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Runoff characteristics in three glacier-covered watersheds of Langtang Valley, Nepal Himalayas

Yoshihiro Fukushima[1], Katsuhisa Kawashima[2], Masakazu Suzuki[1], Takeshi Ohta[3], Hideaki Motoyama[2], Hiroshi Kubota[4], Tomomi Yamada[2] and Om Ratna Bajracharya[5]

1 Faculty of Agriculture, Kyoto University, Kyoto 606 Japan
2 The Institute of Low temperature Science, Hokkaido University, Sapporo 060 Japan
3 Faculty of Agriculture, Iwate University, Morioka 020 Japan
4 Karter Art Landscape Ltd., Chuoh-cho, Meguro-ku, Tokyo 152 Japan
5 Hydrology Section, Department of Irrigation, Hydrology and Meteorology, Babar Mahal, Kathmandu, Nepal

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Abstract

Hydrological observations in glacier-covered watersheds were carried out for a full year from July 1985 to June 1986 at three sites in Langtang Valley of Nepal Himalayas. In the summer from July to August, the high water continued, and the discharge showed a clear daily fluctuation. September to October was the period showing a rapid discharge recession, December to next March showed a gentle recession, and April to May showed a gentle increase in discharge. In June there was a rapid increase in discharge because of rapid snowmelt and icemelt in the glaciers and snowmelt in the snowpack, except for the glaciers, due to the increase in air temperature. Consequently, the seasonal variation in discharge from glacier-covered watersheds seems to depend mainly on the variation in air temperature rather than the distribution of precipitation. Therefore, the discharge seems to be comparatively stable every year, and the difference between the maximum and minimum discharge during a year is small, as indicated by the coefficient of river regime which was 25.6. The discharge rate of each watershed seems to be depend on the distribution in altitude of the glaciers.

1. Introduction

Clarifying the elements determining runoff in glacier-covered watersheds is needed in countries which use then water for irrigation, electric power and others. In Nepal where most rivers come from high mountain regions, the forcasting discharge from glacier-covered watersheds will have many benefits. However, it is very difficult to observe the discharge from glacier-covered mountain regions owing to severe climate conditions.

Yamada *et al.* (1984) have already observed the discharge of Langtang Khola (means "river" in Napalese), located in 60 km north of Kathmandu, during about two months from August to October, 1982. That is the monsoon to post-monsoon season in Nepal. They have tried to quantitatively explain the discharge of two watersheds, one large and the other small, by the process of snowmelt and icemelt.

Japan-Nepal co-operation on glaciology, meteorology and hydrology was carried out for a full year from July 1985 to June 1986 in the same region using Yamada's methodology. The meteorological data has been reported by Takahashi *et al.* (1987), and the hydrological data has been reported by Fukushima *et al.* (1987). This paper reports on runoff characteristics in glacier-covered watersheds using the observed meteorological and hydrological data.

2. Topographical features of three watersheds

The Langtang region, where the meteorological and hydrological observations were carried out, is located 60 km north of Kathmandu, the capital city of Nepal. Figure 1 shows the Langtang region. The main river, called Langtang Khola, has its source area at Mt. Langtang Ri (7232 m a. s. l.), comes down in the

Table 1. Topographical features of three watersheds

Basin name	Basin area (km^2)	Glacier-covered area (km^2)	Mean altitude of the basin (m)	Mean altitude of glaciers (m)	Site name	Altitude of the site (m)
Langtang Khola W.	333	127	5140	5440	S1	3840
Lirung Khola W.	13.8	6.2	5310	4790	S2	4000
Khyimjung Glacier W.	6.6	4.7	5640	5550	S3	4200

