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TEMPERATURE LAPSE RATE STUDY IN SATLUJ CATCHMENT

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PREFACE

In most of the mountainous catchments where snowmelt runoff constitute a significant part of the annual flow, the melt rate is determined using temperature data. Nonavailability of data for energy budget approach for snowmelt and glacier melt runoff computation results in use of temperature index methods. The form of precipitation (rain or snow) is also determined using temperature data of the particular station or elevation zone.

In general, very sparse net work is found in the upper parts of the high altitude catchments. This is because of rugged topography and inaccessiblity to the region during winters due to heavy snow fall. Therefore, the temperature data available at lower altitudes in the basin is extrapolated to higher elevations using temperature lapse rate. Determination of actual temperature lapse rate (TLR) becomes very important parameter in the snowmelt modelling studies. Very limited studies are carried out in India in this subject. Mean monthly temperature lapse rates for maximum, minimum and mean temperatures have been computed and presented in this report. This report has been prepared by Dr.Pratap Singh, Scientist 'B', Mountain Hydrology Division, National Institute of Hydrology, Roorkee.

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ABSTRACT

The temperature lapse rate (TLR) is considered one of the important derived parameter in most of the snowmelt models. The distribution of temperature based on TLR has a major influence on snowmelt run-off computation and on the determination of the form of precipitation. To improve the understanding of distribution of temperature and how best to incorporate its effect in the snowmelt models, a study of TLR in Satluj catchment has been carried out. It is found that TLR values for the two sets of stations which are in the same region vary drastically. The results show a decrease of TLR with elevation at different elevation. The use of derived values of TLR is suggested at least on the monthly basis for the snowmelt season. Separate values of TLR for maximum, minimum and mean temperatures are recommended for temperature extrapolation/ intrapotation for snowmelt computation.

1.0 INTRODUCTION

Air temperature is considered to be the best index of heat transfer processes associated with melting of snow. There are numerous snowmelt models based on the temperature index method of snowmelt computation. In the snowmelt models having option for snowmelt computation using energy balance approach based on simplified or generalizes equations , air temperature is required. In computing snowmelt because of rainfall on the snowpack , air temperature plays an important role. The temperature and precipitation are the only meteorological data which are available at few stations in the snowbound catchments.

The form of Precipitation, rain or snow is also determined by the air temperature prevailing during the precipitation period. Once the form of precipitation is determined, the models take into account the different pattern of contribution in the run-off for the snowfed and rainfed area.

Generally, most of snowmelt simulation models have been designed with the concept of partitioning a basin into elevation zones or bands according to the relief of the basin. Partitioning provides the ability to account for spatial and temporal variation of the physical and hydrologic characteristics, climate variables and system response. The status of the network in the mountainous and snowbound catchments, generally, is not adequate because of inaccessibility and hazardous terrains. A few basin may have a network to meet the requirement of snowmelt models. Consequently, the temperature data is distributed to various elevation zones in the basin on the basis of TLR defined as rate of decrease of temperature with elevation.

The TLR changes from region to region and varies with time. Most of the models use a fixed temperature lapse rate, some use a seasonally varying lapse rate and some models use a lapse rate formulation derived statistically from daily observations. However, daily observations have been used on a statistical basis, lapse rates calculated each day from temperature data at different elevations have not yet proved to be useful (WMO,1986). Some models use monthly data average over a number of years to arrive at values of separate maximum and minimum temperature lapse rates for each month of year.

In our country, also a constant value of TLR has been used in snowmelt studies made in different catchments having the different kind of relief (Thapa,1980 ; Bagchi, 1981 ; Jeyram et al, 1983 ; Agarwal et al, 1983 ; Seth, 1983 ; Roohani, 1986 ; Singh, 1989). The validity of utilization of such value of TLR has not tested so far. In the present work efforts have been made to study the behaviour of TLR in the Satluj basin. This catchment has been selected because of good network and length of data available for the study. The TLR values have been computed using the station in the same climatic zone and having similar type of relief. Such studies have also been recommended by WMO (1986).

