

# **International Conference on Ecohydrology of High Mountain Areas**

**24-28 March, 1996**

**Kathmandu**

**organised by**

**UNESCO  
International Hydrological Programme  
Man and Biosphere Programme**

**His Majesty's Government of Nepal (HMG/N)  
Department of Hydrology and Meteorology**

**International Centre for Integrated Mountain Development  
(ICIMOD)  
Mountain Natural Resources' Division**

**German National Committee for the International  
Hydrological Programme of UNESCO and for the  
Operational Hydrology Programme of WMO**

**In cooperation with**

**The World Meteorological Organisation (WMO)  
The National IHP Committee of Nepal  
The National IHP Committee of Slovakia  
The Steering Committee of the IHP FRIEND Project  
The International Association of Hydrological Sciences (IAHS)  
The IGBP/BAHC**

## **Extended Abstracts**

**S.R. Chalise and N.R. Khanal (eds.)**

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## PREFACE AND ACKNOWLEDGEMENTS

Rapid population growth and the indiscriminate race for accelerated economic development are causing enormous pressure on land and water resources. With the increasing demand for land for agriculture, urbanisation and infrastructural developments, forest areas and water bodies are decreasing rapidly. Such changes in land use have brought about modifications in water flows, nutrients, sediments and pollutants, and loss of biodiversity. Consequently, deterioration in the quality of surficial water in various parts of the world is increasing. Obviously, there is an urgent need for a better understanding of the vulnerability of the land-water system to human activities, particularly in high mountain areas, because of their fragile ecology and susceptibility to irreversible changes.

Theme 2 of the fifth phase of the International Hydrological Programme (IHP-V) of UNESCO, viz., **Ecohydrological Processes in the Surficial Environment**, is concerned with these issues and devoted to the development of improved knowledge and understanding of the processes involved.

Close collaboration of the International Centre for Integrated Mountain Development (ICIMOD) with UNESCO/IHP, The Department of Hydrology and Meteorology (DHM) of His Majesty's Government of Nepal (HMGN), WMO, and the German IHP/OHP committee in programme activities contributing towards a better understanding of Mountain Hydrology, particularly at the regional level, has been taking place over the last few years.

The recommendations made by the Regional Workshop on Mountain Hydrology, organised by ICIMOD, through its programme on Mountain Natural Resources (formerly Mountain Environmental Management), jointly with UNESCO/IHP and DHM/HMGN in December 1989 led to the establishment of a project on Mountain Hydrology (H-5-6) under UNESCO's IHP-IV and a Regional Working Group on Mountain Hydrology in the Hindu Kush-Himalayas. This International Conference on Ecohydrology of High Mountain Areas in Kathmandu has once again brought these collaborating institutions together to organise this important event in which UNESCO/MAB, IGBP/BAHC, IAHS, and the National IHP committee of Nepal and Slovakia have also joined hands.

This International Conference in Kathmandu was one of the activities identified under UNESCO's IHP-V Project 2.4: Comprehensive Assessment of the Surficial Ecohydrological Processes, and its objective is to discuss outstanding issues concerning the ecohydrology of high mountain areas and to help specify needs and relevant components for regional studies. Its aim is to facilitate the exchange of scientific knowledge by bringing together scientists involved in the study of ecohydrology of high mountain areas with special emphasis on regional aspects. It also allows ecohydrologists from different regions to establish contact with each other.

The themes of this conference cover broadly all the relevant water-related problems of most complex high mountain ecosystems, and this is expected to encourage contribution from a wide range of specialists. The issue include:

- regional issues on high mountain ecohydrology;
- network design, instrumentation, data collection and processing, methodology, and modelling;
- atmospheric, hydrologic, and ecological interactions;
- role of permafrost, glaciers, and snow covers; and
- dynamics and hazards of erosion and sedimentation, ecosystems of high mountain areas, and landscape processes.

The response to the first announcement about the Conference was very encouraging and altogether 110 abstracts were received for oral and poster presentation. All of them were accepted and are included in this publication. The abstracts received were not uniform in length. During editing, minimum changes have been made in the length of the abstracts. However, some of the longer abstracts and some of the papers which were submitted in full had to be shortened for various practical reasons, including the incompatibility of computer programmes to read and print out mathematical equations and diagrammes provided by the authors. Due to the time constraint and difficulties in communication, it was not possible to send the shortened versions to the authors for their comments before publication. However, they were informed about it and, if some vital information has been omitted, the editors would like to express their regrets. Some papers submitted in French have also been included after translating the titles, subheadings, and figure captions into English. In terms of language, we have accommodated the original terminology used by the authors as far as possible.

