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# Role of Meltwater in Major River Systems of Nepal

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**Abstract** The Karnali, the Narayani and the Koshi are three major river systems in Nepal with an area of 42 890, 31 100 and 54 100 km$^2$ respectively in the mountainous Himalayan region. The importance of meltwater in these rivers is indicated by the fact that about 53%, 50% and 68% of the total drainage area of the Karnali, the Narayani and the Koshi rivers (respectively) are situated above an altitude of 3000 m asl. Analyses of runoff characteristics of major rivers in Nepal during the recession and low-flow period indicate a similar pattern with lowest flow in the months of February and March. The snowfed rivers show a distinct rise in the pre-monsoon period (April to mid-June) with meltwater contribution exceeding 30% in May. The role of meltwater becomes less important as compared to the role of groundwater and rainfall in the remaining months.

## INTRODUCTION

Despite the importance of meltwater contribution to the hydrology of the Himalayan rivers, its characteristics are less understood primarily due to the complexities of the process involved in snow hydrology and the lack of hydrometeorological data in high elevation zones.

Estimation of annual and seasonal contribution of meltwater to streamflow in different river basins in Pakistan (Young & Hewitt, 1990), India (Singh & Mathur, 1976; Hasnain, 1989; Bahadur, 1992) and Nepal (Motoyama *et al.*, 1987; Yamada & Motoyama, 1988; Chyurlia, 1984) has been made in the past for different Himalayan drainage basins. These studies show that the role of meltwater in the Himalayan rivers is significant especially during the summer and the monsoon.

The present work is an attempt to make an approximate assessment of the meltwater contribution to the major river systems of Nepal. Because of the (high) complexities involved in the hydrological processes in glacier areas during the summer monsoon, only the period from post-monsoon to pre-monsoon has been dealt in more detail in this study.

## HYDROMETEOROLOGICAL CHARACTERISTICS

All the river basins in Nepal are under the influence of monsoon climate.

About 80% of the annual precipitation occurs during the summer monsoon which usually lasts for about three months from mid-June to mid-September. In general, the precipitation above 5000 to 6000 m falls as snow during the monsoons.

The period after the summer monsoon is relatively dry. A few precipitation spells usually lasting for two to three days are observed during winter due to western disturbances which usually bring more precipitation in the west than in eastern Nepal. Almost all the precipitation above 3000 m in this period falls as snow.

The Karnali, the Narayani and the Koshi are major snowfed rivers in Nepal, besides the Mahakali which borders Nepal and India in the west. All these rivers receive flow from numerous tributaries originating in the high mountainous areas with glaciers and snow covers (Fig. 1). The Karnali basin has the least monsoonal effect among the three major river basins.

The snowfalls below the elevation of 3000 m are usually considered to be less significant as its contribution to the streamflow may persist for a few days only.

Upper air observations made in Nepal indicate the annual variation of freezing level from about 3000 to 6000 m. Hence this range of altitude plays an important role in the contribution of meltwater to the rivers downstream. The areas within the altitude range of 3000 m and 6000 m are about 53%, 45% and 61% in the Karnali, Narayani and Koshi basins respectively (Table 1).

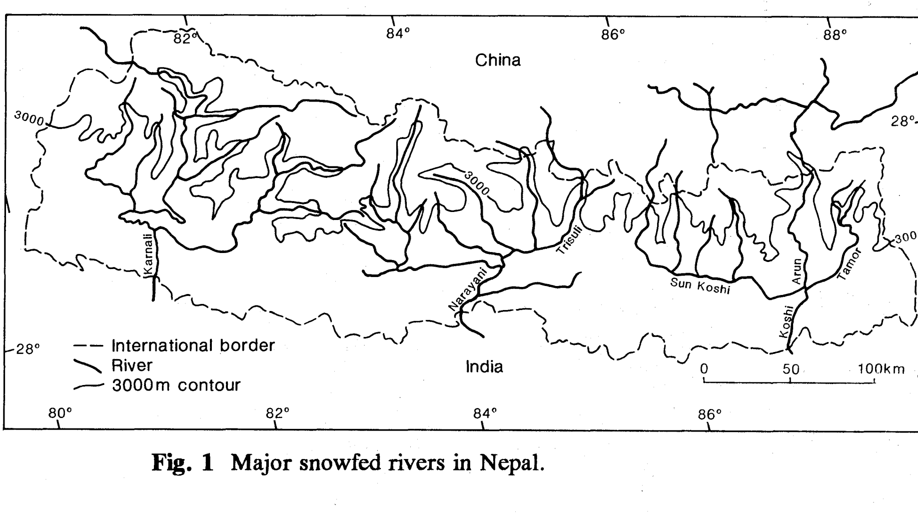


**Fig. 1** Major snowfed rivers in Nepal.

## DATA USED

Long term average monthly flow data have been used to study the influence of meltwater by considering the average flow condition in the rivers throughout the Kingdom. Out of the regular long term data available for forty four