2.0 A TYPICAL EXAMPLE TO ILLUSTRATE THE EFFECT OF TEMPERATURE LAPSE RATE ON SNOWMELT RUN-OFF

The effect of temperature lapse rate value on snowmelt runoff computation for a small sub-basin of Beas has been illustrated in Fig.1. This catchment covers the elevation range from 1900m to 5400m and an area of 345 sq.km. In the months of April-June, it contributes significant snowmelt runoff. To show the effect of lapse rate value on snowmelt run-off computation, a Snowmelt Run-off computation, a Snowmelt Run-off Model (SRM) developed by Martinec and Rango (1983), has been run with values of TLR 5.5, 6.5, and 7.5 °C/km for the months of April and May. The results show that even a minor change in the value of TLR attributes very much into the snowmelt computation. It is observed that if the TLR is increased or decreased by 1 °C/km, keeping other parameters same, the total snowmelt run-off computation vary in the range of 28-37% for two months period. Evidently this variation may be higher if the computation is made for longer duration and basin is having a larger area. The results indicate that consideration of TLR for snowmelt studies is one of the most important aspect, which should be handled very carefully.

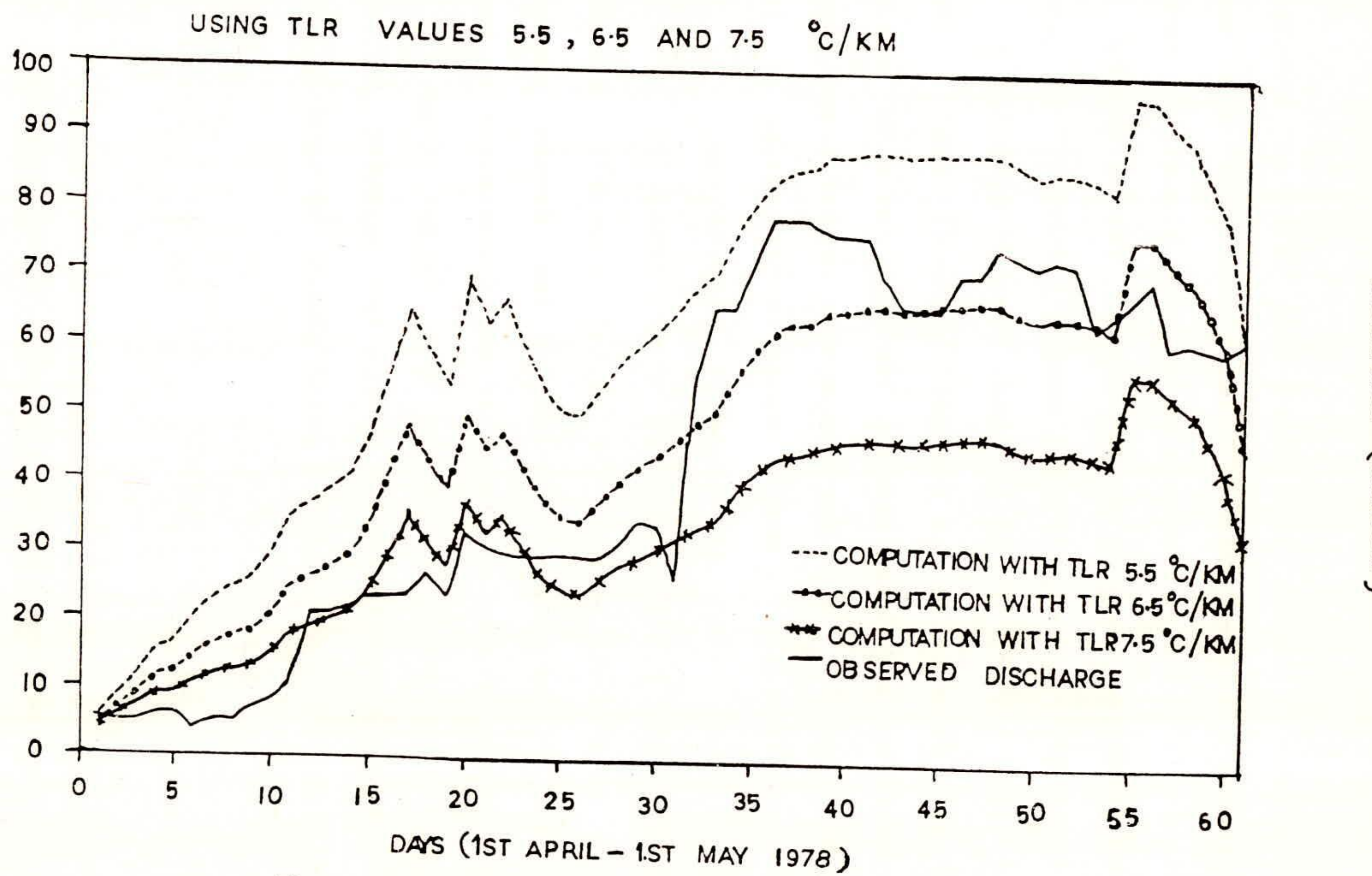

Fig. 1, Computed Snowmelt Runoff in Beas Basin

3.0 DISTRIBUTION OF TEMPERATURE IN VARIOUS SNOWMELT MODELS

Various snowmelt models have the following structure for temperature distribution (WMO, 1986).

1. UBC MODEL (Canada)

Distribution of temperature is made using maximum, minimum temperature lapse rates.

a. Maximum temperature lapse rate

TXLAPS = TZLAPS + (TLXM - TZLAPS) * TD/TERM

b. Minimum temperature lapse rate

TNLAPS = TZLAPS - (TZLAPS - TLNM) * TD/TERM

where:

TZLAPS	=	TZ - PP/PPM * (TZ - TZP)
TD	=	TX - TN (Daily temperature range)
TX	=	Maximum daily temperature
TN	=	Minimum daily temperature
PP	=	Daily precipitation
TERM	=	Maximum observed temperature range
TLXM	=	10.0°C/1000 m
TLNM	=	0.5°C/1000m
TZ	=	6.4°C/1000m
TZP	=	3.2°C/1000m

2. CEQUEAU MODEL (Canada)

There are three options for temperature distribution in this model-

(a) A regression relationship is derived on a daily basis between altitudes of the meteorological station and the temperature at this station. The temperature on the square is then calculated with the altitude of the square and the parameter of the regression. No lapse rates are used with this option.