The abstracts are arranged in alphabetical order using the name of the first author for each theme, and in each section abstracts for oral presentation are followed by those for poster presentation.

Prof. S. R. Chalise of ICIMOD edited the abstracts with the assistance of Mr. N. R. Khanal of the Central Department of Geography, Tribhuvan University, Kathmandu.

This publication would not have been possible within the time available without the support of our colleagues from the Documentation, Information, and Training Service (DITS) of ICIMOD. Special thanks are due to Greta Rana, Senior Editor, DITS, ICIMOD for providing us with assistance in copy editing through the services of Sangeeta Pandey and Veneta Singha, Trainee Editors, DITS. The assistance of Greta Rana and Prof. Dr. A. Herrmann of the Technical University of Braunschweig in editing the French Papers is gratefully acknowledged. The Editors are also thankful to Mrs Reeta Rana, Secretary, Mountain Natural Resources' Division, ICIMOD, and Mr. Narendra R. Shrestha for their efficient secretarial assistance and for patiently bearing with the demands of a rush job.

The financial support of the German IHP/OHP Committee to meet the cost of printing this volume is also gratefully acknowledged.

**Organisers of the Conference**

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# **WATER RESOURCES IN THE ALTIPLANO REGION IN SOUTHERN PERU, THEIR ISOTOPE COMPOSITION AND ORIGIN**

**EDGAR ACOSTA**

Proyecto Especial Tacna, Tacna, Peru

**LUIS ARAGUAS ARAGUAS**

International Atomic Energy Agency, A-1400, Vienna, Austria

**GUIDO ARROYO PAUCA**

Instituto Peruano de Energia Nuclear, Lima, Peru

**AGAPITO MAMANI**

Proyecto Especial Tacna, Tacna, Peru

**RUBEN ROJAS MOLINA**

Instituto Peruano de Energía Nuclear, Lima, Peru

**JAN ŠILAR**

Charles University, Albertov 6, 12843 Praha, Czech Republic

Projects on water management systems supplying water to the arid Pacific coast in southern Peru, are being implemented, and resources of surface water and groundwater in the Altiplano region are being developed.

The Altiplano is a high plateau at about 4,500masl, with andesite volcanic cones and ridges rising from its surface to altitudes of more than 5,700masl. On the rolling surface, there are several shallow lakes, some of which are drained to the Pacific, some to the Titicaca basin, and some are drainless. Springs yielding as much as  $3,00\text{l s}^{-1}$  occur at outcrops of aquifers or faults. Hot springs containing boron and other contaminants occur occasionally in some postvolcanic areas.

On some of the small streams, dams and weirs were constructed to control the discharge and divert water to channels of the supplying systems. Boreholes were drilled to extract groundwater for the same purpose from two main tertiary aquifers in the Maure and Capillune sedimentary formations to complement the surface water resources.

Precipitation along the Pacific coast is about 40mm per year and at the Altiplano, about 600mm per year. The precipitation is considered to originate in the atmospheric moisture arriving from the east from the Atlantic Ocean. Wetlands as well as dry pans occur at the surface of the Altiplano depending upon the geological structure and the hydrological circumstances. Isotope-hydrology methods have been used to correlate the composition of precipitation, surface water, and groundwater. Stable isotopes of oxygen and hydrogen, and occasionally tritium, were analysed.

The results of isotope analyses performed so far can be summarised as follows.

The stable isotopes O-18 and deuterium in the precipitation in the central Altiplano near Lima show a local meteoric line with a similar and only slightly lower slope than the world meteoric line. This phenomenon, if transmitted to the study area between Lake Titicaca and the Pacific coast, is in agreement with the general features of isotope composition of precipitation.

The majority of water samples from rivers, lakes, springs, and boreholes, with low values of O-18 and deuterium, correspond to the precipitation line, showing the direct meteoric origin of these samples.

Water samples, mainly from lakes, show isotope compositions that correspond to an evaporation line which is less inclined than the world meteoric line. This indicates that the water has been exposed to evaporation.

Low concentration of tritium in most groundwater samples shows that this groundwater has a long residence time; this, however, has to be defined more precisely.

The isotope composition shows a close relationship between precipitation, surface water, and groundwater, as well as a very strong influence of evaporation on the hydrological cycle which must be taken into account when considering the development of water resources in the Altiplano region.

