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Winter runoff in the glacialized drainage basin in Langtang Valley, Nepal Himalayas

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Abstract

Hydrological and meteorological observations were conducted during a full year from July 1985 to July 1986 in the glacialized watershed of Langtang Valley, Nepal Himalayas, where glaciers cover an area of 127 km^2, or 38 % of the total watershed area of 333 km^2. This paper focuses attention on the low flow of water that occurs in winter without inflow of rainwater and meltwater from snow and glacier surfaces. The discharge of around 40 m^3s^{-1} (10 $mmday^{-1}$) at maximum that occurs during the monsoon season decreases to around 2 m^3s^{-1} (0.5 $mmday^{-1}$) at minimum in winter. The winter recession curve shows a constant decreasing rate, with a recession rate of 0.010 day^{-1}, the half-value period of decreasing discharge being 67 days, from mid-December to late-March, when the watershed is entirely covered by snow. The constant rate implies that the process is maintained in the discharge throughout winter. The basic and stable winter discharge is 1.7×10^5 m^3day^{-1} at minimum, which corresponds to 4 % of the annual discharge of 4.6×10^8 m^3. The winter discharge is attributed to the inflows from en-glacial water stored during the monsoon season and from meltwater from the glacier bottom due to geothermal heat ; the minimum runoff is estimated as the relatively large value of 1.3 $mmday^{-1}$, referring to the glacier area, which indicates the important role of glaciers as a water reservoir and also as a means by which winter low flow is maintained in the glacialized watershed.

1. Introduction

In order to examine the effective use of latent and undeveloped water resources on the earth, hydrological studies have been conducted in recent years in the glacialized drainage basins of high mountain regions of the world. To clarify the hydrological characteristics of the glacialized areas in Himalaya, the first systematic hydrological investigation was carried out in Langtang Valley, Nepal Himalayas from August to October, 1982, *i. e.*, from the late monsoon season to the postmonsoon season, and the role of glacier meltwater in discharge was defined (Yamada *et al.*, 1984).

The development and effective use of water resources requires an understanding of the various hydrological quantities characterizing river discharge such as mean, maximum and minimum annual runoff. Thus, for a full year, hydrological observations were carried out from July 1985 to July 1986 at almost the same observation points as were used in 1982.

In this report, winter runoff is analyzed, because the features of the drainage basin could be understood clearly in the simple hydrological condition of no runoff from rainwater and glacier meltwater. Furthermore, the influence of large ice masses on winter runoff was discussed. The characteristics of the river discharge during the full year are also presented in this Issue by Fukushima *et al.* (1987).

2. Area of observations

The hydrological observations were made in one large and two small drainage basins in Langtang Valley. The large one belongs to the Langtang Khola (Khola means river in Nepalese), the main river of Langtang Valley, which consists of many glacialized sub-watersheds. The two small basins belong to the Lirung Khola and the Khyimjung Khola, the two tributaries of the Langtang Khola, each of which is fed by a single glacier, Lirung Glacier and Khyimjung Glacier, respectively. The hydrological stations were the same points as used in 1982 for the Langtang Khola and the Lirung Khola, but the station at Khyimjung was newly established. Meteorological elements were also observed at Base House (BH), which was placed at Kyangchen Gomba, which is situated on a river terrace in the vicinity of the station of Langtang Khola. The latter two small rivers were entirely frozen in winter, although flow was recognized under the river ice. It was not possible to make continuous records, but sporadic measurements were made of discharge by man power. In the Langtang Khola, data were successfully obtained throughout the winter. While freezing occurred at both sides of the river at night, the ice flowed away soon after being exposed to sunshine and rising air temperature in the daytime. As the shape of the river cross-section did not change during the winter, the analysis was made of winter runoff in the Langtang Khola.

Glaciers cover an area of 127 km^2, or 38 % of the total Langtang Khola watershed area of 333 km^2. The altitude of the station is 3840 m a. s. l., while the highest point of the watershed extends beyond 7200 m a. s. l. For further details of the watershed such as altitudinal distribution and the method of observations, see Fukushima *et al.* (1987) in this Issue.