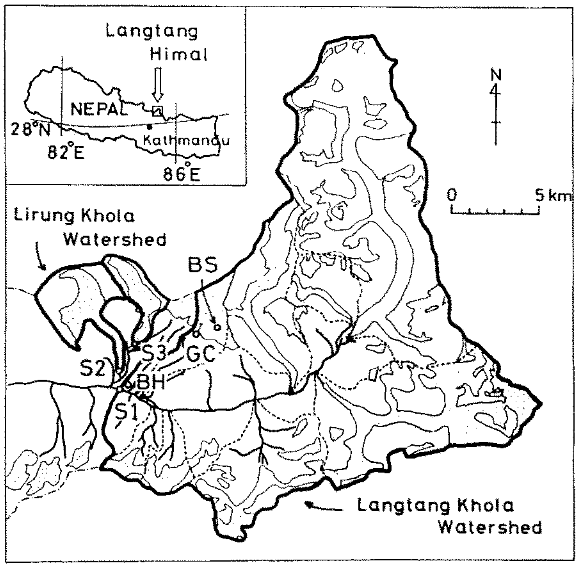

Fig. 1. A topographical map of the Langtang Valley. The thick solid lines indicate the boundaries of the Langtang Khola Watershed (observation site : S1), The Lirung Khola Watershed (observation site : S2) and The Khyimjung Glacier Watershed (obsevation site : S3). BH : Base House for meteorological observations.

south-western and joins the Bhote Koshi River. Their river name changes to the Trisuli River and flows on to the south.

Kyangchen, where the meteorological station were set up, is located 6 km west of Langtang Village, is the camp of the Langtang people during the summer season and is situated on the river terrace which covered with glass. BH in Fig. 1 is the meteorological station and its altitude is 3920 m.

Three hydrological sites were chosen in order to compare the difference in discharge with the basin scale and with the distribution in altitude of the glaciers. In Fig. 1, S1 of 3840 m is the main site in the Langtang Khola Watershed which is the location of several glaciers, such as the Langtang, the Shalbachum and the Langshisa glaciers among others, and has the largest basin area of the three sites, S2 of 4000 m is in the vicinity of the terminus of the Lirung Glacier and is the location of the Lirung Khola Watershed. S3 of 4200 m is in the outlet of a glacial lake of the Khyimjung Glacier and is set up for the Khyimjung Glacier Watershed.

Table 1 shows their topographical features. The basin area of S1, S2 and S3 is 333 km^2, 13.8 km^2 and 6.6 km^2, respectively. The area covered by glaciers is 127 km^2, 6.2 km^2 and 4.7 km^2, and its ratio to the basin area is 38.2 %, 45.1 % and 71.5 %, respectively.

The distribution of altitude at 500 m intervals for both the basin area and the glacier-covered area included in each watershed, is shown in Fig. 2. The mean altitude is 5140 m in the Langtang Khola Watershed, 5310 m in the Lirung khola Watershed and 5640 m in the Khyimjung Glacier Watershed. The mean altitude of the glacier-covered area is 5440 m in the Langtang Khola Watershed, 4790 m in the Lirung Khola Watershed and 5550 m in the Khyimjung Glacier Watershed.

It is clear that the mean altitude of the glacier-covered region in the Lirung Khola Watershed is the lowest of the three watersheds, and the difference is 650-760 m in comparison with the other two watersheds. The debris-covered glacier in the Lirung Khola Watershed is distributed in code 2 (4500-5000 m). Debris-covered glaciers are also distributed in the Langtang Khola Watershed, but the range of the distribution is higher than in the Lirung Glacier Watershed ; It is mainly distributed in code 3 (4500-5000 m) in the Langtang Khola Watershed. The upper slopes of the Lirung Khola Watershed are very steep, and the snowpack on the upper slopes falls immediately downward onto the glaciers as avalanches. The Khyimjung Glacier Watershed is the smallest of the three watersheds and does not have a debris-covered glacier. The glacier-covered area is distributed in a comperatively high region. The area in the altitude of code 5 (5500-6000 m) occupies 52.2 %, and the glacier-covered area is uniformly distributed.