(b) The Thiessen Polygon is used. The temperature on a square is the temperature of the nearest meteorological station. If the altitude of the square is not the same as that of the meteorological station, the temperature is modified according to the lapse rates are used.

(c) The temperature is a weighted average of the three nearest stations. If the altitude of the square is not the same as the mean of the three stations, the temperature is modified according to the lapse rate.

$$Tc = Ts + \Delta ALT * Lr$$

Tc = temperature on a square

Ts = temperature of one station (or 3 stations, option)

Δ ALT = altitude of the square - altitude of the station

Lr = lapse rates

3. ERM MODEL (Czechoslovakia)

No temperature lapse rates; mean value of temperature are used.

4. NAM-II MODEL (Denmark)

Temperatures are externally derived and fixed during the year. The lapse rates are used, one for minimum temperature and one for maximum temperature.

5. TANK MODEL (Japan)

Mean temperature of the I-th zone is given by

T(I) = T + TO - (I-1) * TD

where TO is an adjustment term and TD is temperature lapse per zone. The lapse rate is given by dividing TD by the elevation interval between zones. TO and TD are constant without any seasonal change.

6. HBV MODEL (Sweden)

A constant lapse rate 6.0°C/km is generally used.

7. SRM MODEL (Switzerland, USA)

The temperature is distributed using the following relation-

$$\Delta T = \delta (h_{sT} - h)$$

ΔT = temperature lapse rate correction factor in °C

s δ = temperature lapse rate in °C per 100 m

h_{sT} = altitude of the temperature station in m

h = zonal hypsometric mean elevation in m (from area-elevation curve)

δ can vary on a seasonal basis. If no data are available the rate 6.5°C/km is recommended.

8. IHDM MODEL (UK)

A constant lapse rate 6.5°C/km is used in the model.

9. SSARR MODEL (USA)

With the use of either a fixed or variable lapse rate, weighted temperature readings are distributed to each zone.

10. PRMS MODEL (USA)

Both maximum and minimum daily temperatures are lapsed using a monthly lapse rate and the difference in elevation between the meteorological station and an HRU. For each HRU

$$TMXA = TMXO - \left(TLPX(MO) * \frac{ELHRU - ELMET}{1\,000}\right) + SLASP$$

where

TMXA = adjusted maximum air temperature, °C

TMXO = observed maximum air temperature, °C

TLPX (MO) = lapse rate for maximum temperature for month MO, °C/1000m

ELHRU = elevation of HRU, m

ELMET = elevation of meteorological station, m

SLASP = adjustment factor for slope and aspect, °C

The minimum daily temperature is adjusted similarly.