3. Results of observations

3. 1. *Characteristics of winter runoff*

Since Langtang Valley belongs to the typical monsoon Asia, a conspicuous contrast of precipitation is seen between winter and summer. During the summer monsoon season from June to September, precipitation occurs almost every day, although the intensity of precipitation is rather weak and does not exceed 20 mm of the daily amount ; the monthly amount is approximately 200 mm during the season ; and heavy rainfall over 100 mm in daily amount occurs sporadically at the end of the monsoon season almost every year (Takahashi *et al.*, 1987). After the monsoon season, the dry season continues until the following monsoon season, while occasional snowfall occurs and the watershed is covered by snow in winter. During the 1986-1987 winter, the watershed was covered by snow from December 26 until mid-March, as illustrated in Fig. 4. Daily mean air temperature rose to around 10°C in the monsoon season and fell to around -8°C in winter as shown in Fig. 1. Ablation and accumulation occur mainly at the same time during the monsoon season according to ascending and descending of the 0°C line. From the middle of December to the middle of March, daily mean air temperature continues below the melting point and no melting occurs on the snow and glacier surface.

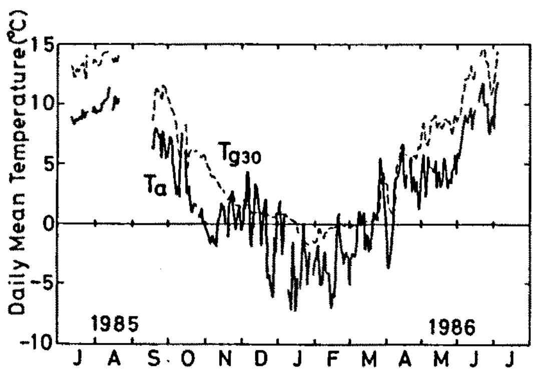

Fig. 1. Daily mean air temperature (°C) and 30 cm–deep soil temperature (°C) at BH.

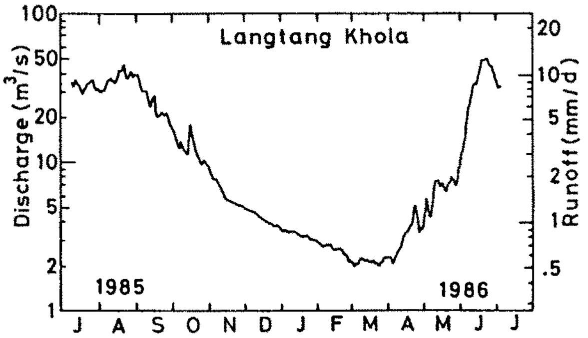

Fig. 2. Discharge (m^3 s^{-1}) or daily runoff (mmday^{-1}) of the Langtang Khola during the current observation period.

Under this climatic condition, the river discharge was varied as shown in Fig. 2. The discharge of 30 to 50 m^{3}s^{-1} (around 10 mmday^{-1} in runoff) in the monsoon season decreased to around 2 m^{3}s^{-1} (around 0.5 mmday^{-1}) in winter. As seen in Fig. 2, the discharge decreased abruptly after the monsoon season, and related to the decrease of air temperature below 0°C, the recession rate of discharge (the logarithmic value in the figure) became fairly constant, 0.010 day^{-1}, which corresponded to the half-value period of decreasing discharge of 67 days from mid-December to late-March, when discharge was at minimum. The rate was almost the same as that of the winter discharge of a snow covered watershed in Hokkaido, Japan (Motoyama *et al.*, 1986). The constant rate

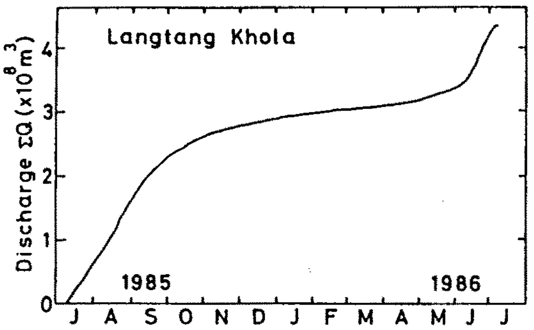

Fig. 3. Discharge (x10^8 m^3) accumulated from the beginning of the hydrological observations.

implies that the process of discharge is maintained throughout winter ; consequently, winter runoff is characterized by a constant recession rate of discharge with no inflow of rainwater and meltwater under the condition of air temperature below the melting point.