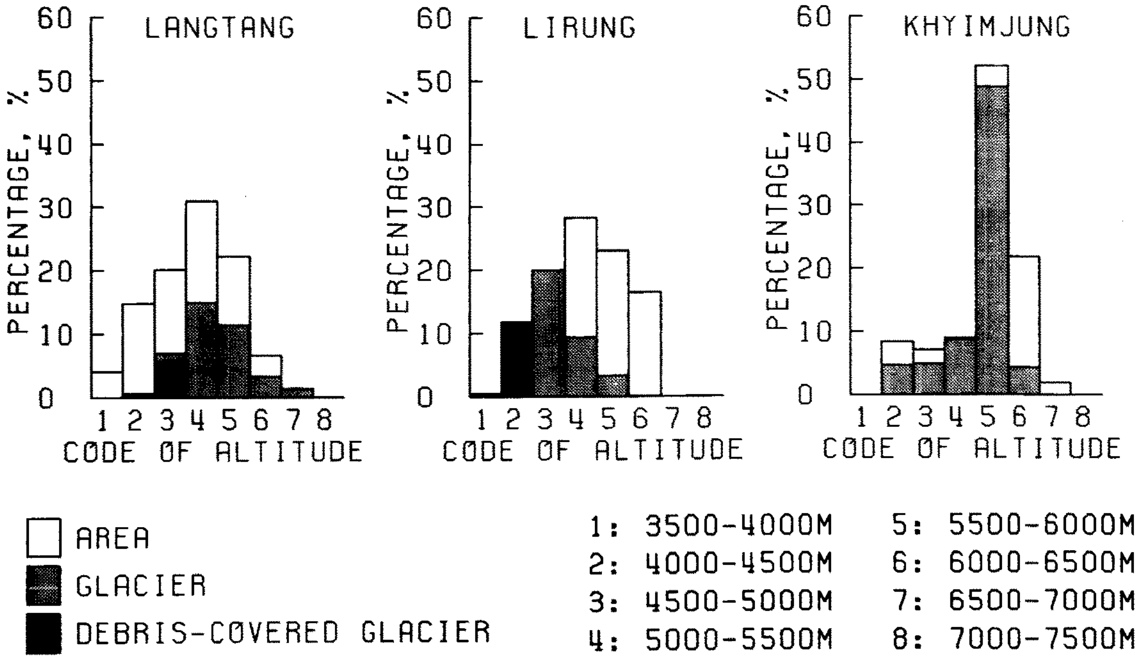

Fig. 2. The distributions of the drainage basins and the glaciers included in the altitude at 500 m intervals in each watershed

3. Methods of observation

The continuous water-level recorder with float was set up at each hydrological site. The discharge at each site was estimated by the measurement of the velocity of flow and the survey of the cross section of the channel, once or twice a month. Discharge was determined by the relationships between the water-level and the discharge at each site, respectively. Fukushima *et al.* (1987) has reported on the methods in detail.

4. Results

4. 1. Relationships between each meteorological element and the daily discharge for a year

Fig. 3 shows the seasonal variation of the daily mean air temperature, the daily precipitation, the snow depth at BH and the daily discharge rate at S1 (site of the Langtang Khola Watershed) for a full year from July 1985 to June 1986. The yearly precipitation and the yearly mean air temperature at BH is 1224.5 mm and 2.7℃, respectively, and the yearly total discharge at S1 is 1357.5 mm.

In Nepal Himalaya, the monsoon period is from June to September, and it rained almost every day at BH from July to September 1985. The amount of rain in the period from July to September 1985 was about 6 mm a day. Since September, the fluctuation of the daily precipitation increased gradually, and the amounts of precipitation were 54.5 mm on September 16, 50.0 mm on October 10 and 112.0 mm on October 17. The last event with a intensive rainfall amount was a rare case due to a cyclone, and a flood occurred in the Khumbu Himal region, eastern Nepal, due to the same cyclone. The monsoon season finished on October 19, and rainless day continued until the end of December. The precipitation in the period from December 26, 1985 to the end of April 1986 was almost entirely in the form of snowfall. The water equivalent amount of snowfall totaled 223.5 mm, and it was 18 % of the yearly precipitation. The principal snowfall at BH occurred because of two events, one at the end of December and one in the middle of Feburary. The maximum snow depth at BH was 77 cm in Feburary, 1986. Precipitation in the period from April to the middle of June, 1986 occurred periodically after several rainless day, and its mean value was about 1.6 mm a day. The monsoon of 1986 started in the middle of June, and the amount of the precipitation began to increase.