11. NWSRFS MODEL (USA)

Temperature lapse rates are determined from available data. Generally mean monthly maximum and minimum temperatures for all stations are plotted against elevation. The monthly maximum and minimum temperature lapse rate determined from these plots are used in computing mean areal temperatures for each catchment or elevation zone. The mean areal temperatures are computed prior to model calibration.

4.0 PRESENT STATUS OF TEMPERATURE LAPSE RATE STUDIES AND THEIR APPLICATION IN SNOWMELT STUDIES IN INDIA

The distribution of temperature to various elevation zones in a basin has been made using a fixed value of TLR (Thapa, 1980 ; Bagchi, 1981 ; Jeyram et al, 1983 ; Agarwal et al, 1983 ; Seth, 1983 ; Roohani, 1986 ; Singh , 1989). Devi (1987) has made an attempt to analyze the typical variation of temperature in the some places in the Uttar Pradesh Himalayas. It was observed that TLR of surface temperature actually observed, both in valley bottoms as well as along mountain slopes, is less than 6.5°C/km, The mean environmental lapse rate. It was reported that temperature decrease up to elevation of 1700 m. Above this elevation temperature first shows an increasing trend and then run in zig-zag manner from 1800 to 2300m.

Bhutiyani (1989) has reported a variation of TLR from 3.8°C/km to 9.6°C/km in the month of August on Chhota Shigri Glacier in Himachal Pradesh. Upadhyay et al (1989) have analyzed the monthly normals of surface temperature for various stations situated at different altitudes in the Western Himalayas and reported that monthly lapse rates of temperature are fairly constant.

The studies carried out on TLR indicate that Devi (1987) and Upadhyay et al (1989) have considered data from the stations scattered over a wide range of mountainous part of Himalaya. Presence of several valleys and high crests between the considered stations affect the distribution of temperature. It occurs because of numerous cold and warm air pockets in differet valleys at different altitudes. Therefoe TLR values determined from the stations located in different valleys does not represent the value which can be used for temperature interpolation for snowmelt estimation in a basin. The results presented by Bhutiyani (1989) are found based on very limited period, about a month data only.

5.0 TEMPERATURE LAPSE RATES IN FREE ATMOSPHERE AND MOUNTAINOUS REGIONS

In the free atmosphere the decrease of air temperature with altitude assuming adiabatic conditions is approximately 10 °C/km for unsaturated air. For air saturated with water vapour , the wet adiabatic lapse rate depends on the temperature and the atmospheric pressures. With a change in air temperature from -20 to +20 °C its value changes at 100 mb level from 8.7 to 4.3 °C/km, and at 500 mb level from 7.8 to 3.3 °C/km (Kuzmin,1961). With the normal variation of temperature and pressure in atmosphere, it is found that the TLR tends to increase with altitude. On the average,TLR is between 3.0 to 4.0 °C/km in layer up to 1.5 km and 5.0 to 6.0 °C/km between 1.5 to 5.0 km (Kuzmin,1961).

Air temperature measurements in mountains are not always equal to those made in the free atmosphere at the same level. The mountain air temperature is often greater than free atmosphere temperature at the same level when the surface heated during the day and less when the surface is cooled at night. In the case of snowcover the surface can only be heated to 0 °C during the day after which the snow has a cooling effect on the mountain air temperature. Continuous observations in one mountainous region showed that the mean difference between free atmosphere air temperatures as close to zero for a period from May to September but that difference was as great as + 5 °C for individual measurement (Kuzmin,1961).

The mean air temperature lapse rate in mountains is generally considered 6.0 °C/km. There are seasonal variation and also a high variation with altitudes due to varying surface characteristics and local climate effects.

6.0 STUDY AREA AND DATA USED

In this study the TLR computations have been made for Satluj catchment. This catchment was selected because of availability of continuous temperature data at the stations established at different elevations by Bhakra Beas Management Board (BBMB). This catchment is of vital importance for snowmelt run-off studies. The snowmelt contribution in the river Satluj varies from 50 - 60% in different years depending upon the quantum of snowfall in winter and the rainfall in monsoon period (BBMB, 1988).