**Table 1** Monthly discharges (mm) in Karnali, Narayani and Koshi basin rivers witn snow component.

| | Total drainage area (km²) | % of area | | | Discharges (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | >3000 m | >6000 m | 3000-6000 m | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
| KARNALI BASIN RIVERS | | | | | | | | | | | | |
| Karnali, Asaraghat | 19260 | 75 | 1 | 74 | 61 | 33 | 23 | 18 | 16 | 18 | 28 | 52 |
| Karnali, Benighat | 21240 | 32 | 1 | 31 | 70 | 37 | 26 | 20 | 18 | 19 | 29 | 52 |
| Seti, Banga | 7460 | 71 | 0 | 71 | 93 | 46 | 32 | 26 | 24 | 27 | 33 | 47 |
| Bheri, Jamu | 12290 | 50 | 0 | 50 | 84 | 39 | 26 | 21 | 18 | 18 | 22 | 33 |
| Karnali, Chisapani | 42890 | 47 | 0 | 47 | 82 | 39 | 28 | 23 | 21 | 22 | 28 | 44 |
| NARAYANI BASIN RIVERS | | | | | | | | | | | | |
| Kali G., Setibeni | 7130 | 66 | 4 | 62 | 98 | 44 | 26 | 18 | 15 | 15 | 21 | 34 |
| Kali G., Kotagaon | 11400 | 42 | 3 | 39 | 126 | 59 | 36 | 27 | 21 | 18 | 21 | 33 |
| Seti, Phoolbari | 582 | 40 | 5 | 35 | 253 | 116 | 78 | 60 | 53 | 53 | 62 | 91 |
| Marsyangdi, Goplinghat | 3850 | 70 | 8 | 62 | 146 | 72 | 46 | 34 | 29 | 28 | 38 | 66 |
| Chepe K., Garambesi | 308 | 17 | 0 | 17 | 244 | 112 | 68 | 47 | 38 | 34 | 37 | 49 |
| Burhi G., Arughat | 4270 | 80 | 8 | 72 | 107 | 57 | 34 | 24 | 20 | 23 | 41 | 66 |
| Phalanku K., Betrawati | 162 | 20 | 0 | 20 | 205 | 86 | 52 | 37 | 31 | 26 | 29 | 40 |
| Trishuli, Betrawati | 4640 | 85 | 11 | 74 | 95 | 49 | 33 | 26 | 22 | 23 | 29 | 49 |
| Tadi, Belkot | 653 | 7 | 0 | 7 | 180 | 92 | 54 | 37 | 29 | 22 | 24 | 34 |
| Narayani, Narayanghat | 31100 | 50 | 5 | 45 | 137 | 68 | 42 | 30 | 25 | 23 | 30 | 49 |
| KOSHO BASIN RIVERS | | | | | | | | | | | | |
| Arun, Tumlingtar | 28200 | 95 | 10 | 85 | 39 | 20 | 14 | 11 | 11 | 13 | 17 | 25 |
| Bhote K., Barhabise | 2410 | 89 | 11 | 78 | 89 | 45 | 29 | 24 | 20 | 18 | 24 | 36 |
| Balephi, Jalbire | 629 | 54 | 2 | 52 | 226 | 104 | 66 | 50 | 42 | 39 | 45 | 61 |
| Sun K., Pachuwarghat | 4920 | 57 | 6 | 51 | 130 | 67 | 42 | 31 | 26 | 24 | 28 | 40 |
| Tama K., Busti | 2753 | 81 | 12 | 69 | 137 | 65 | 41 | 29 | 25 | 23 | 29 | 55 |
| Khimti, Rasnalu | 313 | 32 | 0 | 32 | 173 | 84 | 55 | 43 | 37 | 33 | 38 | 63 |
| Sun K., Khurkot | 10000 | 51 | 6 | 45 | 133 | 62 | 39 | 29 | 24 | 22 | 26 | 40 |
| Likhu, Sangutar | 823 | 35 | 0 | 35 | 215 | 107 | 68 | 48 | 38 | 34 | 38 | 58 |
| Dudh K., Rabuwa | 3780 | 61 | 5 | 56 | 154 | 71 | 45 | 34 | 28 | 27 | 32 | 53 |
| Sun K., Kampughat | 17600 | 44 | 5 | 39 | 119 | 54 | 36 | 29 | 25 | 23 | 24 | 33 |
| Tamor, Mulghat | 5640 | 37 | 1 | 36 | 160 | 71 | 44 | 32 | 26 | 25 | 38 | 84 |
| Sapta K., Chatara | 54100 | 68 | 7 | 61 | 72 | 39 | 25 | 18 | 16 | 16 | 21 | 35 |

stations, twenty eight stations have significant areas covered by snow and glaciers.