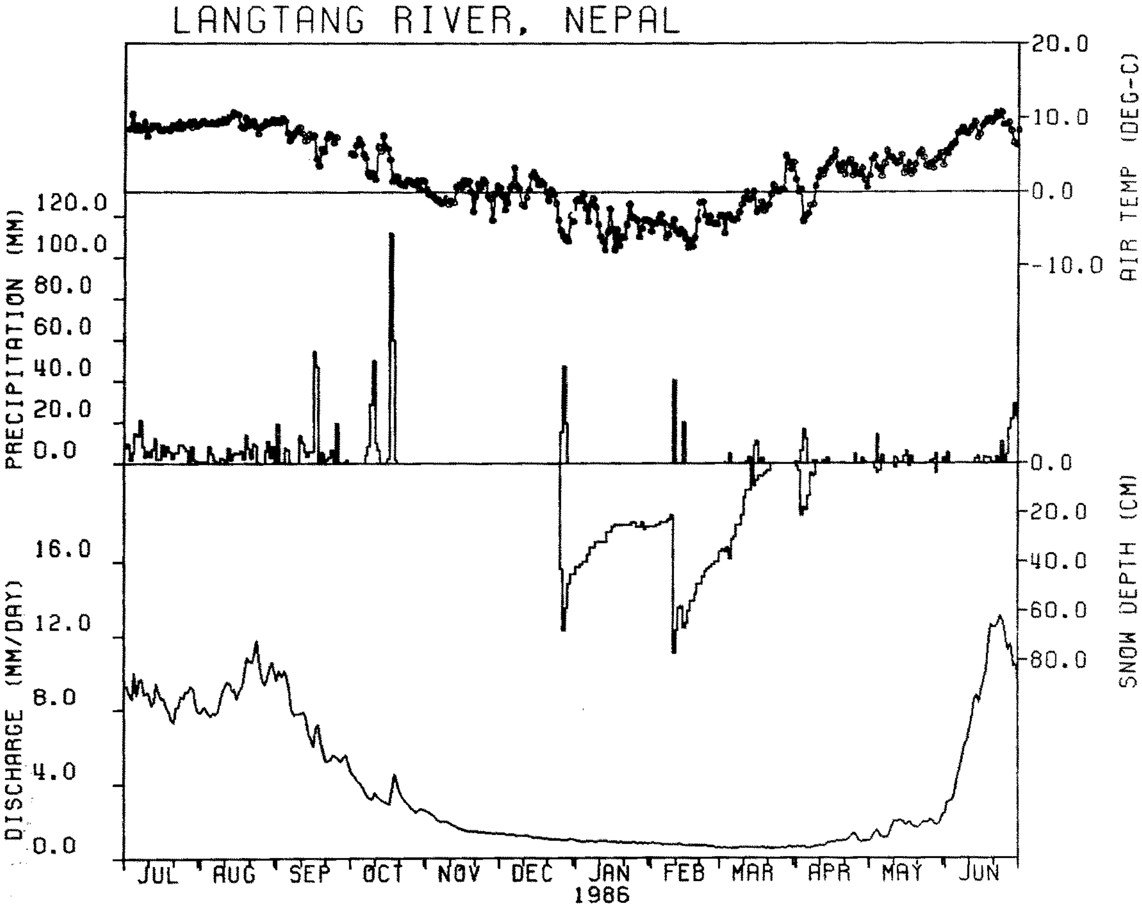

Fig. 3. Yearly variations in the daily precipitation, the daily mean air temperature and the snow depth at BH in Kyangchen, and the discharge rate at S1, the site of the Langtang Khola W. (basin area : 333km²)

The air temperature at BH in the period from July to the middle of September 1985 was high and stable, and its value was 8–10°C. It decreased gradually with repeated fluctuations starting in September and reached below 0°C in November, 1985. The air temperature below 0°C continued in the period from the end of December 1985 to the middle of March 1986. From that time on, it increased gradually and finally rose to above 0°C in the end of April, 1986. It showed periodical fluctuations in the duration from the middle of April to the end of May 1986, but it began to increase rapidly starting early in June, 1986.