To study the behaviour of TLR in Satluj catchment the following sets of stations were selected depending upon their location in the same region at the different elevations.

1. Rampur (1066m) and Kalpa (2439m
2. Kalpa (2439m) and Rakchham (3130m)

The location of stations considered for this study has been shown in Fig.2.

The mean of daily maximum and minimum temperatures for a period of 5-6 years was used to compute monthly mean values of TLR. The data used for this study was supplied by BBMB, Nangal Township (Punjab).

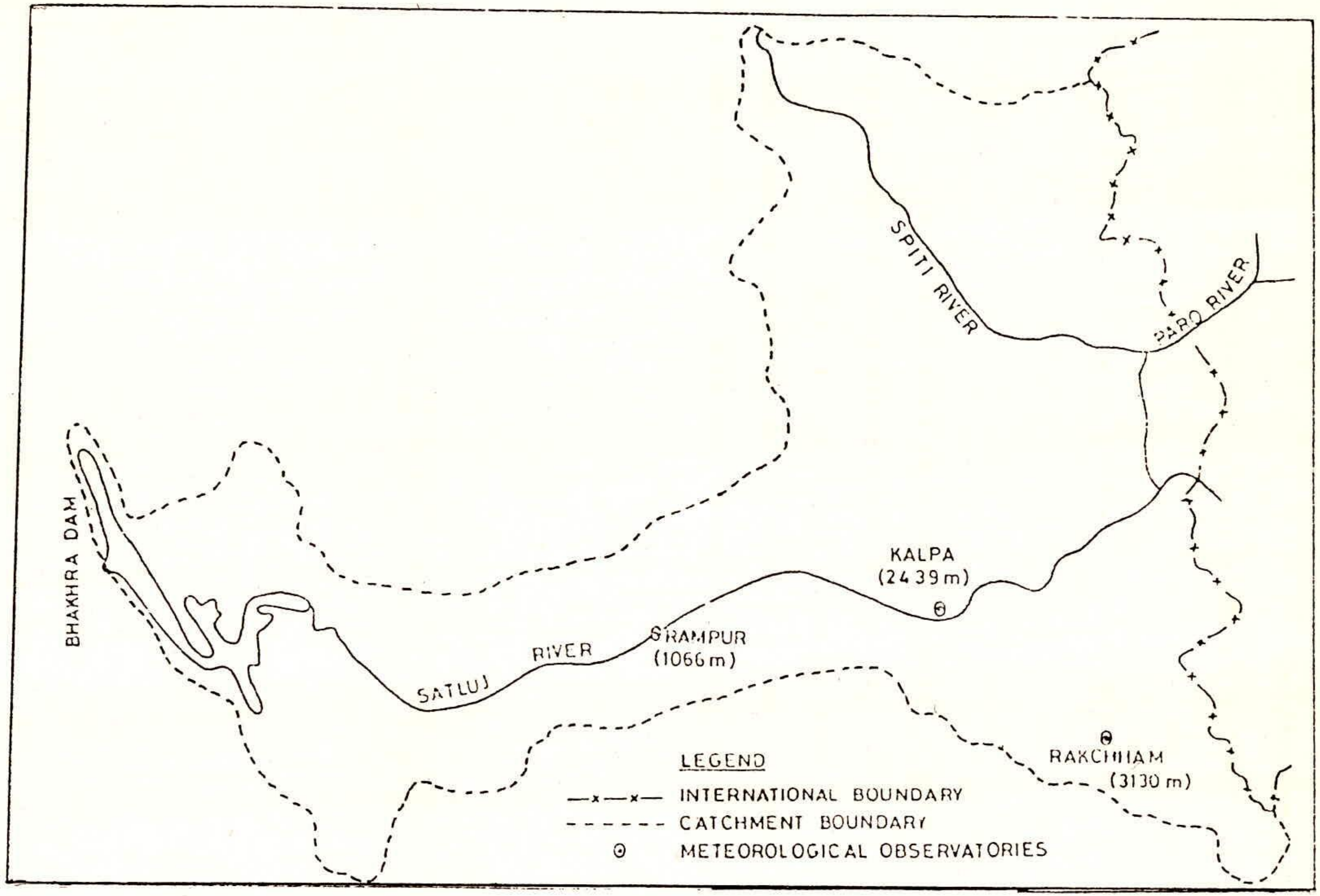

FIG. 2-SATLUJ CATCHMENT SHOWING LOCATION OF THE OBSERVATORIES

7.0 METHODOLOGY

The TLR values are computed using the following relation

$$TLR = \frac{DT}{(H_2 - H_1)} \qquad (1)$$

where,

TLR is temperature lapse rate in (°C/km),

DT is the temperature difference between considered two stations (°C) i.e. $(T_1 - T_2)$