In order to distinguish the hydrological seasons from a full year's discharge, accumulated value of daily discharge from the beginning day of observation was plotted against time as shown in Fig. 3. The figure shows a very rapid and a comparably slow increasing rate of accumulated value in the monsoon season and in winter, respectively. The post-monsoon and pre-monsoon seasons are regarded hydrologically as the traditional seasons between the monsoon and the winter discharge. The post-monsoon season is considerably longer than the pre-monsoon one. While winter discharge occupies only 4 % of the annual discharge of 4.3×10^8 m^3, it is an important water resource functioning as a basic and stable flow in the Langtang Khola ; the minimum is 1.7×10^5 m^3 day^{-1}.

3. 2. *Some topics of winter discharge*

Diurnal variation of discharge occurs in the melting season due to the inflow of glacier meltwater, as is well known (Yamada *et al.*, 1984). Air temperature mostly rises above the melting point in the daytime, even in winter, according to the hourly values shown in Fig. 4, but melting was not observed even at Base House, the lowest place in the watershed. Nevertheless, diurnal variation was also recognized in discharge throughout the winter. However, the variation was quite unusual and considerably different from that of the melting season, as shown in Fig. 5, as it was observed in the coldest season. The variation may be attributed to freezing in the night and melting in the daytime of the braided flow situated in the upstream of our hydrological station. As air temperature decreases to around −5°C after sunset, part of the braided flow may be frozen, which may dam up the river water. Accordingly, downstream discharge abruptly decreases to 10 to 20 % (0.2–0.5 m^3s^{-1}), less

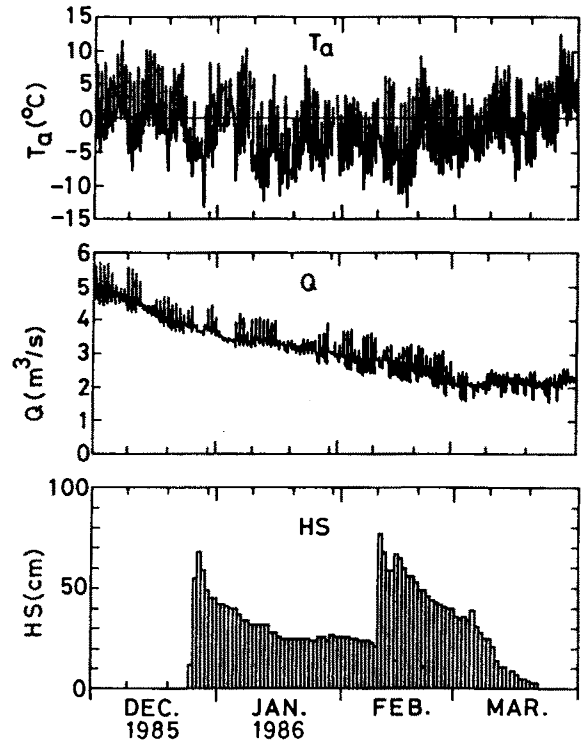

Fig. 4. Variation of hourly air temperature (°C) and daily maximum snow depth (cm) at BH, and discharge (m^3 s^{-1}) in the Langtang Khola.

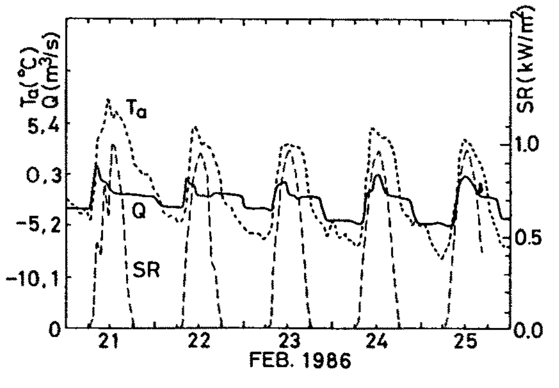

Fig. 5. Hourly variation of air temperature (°C), discharge (m^3 s^{-1}) and shortwave radiation (kWm^{-2}) from 21 to 25 February, 1986.

than that in the daytime, and keeps an equilibrium level of discharge throughout the night. Just after sunrise, the ice that accumulated during the night is immediately melted or broken up by means of radiation and rising air temperature, which causes mini-floods for several hours, as seen in Fig. 5. Discharge after the mini-flood may reach the normal level. After early March, snow starts to melt and finally disappears starting from lower places and moving up to higher ones. The usual pattern of diurnal variation reappears, synchronizing with the start of snow melting.