The summarized streamflow and the basin characteristics data used in this study were basically taken from the Department of Hydrology and Meteorology and Water and Energy Commission publications (WECS/DHM, 1990).

The recorded water level charts of the Trishuli River (Betrawati) and the precipitation data of Timure, located near the Nepal-China border, were obtained from the Department of Hydrology and Meteorology for the case study of snowmelt characteristics in the Trishuli basin in 1990.

## TRISHULI RIVER IN 1990

Trishuli is one of the major tributaries of the Narayani River basin in central Nepal. More than 60% of the total drainage basin of the Trishuli lies in Tibet with about 9% covered by snow and glaciers. 85% of its catchment area (4640 km$^2$) lies above 3000 m out of which 11% lies above 6000 m (Table 1). It has been regularly gauged at Betrawati at an elevation of 600 m. The average lowest and the melt season discharges of this river are close to average discharges recorded on the Narayani River (Table 1). As the river represents the glacier area of central Nepal, this case study provides information about an average condition and general nature of snow and glacier melt in the Nepal Himalayas.

Figure 2 presents the hydrographs recorded during different periods in 1990. The case study indicates that the flows are minimum in March. The least diurnal variations of the hydrograph in March indicate the least contribution of meltwater. The effect of snowmelt can be clearly noticed by the end of the

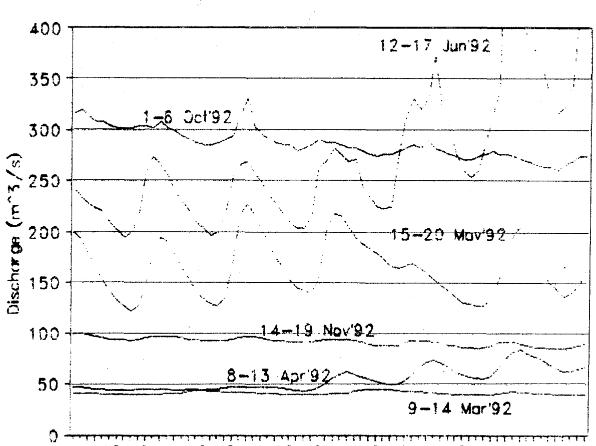


**Fig. 2** Hydrographs of the Trishuli River at Betrawati during different periods in 1990.

second week of April as observed in the hydrograph showing the diurnal variation with maximum flow in the early morning and minimum flow towards the afternoon. The base flows as well as the range of diurnal variation becomes much higher in May and June showing a significant contribution of snowmelt in these months.

The post-monsoon flow pattern is completely different from the pattern observed in pre-monsoon month. The hydrograph shows continuous recession with response to effective rainfall only. The magnitudes and ranges of the flows are presented in Table 2.

**Table 2** Flow components during dry conditions in 1990 Trishuli River at Betrawati.

| Date | Mean flow ($m^3 s^{-1}$) | Diurnal variation % of mean | % of minimum in March |
|---|---|---|---|
| March 9-14 | 41 | 8 | 6 |
| April 8-13 | 54 | 17 | 40 |
| May 15-20 | 162 | 41 | 316 |
| June 12-17 | 269 | 36 | 590 |
| Oct 1-6 | 286 | 8 | 634 |
| Nov 14-19 | 92 | 7 | 136 |

## RECESSION RUNOFF CHARACTERISTICS

Figure 3 presents the recession runoff characteristics of the Karnali, the Narayani and the Koshi basins. The recession of these three major basins has been compared with two extreme cases of snowfed rivers represented by the Seti River at Pokhara and the Arun River at Tumlingtar.