H_1 is the altitude of the station at the lower elevation(m)

H_2 is the altitude of the station at the higher elevation(m)

8.0 RESULTS AND DISCUSSION

Generally mean monthly values of TLR are used in snowmelt computations. The computed mean monthly TLR for maximum, minimum and mean temperatures alongwith observed mean temperature for two set of stations namely Rampur-Kalpa and Kalpa-Rakchham are illustrated in Fig.3 & Fig.4 respectively. These plots illustrate the variation in temperature and TLR with time.

It is observed that mean monthly TLR for Rampur-Kalpa varies between 6.9-10.6, 5.4-7.9, 6.8-8.9 °C/km for maximum,minimum and mean temperatures respectively. For the other set of stations, Kalpa-Rakchham, the variation in the respective values of TLR has been observed between (-0.8)-5.1, 3.2-8.9 and 3.0-5.3 °C/km. The annual average values for the first set of stations are 8.8, 6.9, and 7.8 °C/km for maximum, minimum and mean temperatures respectively, while the respective values for second set of stations are 2.8, 5.7, and 4.3 °C/km. It shows that inspite of both sets of stations being in the same region, there is drastic variation in TLR values on the monthly and annual basis.

Figure 3 illustrate that mean monthly TLR for maximum and minimum temperatures are higher and lower respectively while compared with TLR for mean temperature. It may be explained very easily on the basis of much variation in maximum temperature range and less variation in the minimum temperature range for Rampur-Kalpa. It is observed that differences in TLR for maximum and minimum temperatures start to reduce in the month of May and minimize in the months from July to August.The differences again become substantial after the month of August. In the period from

