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Short Term Glacio Hydrological Relationships and their Effect on the Water Balance in a Glacierised Basin

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ABSTRACT

The results of glaciological studies carried out during 1988 expedition to Chhota Shigri glacier basin have been discussed. The analysis of hourly temperature data collected at 3 different locations in the valley indicates that the environmental lapse rate in the basin remained in the pseudo adiabatic range i.e. 0.38 oC/100m to 0.67 oC/100m during the observation period. This could be attributed to high values of relative humidity (70-95%) recorded during this period. The phenomenon of temperature inversion was also observed during early morning hours just after the sunrise and negative values of temperature lapse rate (as low as -1.1oC/100m) were recorded. The study of energy balance over the glacier surface during this period reveals that of all the energy fluxes, insolation was the largest contributor to the energy budget. Temperature was found to be the most meaningful surrogate variable of energy exchange process over the glacier surface. The degree day factor for Chhota Shigri glacier was worked out to be 8.2 mm/oC for the ablation season and threshold temperature was estimated to be -1.9oC. The studies with regard to the water balance for the basin during the ablation period show that groundwater contribution is maximum to the total runoff and it's share varies from on an average 56.2% on rainy days. The contribution due to surfacial melting on glacier surface to the daily runoff varies from 9.8% to 57.1% depending upon the meteorological conditions.

INTRODUCTION

The runoff in majority of Himalayan rivers during the ablation period contains large amounts of meltwater from glaciers as well as seasonal snow cover. In the same period, large contribution comes from the groundwater storage too. It is estimated that in Central Asia as a whole, the groundwater component is slightly more than 40% varying from 25% to 75%. It has also been observed that higher the watershed smaller is the groundwater component. (Lvovich,1971). In order to develop and utilize water resources of Himalayan rivers effectively, the study of various glacio hydrological relationships and the water balance of mountainous watersheds assumes considerable importance.

An attempt has been made in this paper to evolve various relationships in terms of temperature lapse rate variation, energy balance over the glacier surface and their effect on variations in discharge in Chhota Shigri glacier basin in Lahoul & Spiti district of H.P. The data used in various analyses was collected during a scientific expedition to this glacier in the summer of 1988.

STUDY AREA AND METHOD OF STUDY

Chhota Shigri glacier basin draining into Chandra valley is located about 36 kms due SE of Rohtang Pass in Himachal Pradesh. Total area of basin is about 36 sq. kms. out of which about 16 sq. kms is glacier covered. Bound by longitudes 32o 14' to 32o 1', the basin lies in the Lahoul & Spiti district and forms parts of Survey of India toposheets no 52 H/12 & 52 H/11. The Chhota Shigri glacier, located in a lap of a U shaped valley with a northern aspect, has a length of about 9 kms and width of about 1.5 kms at it's widest portion. The altitudinal variation in the valley ranges from 3800m to 5700m.

To study the environmental lapse rate and energy balance on the glacier surface, three manned observatories at altitudes 3870m, 4610m, and 4900m, recording hourly data pertaining to insolation, albedo, air temperatures wind relative humidity and glacier surface temperature were installed during the expedition. The discharge data was collected at a gauge site about 1 km downstream of the snout. To study the diurnal variation in discharge, air temperature and river temperature hourly data was collected on two days during the expedition

TEMPERATURE LAPSE RATE VARIATIONS

The data from two observatories on glacier ice, was used to calculate temperature lapse rate values. An analysis of the data reveals that on partially cloudy to clear days (Fig 1), a phenomenon of temperature inversion was observed during early morning hours just after the sunrise when negative values of lapse rate were obtained. The destruction of temperature inversion was observed to take place within few hours (generally 2 to 3 hours) after the sunrise. This phenomenon on clear or partially cloudy skies in mountain valleys can be attributed to the formation of convective boundary layer (CBL) over the valley floor due to week surfacial heating on the valley floor and sides in first 1 or 2 hours after the sunrise. Fig. 1 shows the daily variation of temperature lapse rate with time on different dates. The data shows that on cloudy days (e.g. 15.8.88), the lapse rate remained in pseudo adiabatic range varying from 0.08 oC/100m in the early morning hours to 1.2 oC/100m in the afternoon. The relative humidity values remained comparatively high (about 85-95%) on these days. On partially cloudy to clear skies, negative values ranging from -0.04 oC/100 m to -1.2 oC/100m were obtained. Positive values were obtained then after indicating destruction of temperature inversion. The values of relative humidity remained moderate on these days. The average environmental lapse rate values on Chhota Shigri glacier during the period of observation remained in the pseudo adiabatic range on maximum number of occasions i.e. in the range 0.38 oC/100m to 0.67 oC/100m except for only one occasion when the lapse rate value was observed to be near dry adiabatic i.e. 0.96 oC/100m.

RELATIONSHIP BETWEEN TEMPERATURE AND ENERGY BALANCE

Energy balance over the glacier surface was studied by the method discussed by Anderson (1976). Different energy fluxes contributing to the energy balance were calculated over the glacier body by dividing it into 4 different altitude zones. The extrapolation of temperature data at mean hypsometric altitudes of different zones was done by using actual temperature lapse rates computed from data of two stations on glacier ice. Fig. no. 2, 3, 4 and 5 give the contribution of various energy fluxes to the net energy balance in the accumulation as well as ablation zone. It is seen from this data that in the ablation area, the albedo values being small (10-20% for hard glacier ice and 42% for firm), the insolation is the largest positive contributor to the energy budget. The contribution due to sensible heat is also significant on these days (when mean air temperatures were about 0 oC). It was also observed that contribution due to latent flux was positive only when mean air temperatures were over or about 2.5 oC. In the accumulation zone, due to high albedo values (80-90% due to fresh snow fall), the contributions from insolation and sensible heat flux are fairly low and are almost negated by the outgoing longwave radiation and latent heat flux thus resulting in no effective melting on the glacier surface except on only few days during the observation period. It is also seen that although energy balance method gives the best results, it can not always be used as it involves data collection of too many parameters. Of all the meteorological parameters, temperature alone could be used as a meaningful surrogate variable to represent the energy exchange process over the glacier surface.