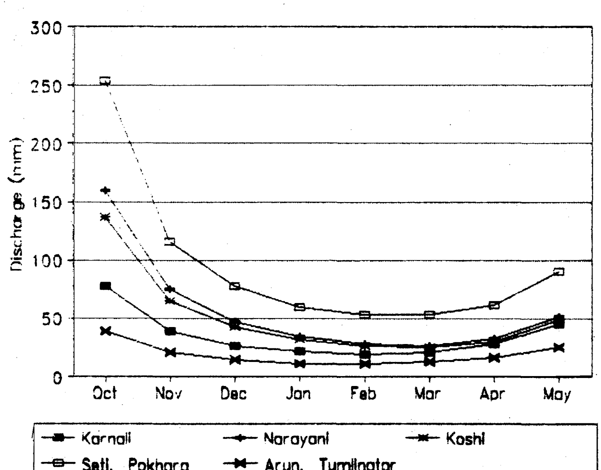


**Fig. 3** Recession runoff characteristics of snowfed rivers in Nepal.

Seti at Pokhara drains the wettest river basin in Nepal with annual precipitation exceeding 3000 mm in major parts, whereas, the major portion (about 90% upstream of Tumlingtar) of the Arun basin lies in the dry area of Tibet (China).

Rapid recession of the discharge is observed in all the rivers in the months following the monsoon. The recession coefficient is usually expressed in the following exponential decay form:

$$Q = Q_0 e^{-kt}$$

where Q in this example is considered as the monthly average flow, $Q_0$ the flow in the previous month and t the time which is one month for the monthly data. The recession coefficients (k) obtained with the monthly data for three major and two typical river basins are presented in Table 3.

Table 3 shows that the recession coefficient in the post monsoon month is the highest for the wet basin (Seti) and lowest for the Arun River which has a very dry basin. The highest recession coefficient in October-November gradually decreases in all these basins with minimum value in February-March after which the recession coefficient becomes negative indicating increasing discharge.

The runoff coefficients in all the recession and dry period months are similar between the Narayani and the Koshi basins. However, the coefficients for all the three rivers considered are very similar during the melt season of April and May when there is not much contribution from precipitation.

**Table 3** Recession runoff coefficient.

| | Nov | Dec | Jan | Feb | Mar | Apr | May |
|---|---|---|---|---|---|---|---|
| Karnali (280) | 0.73 | 0.35 | 0.19 | 0.10 | -0.04 | -0.25 | -0.46 |
| Narayani (450) | 0.70 | 0.47 | 0.34 | 0.20 | 0.80 | -0.28 | -0.49 |
| Koshi (695) | 0.61 | 0.46 | 0.32 | 0.14 | -0.01 | -0.29 | -0.51 |
| Seti (430) | 0.78 | 0.40 | 0.26 | 0.11 | 0.01 | -0.15 | -0.38 |
| Arun (604.5) | 0.64 | 0.39 | 0.22 | 0.00 | -0.15 | -0.25 | -0.42 |

## MELTWATER ASSESSMENT

Due to extreme variations of geographical and physiographical conditions in Nepal, the hydrometeorological characteristics of basins may differ significantly within short distances. For example, as shown in Table 1, discharge of the Tamor River in May is 84 mm whereas, the discharge of the Arun for the same month is 25 mm only. Both of these rivers meet almost at the same location contributing to the Koshi basin. Although these are the usual cases of small and medium sized basins, there are certain homogeneities if we consider large basins of Nepal.

All the three large basins considered in this study have similar physiographic features. All of them originate in the dry areas of Tibet (China) or in the dry areas of Nepal. All these rivers travel south passing through the great Himalayas, Middle Mountains and then the Siwaliks before entering in the southern Tarai of Nepal which is a part of the Ganges plain.

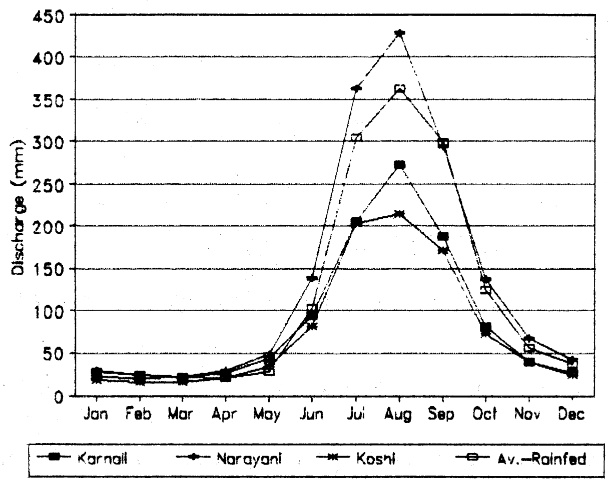


**Fig. 4** Average annual hydrographs of the major snowfed rivers and the average of rainfed rivers.

Figure 4 compares the annual hydrograph among the three major snowfed river basins and the average of rainfed rivers. The comparison shows that the shape of the hydrograph for all the cases is similar with minimum flow in winter and summer and the maximum in August.

Figure 4 also shows that the highest annual discharge is observed in the Narayani basin whereas the lowest discharge is observed in the Koshi basin both of which are snowfed. The major difference between these two rivers is the location of the basins with respect to exposure to the monsoon activities.