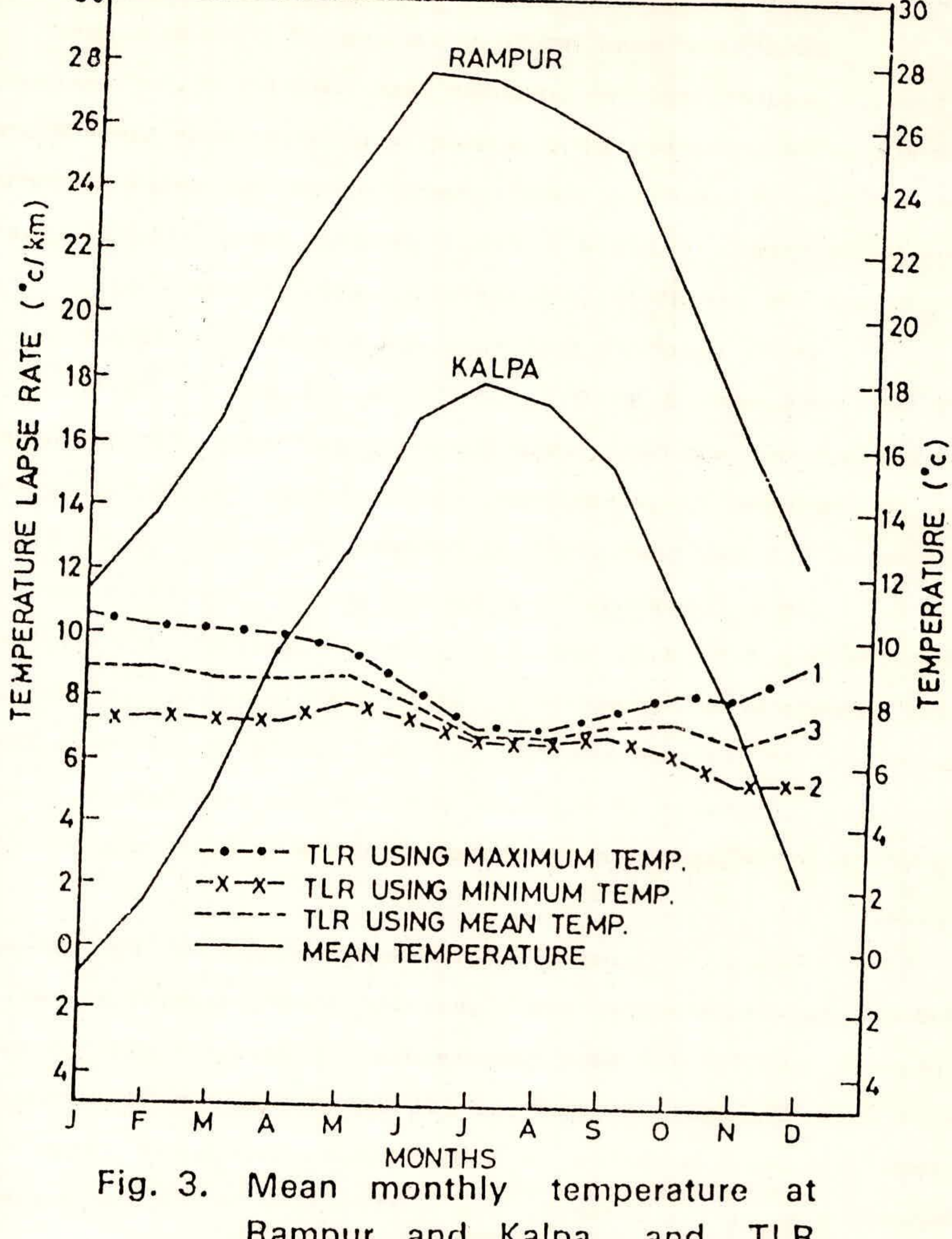

Fig. 3. Mean monthly temperature at Rampur and Kalpa and TLR

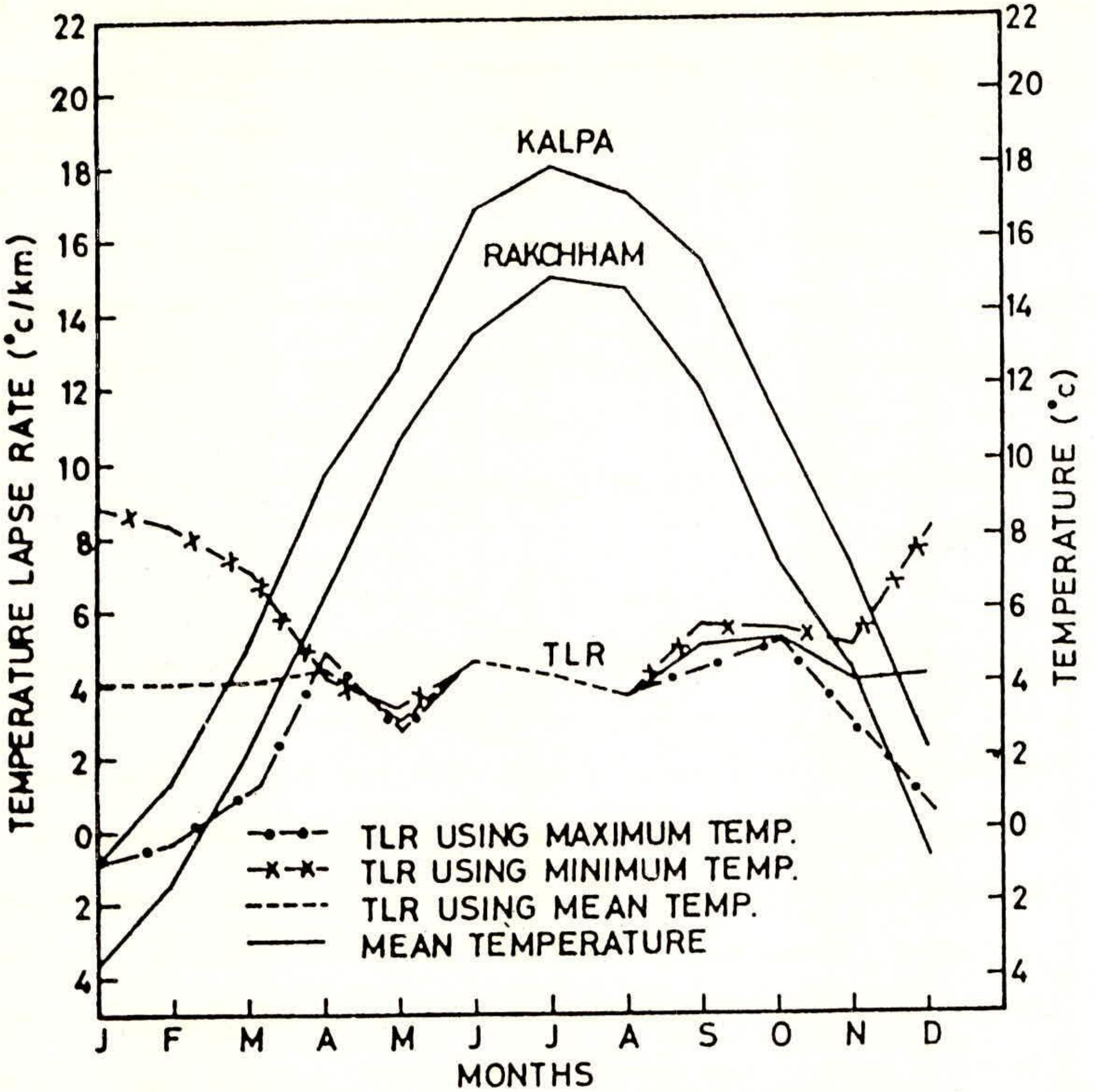

Fig. 4. Mean monthly temperature at Kalpa and Rakchham and TLR

July to August , there is not much difference between TLR for maximum, minimum and mean temperatures. Moreover for these three months TLR for maximum, minimum and mean temperature, seems to be constant. Such variation in TLR for the months of July to August, which is monsoon period, may be expected because of rains in this area. The range of temperature variation would be reduced due to rains at both stations, which would lower down the TLR. Further, there is not much variation in range between July to August,therefore, TLR becomes approximately constant during this period.

Figure 4 shows that TLR for maximum temperature is lower and TLR for minimum temperature is higher in comparison of TLR for mean temperature for the second set of station, Kalpa-Rakchham. It is a reverse trend of TLR for maximum and minimum temperature in comparison with first set of stations. It may be because of much variation in minimum temperature range and less variation in maximum temperature range for this set of stations. It is also seen that TLR values reduce drastically by the month of April and in the months from July to August, TLR for maximum, minimum and mean temperatures have same values. The monsoon rains from July to August affect the temperatures in the same manner as in the first case of stations which results in minimizing variation in TLR for maximum, minimum and mean temperatures.