The discharge rate of the Langtang Khola Watershed maintained a flood stage and repeated the fluctuation at intervals of several days during the period from July to August 1985. The maximum discharge was recorded at the end of August. After that, the discharge decreased rapidly from September to October, 1985. Three events with intensive amounts of precipitation in the same duration had little effect on the discharge. In the season of low temperature from November, 1985 to April, 1986, the discharge showed a gradual decrease. It increased gradually from April to May, 1986, and it increased rapidly starting in June. The discharge reached its peak for the year, on June 23, 1986.

4. 2. Seasonal variation in the daily discharge rate of three watersheds

Fugure 4 shows the seasonal variation in the discharge rate of three watersheds. At S2 and S3, observations sometimes failed due to water surface froze in the winter and due to the high fluctuation of the water-level over the range recorded on the chart. Neverthless, this figure shows the characteristics of each watershed.

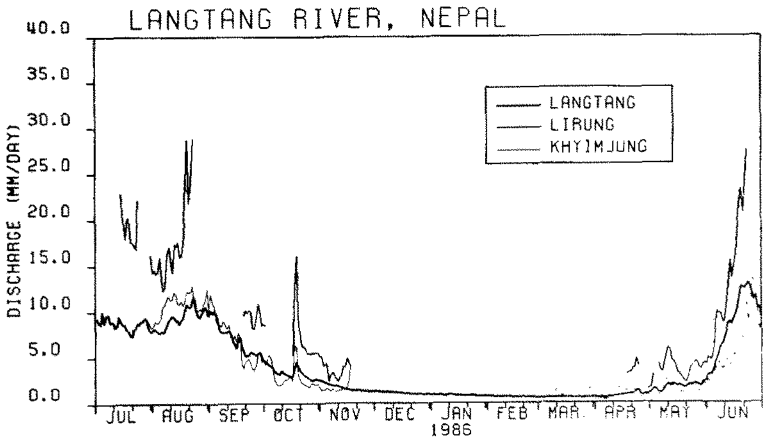

Fig. 4. Yearly variations in the daily discharge rate of the Langtang Khola Watershed, the Lirung Khola Watershed and the Khyimjung Glacier Watershed