For Chhota Shigri glacier, the value of degree day factor was estimated to be 0.8 mm/ oc during the observation period and 1.9 oC is the threshold temperature indicting thereby that effective melting on the glacier surface at this temperature (Bhutiyani, 1990).

WATER BALANCE DURING THE ABLATION PERIOD

Although the study of water balance of glacierised watersheds presents many problems due to great variety of natural complexities, the general water balance equation can be written as :

$$R = Pm + Pr + Sg - E$$

where

R = Daily runoff in m/sec

Pm = Daily amount of ablation over the glacier surface

Pr = Contribution due to rain in the areal mean value of the watershed.

Sg = Daily contributions due to changes in ground water storage

E = Daily evaporation losses

Considering that the losses due to evaporation are negligible due to prevalence of sub zero temperatures and high values of relative humidity, the water balance equation can be rewritten as :

$$R = pm + Pr + Sg$$

The water balance in the Chhota Shigri glacier basin during the ablation period was studied by computing various components of runoff by different methods. The share of meltwater production on the surface of the glacier body was obtained by computing the net energy available and amount of meltwater produced. This was calculated separately in every zone and total meltwater component was obtained by adding these values. The contribution due to rain on rainy days was obtained by using the expression (Yamada. 1986) :

$$r = \frac{a.P}{A} \int_{Z1}^{Zr} Ar\,(Z).dZ$$

P = amount of rain in cm. at glacier camp.
A = 1
Ar = Area of rainfall

Where integration covers the entire rainfall area in the watershed between uppermost altitude Zr of rainfall to the lowermost altitude Z1 of the watershed. a is the correction factor of making P the reasonable value applicable to whole area when multiplied by it. Since the data from the glacier camp site was assumed to be representative of the entire basin, the value of a was taken to be 1 and uppermost altitude Zr of the rainfall area was taken to be the altitude of the equilibrium line. Total runoff in the Chhota Shigri river was computed by measuring discharge at a gauge site four times a day.

Fig. 6 shows the diurnal variation of discharge along with mean air temperature and river temperature. It can be seen from these two graphs that the time lag between the maximum air temperature and the peak river discharge is about 2 hours. Fig no.7 shows the contributions of various components of to the total runoff in the Chhota Shigri glacier basin. It is seen from this data that on non rainy days, the largest contribution to the total runoff comes from the groundwater average about 64%. On rainy days it's contribution is observed to reduce (average of about 56%) which could be attributed to the fact that upper layers of soil become saturated with water, thus inhabiting the flow of groundwater to the glacier stream. The share of glacier melt to the total runoff varied from 9.8% on fully cloudy day to about 57% on totally clear days, the average being about 35%.

1. The temperature lapse rate on Chhota Shigri glacier during the ablation period varied from 0.38 oC/100m to 0.67 oC/100m. The phenomenon of temperature inversion was also observed during early morning hours after the sunrise.

2. The temperature appears to be the best surrogate variable representing the energy exchange process during the ablation period.

3. The degree day factor and threshold temperature have values 0.82mm/oC and -1.9 oC respectively for Chhota Shigri glacier during the ablation period.

4. During the ablation period, the groundwater appears to be the largest positive contributor to the total daily runoff in the Chhota Shigri glacier stream.

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REPLIES BY AUTHOR ON POINTS RAISED BY GENERAL REPORTER

(1) While agreeing with the observation that the data pertained only to a period of about a month, it may be brought out that a good quality data from manned observatories was recorded throughout the day an hourly basis and not at 0830 & 1730 hr. only. This way ,the number of data points were increased significantly (about 200) for analysis and computation lapses rate. This quantum of data was felt to be adequate to establish temperature lapses rate with reasonable level of accuracy.

The altitudinal difference between two stations was about 250m and was sufficient to compute the environmental lapse rate (which is defined at the rate of variation in temperatures recorded at different altitudes at a given instant along the same valley or feature). Comparison with dry adiabatic lapse rate was done just to indicate the instability of atmosphere in the valley.

(2) In the expression given by Yamada (1984), the uppermost limit of rainfall area (Zr) was assumed to be roughly the altitude of equilibrium line and the lower limit (Zi) to be the altitude of the gauging site. The area between these two altitudes was planimetered. In the absence of rainfall data from any other stations except Glacier camp observatory & Base camp, the data from the former was taken to be representative of the whole basin between Zi & Zr as it was located in geographically & altitudinally in the central portion of the valley. The data from the Base camp was discarded & hydro-meteorological conditions. the contribution of rainfall was calculated by averaging it out over the entire area by an expression

$$Pr = P*A(Z)$$

Where Pr = Daily rainfall amount at Glacier camp observatory.
A(Z) = Area between Zi & Zr.

The ground water component Δ Sg was worked out by subtracting from total run-off the contributions due to glacier melt & rainfall and hence the addition of all components tallies with total run-off in chhota shigri glacier stream.