The average values of TLR for the snowmelt season (March-June) for Rampur-Kalpa stations are computed to be 9.42, 7.47,and 8.45 °C/km for maximum, minimum and mean temperatures respectively. Those values for Kalpa- Rakchham stations are to be 3.35, 1.77 and 1.05 °C/km. These results indicate that even for the snowmelt season, TLR changes significantly and reaches to approximately half or less than that for the set of stations located at higher elevation. The results shows that TLR decreases with elevation. Such variations pose restrictions in using a single value of TLR in interpolation/extrapolation of temperature at different elevations in basins. Moreover, these computed values of TLR derived from the observed surface temperature is much different from the generally used value of TLR , 6.5 °C/km, in snowmelt studies. The derived TLR values may be used for snowmelt studies in the Satluj basin. Snowmelt studies for each subbasin of the catchment using the derived TLR values for that subbasin should be preferred.

This study shows that a constant value of TLR for all the basins should not be used and efforts should be made to use the representative value of TLR in accordance with temperature data used (maximum, minimum or mean temperature). The computation of TLR for the proposed basin for snowmelt studies should be made-10-at least on the monthly basis for the snowmelt season (March-June). For higher accuracy , a separate value of TLR may also be used for each month in snowmelt season. The use of derived TLR value would help in accurate estimation of snowmelt run-off and the other parameters used in the modelling studies would also be calibrated properly. It is recommended that the temperatures recorded at the same time for a set of stations situated at different elevations may help in higher accuracy of TLR. The TLR values may be determined for each basin of Himalayas which need strengthening of existing network in the Himalayas. A micro-scale study is required to study the local and regional factors influencing the temperature variation at the high altitude basins.

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