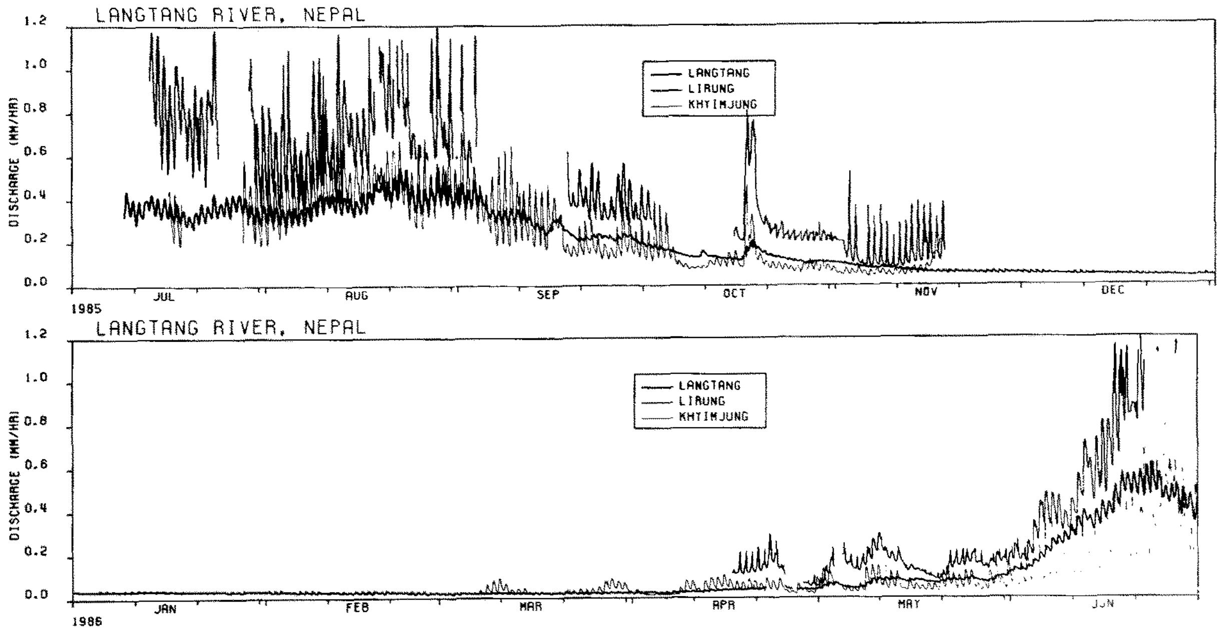

Fig. 5. Yearly variations in the hourly discharge rate of three watersheds

The discharge rate of the Khyimjung Glacier Watershed is almost equal to that of the Langtang Khola Watershed, but that of the Lirung Khola Watershed is about twice that of the Langtang K. W., for the year. The discharge rate of the Lirung K. W. began to increase at the same time as that of the Langtang K. W., beginning of June, but that of Khyimjung G. W. began to increase later than that of other two watersheds, that is in the middle of June.

4. 3. Seasonal variation in the hourly discharge rate of three watersheds

Figure 5 shows the seasonal variation of the hourly discharge rate of three watersheds. The hourly discharge rate of the Langtang K. W. shows a clear daily fluctuation in the period of high water, and the daily fluctuations of other watersheds were larger than that of the Langtang K. W.

Figure 6 shows examples of the diurnal fluctuation of discharge of three watersheds. The daily fluctuation of discharge of the Langtang K. W. is smaller than that of other watersheds. Furthermore,

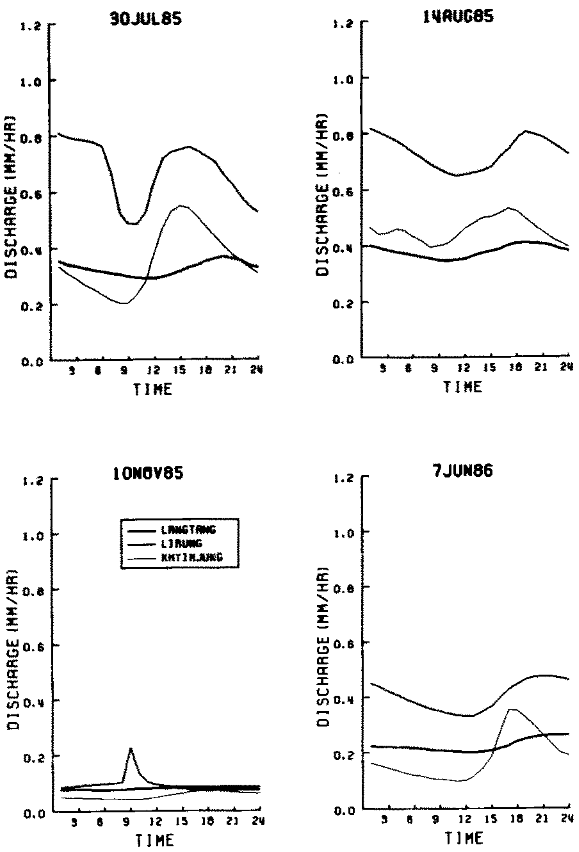

Fig. 6. Daily fluctuations of the hourly discharge rate of three watersheds

the hourly maximum discharge rate appears from 21h to 24h in the Langtang K. W., and from 15h to 18h in other watersheds. The maximum hourly discharge rate in the Langtang K. W. occurred about 6 hours later than that in other watersheds. In Fig. 6, the discharge record in Lirung K. W. on November 10, 1985 has a sharp peak at 9h. This event is explained by the fact that the stream water was dammed up by ice freeze during the night in the braided channel upstream of the observation site and that it flowed down in the morning by the icemelt due to the increase in air temperature and solar radiation. The same phenomena has also reported by Motoyama *et al.* (1987).

