TREE GROWTH/GLACIER/CLIMATE RELATIONSHIP IN THE HIMALAYAN REGION AND ITS IMPORTANCE IN THE UNDERSTANDING OF HYDROLOGICAL RESPONSES

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A variety of conifer species, having distinct datable annual rings, are found throughout the Himalayan region extending from northwest Kashmir to southeast Sikkim. Tree ring samples of many of these species, viz *Pinus gerardiana, P. roxburghii, P. wallichiana, Cedrus deodara, Taxus baccata, Abies pindrow, A. spectabilis, Picea smithiana, Tsuga dumosa,* and *Larix griffithiana,* have been studied to develop long tree ring chronologies to understand various changing environmental parametres in time and space. To maximise the climate signal in tree rings and avoid cases where that signal has been disrupted by human or other natural disturbances, utmost care has been taken in the selection of sites, species, and even individual trees. Several tree ring chronologies have been prepared by using ring width data. These regional chronologies are expected to reveal information on global climate phenomena such as the Medieval Warm Period and Little Ice Age.

To understand the effect of environmental factors, especially of temperature and precipitation on tree growth, response function analyses have been carried out with different chronologies using climate data of meteorological stations close to the sampling sites. The response function study involved the regression of principal components of the monthly temperature and precipitation data on the annual tree ring indices to derive a set of regression coefficients that indicate the direction and relative strength of the impact of monthly data on tree growth.

The response function analysis of *Pinus gerardiana* from Kinnaur in the northwest Himalaya shows that precipitation of previous year's October and December and current year's January and July plays an important role in tree growth. Tree ring chronologies extending back 500 years have been prepared for this species and would be very useful in the reconstruction of winter precipitation. Around 400 years' chronology of *Pinus wallichiana* has also been prepared from the same area. The tree growth in this case is closely related to the precipitation of previous year's October and February, and March of the growth year. A comparative study of tree ring data with glacial mass balance has also shown poor tree growth during the positive mass balance years. *Deodar* (*Cedrus deodara*) growing in diverse ecological conditions has been found to provide ideal tree ring material for developing very long chronologies in India. The longest chronology constructed so far from the Indian region extends back to 1243 AD. Tree ring chronologies of this species, prepared from the moisture-stressed site in the western Himalaya, show the strong signature of the precipitation of March, April of the growing year, and October of the previous year.

Tree ring chronologies from the eastern Himalayan region in India were taken up very recently. The study has shown the prospect for developing several centuries long chronologies.

Tree ring chronologies of *Cedrus deodara* from Nepal, with excellent internal dating, show strong common signals. Very long tree ring chronologies of *Tsuga dumosa* (1569-1978 AD) and *Abies spectabilis* (1607-1978 AD) have also been prepared for climatic studies from Nepal.

The tree ring studies so far, conducted from diverse climatic zones of the Himalayan region, reflect strong signatures of climatic conditions, such as fluctuations in temperature, precipitation, glacier mass balance, and glacial fluctuations. Long, well-replicated tree ring chronologies seem to be very useful in the reconstruction of variations in temperature, precipitation, and water budgets of major rivers originating from the Himalayas.

OBJECTIVE EVALUATION OF SPECIFIC RATE OF RUNOFF DISTRIBUTION BY ALTITUDE IN MOUNTAIN REGION

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The rapid development of water resources in the Central Asian mountain area requires objective methods for runoff calculation for rivers without hydrometric data. Besides, the methods should be useful for the evaluation of climate change impact on rivers.

Runoff-forming factors are interspersed throughout mountains. However, all of them depend on altitude. That is why altitude is the main argument in the calculation of various hydrological parametres of mountain rivers.

Users are usually interested in the runoff data of certain rivers in some sections where there are no measurements. The proper method of getting such data is to find a relationship between the mean specific rate of runoff (M, [$dm^3.km^{-2}.s^{-1}$]) and mean watershed altitude for regions with similar hydrometeorological conditions. But, obviously, the relationship does not apply for all altitudinal ranges. The runoff calculation of high- or low-mountain rivers needs further extrapolation.

To avoid this difficulty, Bolshakov (1974) has proposed the concept of "zonal-specific rate of runoff" (m). It is the mean specific rate of runoff in an altitude belt. Its values permit us to:
(a) calculate M for watersheds where there are no measurement data,
(b) make the maps of runoff distribution for mountain areas, and
(c) evaluate the alteration of water-balance components by altitude.

It is important to note the following necessary information.

Q_j = long-term mean annual discharges of rivers, having runoff gauges,
f_i = watershed area distribution by altitude

j = river index, and
i = altitude belt index.

If we know the watershed area (F_j) and the mean M_j of a river, then the mean annual runoff is calculated from the following equation.

$$Q_j = M_j * F_j = \sum_{i=1}^{n} M_i . f_{ij} \qquad (1)$$

It is easy to find

$$M_j = \sum_{i=1}^{n} m_i . f_{ij} / F_j = \sum_{i=1}^{n} mi . k_{ij} \qquad (2)$$

Let us have Nr rivers with known M_j, F_j, f_{ij}. Now we have N_r linear equations like (2). We assume that m_i is the same in all watersheds of the region. M_i can be calculated by the method of least squares minimising (3). N_r has to be more than the number of altitude belts. However, Bolshakov did not do this as calculated m_i changed unsystematically with altitude. It could not be explained by natural reasons. Thus, he began to roughly form the smoothing curves m(Z).

$$\delta = \sum_{j=1}^{k} (M_j - \sum_{i=1}^{n} m_i . k_{ij})^2 \qquad (3)$$

However, it is possible to assume the relationship m(Z) to be an appropriate analytic function and introduce some reasonable conditions. Then the parametres of the function would be estimated objectively. The functions then chosen would be third degree polynomial

$$m = a_0 + a_1 . Z + a_2 . Z^2 + a_3 . Z^3$$

or exponential

$$m = b_1 .\exp((Z - b_2)^2/b_3),$$

where a_0/a_3 and b_1/b_3 are required parameters.

The conditions are as follow.

(a) In the Central Asian mountains, m = 0.5 / 1.0 $dm^3.km^{-2}.s^{-1}$ at the belt where the rivers come to the plain;

(b) If there are glaciers in the area then the maximal m take place at the equilibrium line altitude (ELA) (Shcheglova 1960), hence dm (ELA)/dZ =0. It permits the reduction of the number of parametres and their calculation.

The calculations were carried out for the mountain area of Aral Sea watershed, and a map of m was made.

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