4. Discussion

As indicated in Fig. 2, the recession rate of discharge or runoff was kept constant from mid-December, corresponding to no inflow of rainwater and meltwater. Then, the final amount of decreasing runoff came to around 0.5 mmday^{-1} in minimum in late-March. How, then, was the winter runoff maintained for more than 90 days without rainwater or meltwater ?. The following explanation is suggested.

Mass balance of a watershed is generally presented as :

$$Q+E=Q_{rain}+Q_{melt}+\Delta Qg, \qquad (1)$$

where Q and E are, respectively, total discharge and evapotranspiration ; Q_{rain} is discharge due to rainwater and Q_{melt} is discharge due to meltwater from snow and glacier ; ΔQg is the change in groundwater storage. Q_{melt} and ΔQg could be separated as :

$$Q_{melt}=Q_{sursnow}+Q_{botsnow}+Q_{surgla}+Q_{botgla}, \qquad (2)$$

and

$$\Delta Qg=\Delta Q_{soil}+\Delta Q_{glacier}, \qquad (3)$$

where the subscripts of discharge Q in eq. (2) imply surface and bottom melt of snow and glacier, respectively, denoted as sursnow, botsnow, surgla and botgla, and ΔQ_{soil} and $\Delta Q_{glacier}$ in eq. (3) demonstrate discharges due to the change in groundwater storage of soil and glacier. Hereafter, the term "groundwater" is used for water stored in the glacier body.

Q_{rain} was zero and E was thought to be negligibly small in winter because of comparatively low temperature and absence of a vegetative cover in the watershed. Surface melting was also absent from the snow and glacier ; no bottom melting of snow cover was observed at BH, even at the lowest point of the watershed, due to freezing of the soil surface, as shown by the 30 cm deep soil temperature below 0°C in Fig. 1. Melting possibly occurs only at the bottom of the glacier due to geothermal heat flux at the interface between the glacier and bedrock.

Discharge from the soil storage is considered to be small, compared to that from the glacier storage, that is, $\Delta Q_{glacier}>>\Delta Q_{soil}$. Soil storage may play a relatively less important role in winter discharge. The Langtang Khola watershed situated in the alpine zone is mainly composed of a glacialized area with a steep bare bedrock slope. The soil covered area is distributed in a limited area along the river in the Langtang Valley and is situated in a relatively low altitude with no steep inclination. Considering the limited water permeability of soil, the rate of discharge is not expected to the high, although no information on the thickness or the volume of soil is available.

The result of drilling through the full-depth of the glacier revealed the existence of abundant water in the glacier body, which flowed in the post-monsoon season in the accumulation and ablation zone of Yala Glacier in Langtang Valley (Iida *et al.*, 1984). En-glacial water has been reported in other temperate glaciers such as Mendenhall Glacier in Alaska (Wakahama *et al.*, 1973), Vallée Blanche in the Massif du Mont-Blanc (Vallon *et al.*, 1976) and San Rafeal Glacier in the northern Patagonia Icefield (Yamada, 1987) ; even in winter, a temperate glacier contains a large amount of en-glacial water (Takahashi and Wakahama, 1970). In fact, occasional observations revealed an unexpected runoff of 0.6 mmday^{-1} in the Lirung Khola and 0.3 mmday^{-1} in the Khyimjung Khola as the minimum values, notwithstanding the fact that the watershed consists of a glacier area located on a steep bedrock mountain slope that is almost completely without soil coverage. Consequently, the glacier body can be regarded as a good water reservoir. Winter discharge is believed to be supplied from outflow of en-glacial water and its bottom melt water, which can be presented as ;

$$Q=Q_{botgla}+\Delta Q_{glacier}. \qquad (4)$$

If this hypothesis is valid, winter runoff in the glacier area, which occupies 127 km^2, or 38 % of the total area of Langtang Khola watershed, is estimated as 1.3 mmday^{-1} in minimum value from the 0.5 mmday^{-1} in minimum value, referring to the total area of the watershed. This value indicates the important role of glacier as a water reservoir and also as means by which of winter low flow can be maintained in a glacialized area.

Acknowledgments

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