5. Discussion

The amount of the yearly precipitation at BH was 1224.5 mm, and the yearly total discharge of the Langtang K. W. was 1357.5 mm. The water balance in a glacier-covered watershed is written as follows ;

$$P = Q + E \pm \Delta G \pm \Delta S$$

where, P is precipitation, E is evaporation, ΔG is change in the glacier (+ : accumulation, − : ablation) and ΔS is change in the stored water.

E is nearly equal zero because of the low temperature in summer, and ΔS is zero because the period is a year. If the precipitation at BH is assumed to be nearly equal to P, G is calculated as −133.0 mm. Though this amount means the ablation of glaciers in the Langtang K. W., the ratio for the amount of precipitation is only 10 %. Consequently, the discharge in the Langtang K. W. is almost balanced by the amount of precipitation. The final determination of G must be carried out based on the estimation of the areal mean precipitation and the areal mean evaporation.

It is clear that the discharge in the Langtang K. W. shows a pattern of yearly fluctuation as shown in Fig. 3 and as above mentioned. The maximum discharge rate was 13.1 $\mathrm{mm^{1}day^{-1}}$ on June 23, 1986, and the minimum one was 0.51 $\mathrm{mm^{1}day^{-1}}$ on March 3 and 25, 1986. The coeffient of the river regime is 25.6. This value is very low in comparison with the basin scale and with the annual distribution of precipitation.

The tendency of the seasonal variation of the discharge in both the Lirung K. W. and the Khyimjung G. W. is almost the same as that in the Langtang K. W. as shown in Fig. 4. The discharge rate, however, in the Lirung K. W. was about twice of both the Langtang K. W. and the Khyimjung G. W. for almost a year.

A rapid increase in the discharge in June seems to have occurred not only because icemelt and snowmelt of the glaciers, but also because of the snowmelt in the non-glacier area. Though the snowline was about 4500 m in the beginning of June, it rose rapidly and reached to an altitude of 5100 m, just the same altitude as the turminus of the glaciers on the mountain hillslope at the end of June. After the end of June, 1986, the discharge decreased a little and returned to the discharge at the beginning of July, 1985.

Fig. 7 shows the seasonal variation in the daily discharge observed by Yamada *et al.* (1984) in 1982 with the data in 1985–1986, in both the Langtang K. W. and the Lirung K. W. Though the observed data in 1982 was for the period from the end of August to the end of October, the discharge in the Langtang K. W. in 1985 was in almost the same range as that in 1982, and

