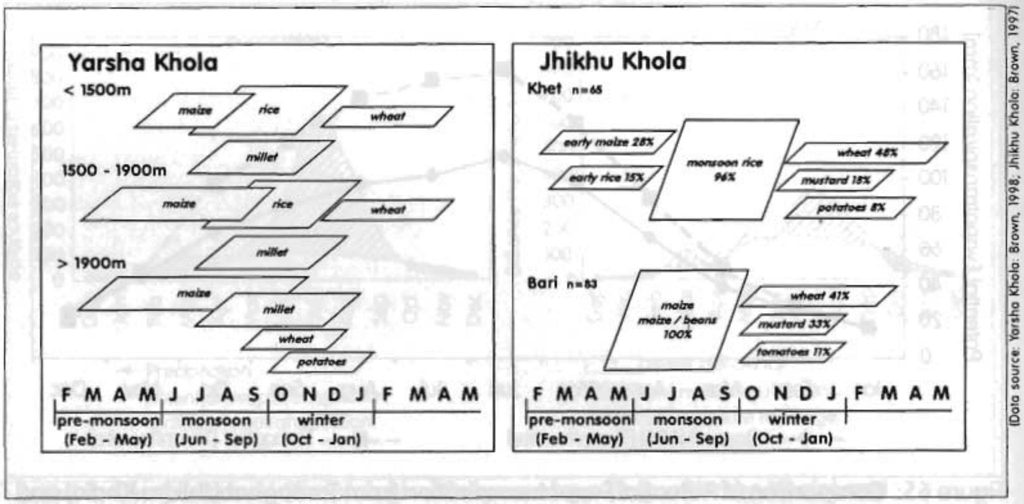


Figure 66: **Comparison of Daily Rainfall Sum Curves (Amount) from Tamaghat (Jhikhu Khola) and Bagar (Yarsha Khola)**

large input of irrigation water is needed. Even towards the end of the monsoon in September, water shortages can occur. This may affect the yield of the rice harvest as adequate moisture is needed at this time when the rice plants are at the flowering and milky stage.

On the rainfed land, maize is planted after the first monsoon rains, exactly at the time of high rainfall—the time of water surplus or adequate moisture. Maize, however, has high transpiration rates which may affect the water availability if soil moisture recharge is not ensured. Winter crops are planted in October when soil moisture utilisation has already begun; second winter crops are planted during water deficiency periods.



(Data source: Yarsha Khola: Brown, 1998; Jhikhu Khola: Brown, 1997)

Figure 67: **Agricultural Calendars for the Yarsha Khola and Jhikhu Khola Watersheds**

In Yarsha, the monsoon crops do not seem to be affected by water availability. Winter crops on the other hand are planted during the time of very low water availability, and water shortages are to be expected when winter rains are poor.

In the Yarsha watershed, there are areas of considerable water potential (regions above 2000 masl) which can be tapped effectively for irrigation supply at lower elevations, but there are no such areas in Jhikhu. Irrigation, however, is essential in Jhikhu due to the high likelihood of water deficiency. A possible solution to reduce the pressure on both surface and ground water is the introduction of water harvesting and conservation techniques, with simultaneous changes in farm and land management.

Conclusion

The results show that there are areas and times of water shortage in both watersheds. In the Jhikhu watershed, most of the intensively used agricultural areas face acute water shortage during at least half the year, with a subsequent high demand for irrigation water. At the same time the availability of irrigation water is limited as there are no rainfall rich areas in Jhikhu watershed. Further pressure on water resources from population growth and the increasing trend towards agricultural intensification will lead to serious water shortages in the coming years. As climatological input of water cannot be changed, changes have to be made within the watershed. The possibilities suggested for changing water availability are:

- water harvesting technologies;
- water conservation technologies such as mulching and support of recharge; and
- changing land use practices and cropping patterns (agronomic interventions).

The PARDYP teams will have to focus on these issues in the future in order to mitigate the water availability problems occurring in the middle mountain watersheds of Nepal.

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