About 53% of total catchment area of the Koshi basin lies in Tibet which is relatively dry land with very low annual precipitation. In the case of Narayani river, however, the percentage of basin area in Tibet is only about 14. Furthermore, some parts of the Narayani basin drain the area with high precipitation. Although the Karnali basin has only about 5% of its area in Tibet, the annual yield is relatively low as it drains a relatively dry area of Nepal. The figure shows that the role of monsoon rainfall is more dominant as compared to the role of snow in deciding the monsoon as well as annual yield and temporal variation of runoff during the monsoons and recessional period.

For further assessment of the role of meltwater, comparison has been made between the average recession and low-flow discharge of snowfed and rainfed rivers as given in Fig. 5.

The average discharge of the rainfed rivers presented in this figure is an average for the whole country. All the gauged rainfed rivers in Nepal originate

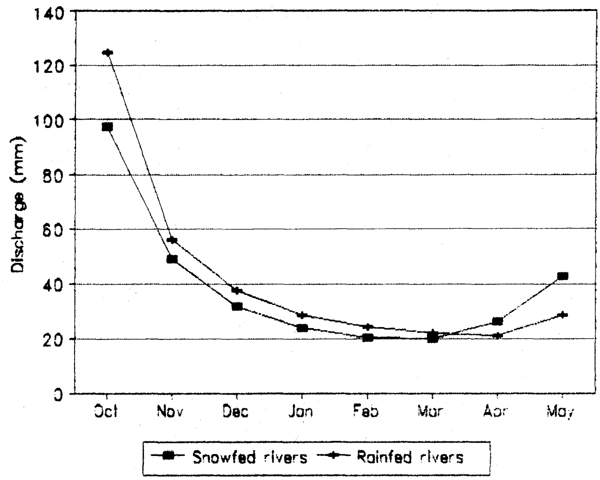


**Fig. 5** Average recession discharge of snowfed and rainfed rivers in Nepal.

in the middle mountains or Mahabharat range with sizes ranging from 5 to 3500 $km^2$.

Figure 5 shows that there is no significant difference between the rainfed and snowfed rivers from October to March except that the overall average discharge for the snowfed rivers is relatively low. The difference becomes significantly noticeable in April and May. The discharge in April in rainfed rivers is in further recession in relation to March, whereas, the rise is noticed in the case of snowfed rivers.

Some rise in discharge of rainfed rivers in May is due to pre-monsoon showers which are a regular feature especially in the mountainous areas of Nepal. The rise in snowfed rivers is the combined effect of snowmelt in high altitude zones and the flows caused by pre-monsoon showers in the tributary basins downstream.

Assuming the difference in discharge between rainfed and snowfed rivers as an approximate indication of snowmelt contribution, Table 4 shows that the role of meltwater in the river system is the minimum during the winter months of January and February. Its role becomes very important in the low-flow months of April and May.

**Table 4** Percentage difference in average flow between snowfed and rainfed rivers.

| Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
|---|---|---|---|---|---|---|---|
| -28 | -15 | -18 | -20 | -20 | -1 | 19 | 32 |

The lower discharge values from October to March in snowfed rivers are basically due to the negligible contribution of a significant area in the high elevation zones. This is also a period of snow accumulation in high elevation areas.

## CONCLUSION

The low-flow period before the onset of the summer monsoon is critical for most of the water resources projects. Since it is the time of the annual maximum temperature, the meltwater contribution becomes significantly important for the development of water resources.

The study shows that the meltwater contribution is at the highest in the month before the onset of the monsoon exceeding 30% of overall average of the monthly average discharges. Low meltwater contribution is expected in the post-monsoon and winter during which mainly the snow accumulation takes place.

The recession pattern of all the rivers in Nepal are similar with usually higher recession coefficients in wet areas of the central and eastern Nepal.

Groundwater is the primary source for the maintenance of base flow in all the major rivers in Nepal. The role of meltwater becomes less important in winter months when snow accumulation processes in the high mountains become active and during the monsoon when precipitation dominates over all the other hydrological processes.

Since the amount of meltwater during the monsoon is expected to be the highest in terms of annual melt, this aspect is less understood due to the high complexities involved in analysing the hydrograph. This aspect needs a careful study with appropriate measurements and analyses.

The lack of regular hydrometeorological observations in the high altitude areas is the major hindrance for accurate assessment of meltwater contribution to the major river systems in Nepal. Establishment and operation of a hydrometeorological network on a regular basis is hence required for the representative catchments in high altitude areas for better understanding of the role of glacier and snow in the Himalayan river systems.

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