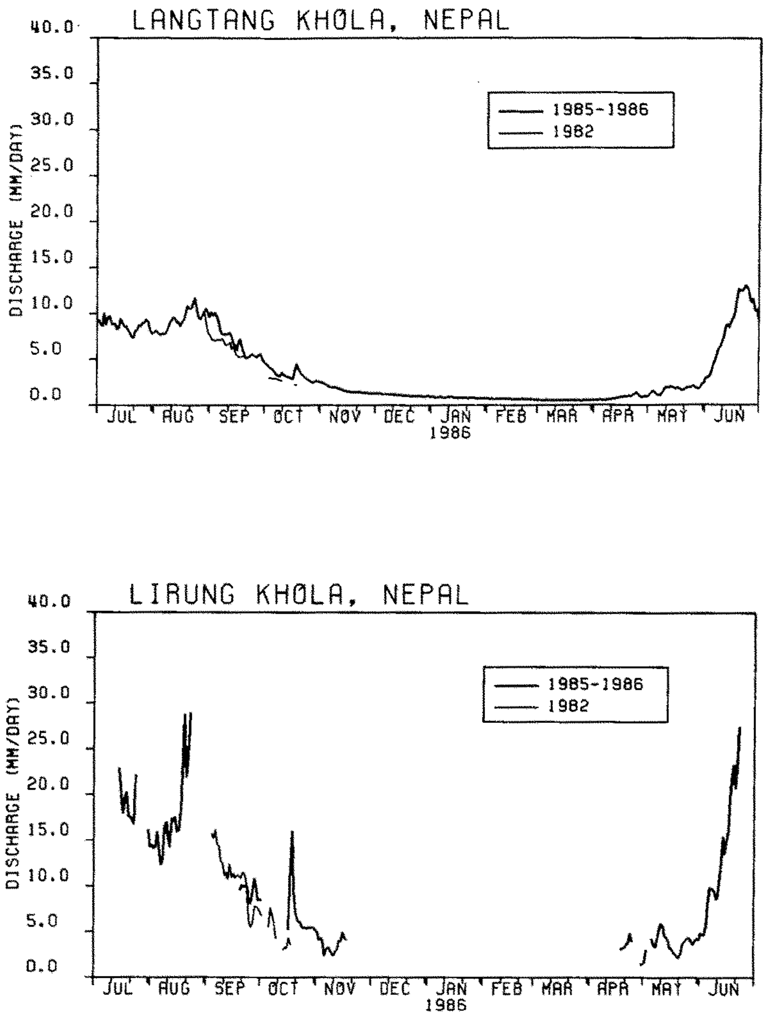

Fig. 7. Comparison of both daily discharge rates observed in 1985–86 and 1982 (Yamada *et al.*, 1984), of the Langtang K.W. and the Lirung K.W.

its tendency is also similar to that in the Lirung K. W. Though three intensive rainfall events above 50 $mm^1 day^{-1}$ in the period from September to October 1985 occured at BH in Kyangchen, they were snowfall events at a high altitude region. Therefore, there were few increases in hydrographs, as shown in Fig. 3, 4 and 5. Yamada *et al.* (1984) showed that the rainfall events above 50 mm^1day^{-1} had never occurred in the same period in 1982. Thus, the hydrographs in a recession period are similar in both 1982 and 1985 in each watershed. This could means that pattern of seasonal variation in the discharge is almost the same, and the discharge rate in the Lirung K. W. is much more than that in the Langtang K. W., every year.

The daily fluctuation in the discharge is clear in high water period, and the daily fluctuation is larger in a small watershed than in a large one. In general, a large glacier-covered watershed, such as the Langtang K. W., has several glaciers and long river channels. It is assumed that the fluctuation of the daily discharge decreases and that the peak time of the discharge is delayed, because of time lag of streamflow in the river channel.

Consequently, it seems that the amount of discharge in a glacier-covered watershed is mainly controlled by the amount of snowmelt and icemelt in a watershed. Moreover, the snowmelt and icemelt are controlled by the heat budget. Air temperature is an important element and an index of the heat budget. The annual fluctuation of air temperature is generally smaller than that of perecipitation. Therefore, the annual fluctuation in the discharge of a glacier-covered watershed seems to be stable and small because glaciers act as buffers. However, the fluctuation of climate for a long term is supposed to consequently control the amount of runoff because the amount of precipitation controls a mass balance of glaciers as an input, and a change in the air temperature controls that as an output.

The yearly total discharge in the Lirung K. W. is supposed to be a comparatively high amount because the discharge rate was about twice that of other two watersheds for the observed period. On the other hand, the mean altitude of the glacier-covered area in the Lirung K. W. was lower than that in the other two watershed. Therefore, there probably is plentiful amount of meltwater flowing down. This possibility means also that the amount of the ablation in the Lirung Glacier is much more than that in the other glaciers.

The runoff characteristics of a glacier-covered watershed, such as the above mentioned one, are very useful. They can help for the stable supply of water resources and for the protection from flood disaster, in comparison to a watershed without glaciers.

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