# THE USE OF SNOW LINE DATA FOR THE ASSESSMENT OF WATER RESOURCES IN THE HIMALAYAN-HINDU KUSH REGION: RESULTS AND PROBLEMS

**KRENKE ALEXANDER**

Institute of Geography, Russian Academy of Sciences, Staromonetny Lane,  
29, Moscow, 109017, Russia

The assessment of precipitation, snow accumulation, and runoff in the alpine zone is very difficult because of many reasons. The altitudinal dependencies are not justified physically and hide the differences in water resources between the valleys which are orographically differently protected from atmospheric moisture fluxes. Using some ideas of H. Ahlmann (1924), we (Krenke 1973, 1982) have developed an alternative method based on the equality of ablation and accumulation at the snow line according to its definition. Accumulation depends on solid precipitation, and ablation on summer air temperature. The interpolation, and even extrapolation, of summer air temperature could be done with better accuracy than that of precipitation. Still, to implement this idea the number of problems has to be settled.

## **The Determination of the Equilibrium Line Height**

To know the yearly amount of ablation or accumulation, we have to use the highest position of the snow line. On a glacier, it is close to the equilibrium line where ablation and accumulation are exactly equal to each other. The discrepancy is explained by the superimposed ice in the accumulation area or by the firn transported down to the ablation area due to glacier movement. Still, for a few years these discrepancies between two values are small compared to the other errors involved in the method. That is why we will use the term "equilibrium line" as a synonym for the highest position of the snow line on the glacier.

According to our previous analysis, the equilibrium line height could be estimated with sufficient accuracy as the average between the highest and the lowest points of the glacier. We have used the catalogues, maps, and satellite images at our disposal. The local variability of the snow line height in the Central Asia is characterised by the standard deviation equal to 250 metres. It depends on the glaciers' morphology, exposition, and size. To avoid its influence, we have grouped the glaciers in groups of 10 to 15, thus lowering the role of the local variability to about 60 to 70 metres, which corresponds to about 0.3-0.5°C of summer air temperature. The special correction is used for cases of unusual glacier distribution in the groups by types or expositions.

### *Extrapolation of the Summer Air Temperature up to the Equilibrium Line Height*

The vertical summer temperature gradient in the area was investigated by Lebedeva(1993). It changes from 0.55°C per 100 metres in the wet areas to 0.72°C in the dry areas. These gradients could be used in four different ways.

- a. The "Points to Points" method: the altitudinal difference between the meteorological station and the average height of the equilibrium line for the glacier group is multiplied by the vertical gradient.
- b. The "Points to Field" method: the isolines of equal heights of equilibrium lines are plotted, and the temperature is estimated above each meteorological station, thus making it possible to take into account the horizontal temperature differences.
- c. The "Field to Points" method: isolines of equal temperature adjusted to the fixed height of 4,000m are plotted, and the summer temperature at the equilibrium line is determined from the points with the same position on this map.
- d. The "Field to Field" method: used in the present study. Two maps are compared with each other and the summer air temperature at the equilibrium line is determined for the regular network according to the altitudinal difference between the two maps. This procedure does not take into account the cooling above the glacier surface. According to field experience, it changes from 0.5° to 2.5°C depending upon the air temperature and size of the glaciers. The corresponding corrections are implied.

## **The Calculation of Ablation and Accumulation at the Equilibrium Line Height**

To move from summer air temperature to ablation and thus to accumulation, global, and regional formulas are used. The global formula (Krenke and Khodakov 1966) is as follows.

$$A = (T + 9.5)^3,$$

where

A = yearly ablation (accumulation) in mm and

T = the average summer air temperature in °C. The accuracy of the global formula is about 18%, but it still appears to be higher (10%) in the Pamirs and the Karakoram. The results of calculation using the global formula are shown in Fig.1.

According to Fig. 1, accumulation is above 2,500mm in the wet areas fed by moisture from the Atlantic flow and Bengal monsoon. Along the southern slopes of Central Himalayas, accumulation is of the order of 1,500-2000mm. In dry leeward areas it decreases to 500mm.

### **Assessment of Precipitation, Glacier Runoff and Total Runoff**

According to field data and simple theoretical considerations, the glacier runoff could be assumed by the first approximation to be equal to the accumulation at the snow line and thus calculated from its maps. The glacier runoff from the Hindu Kush is equal to seven cubic kilometres; from Karakoram, 17 cubic kilometres; and from the Himalaya, 36 cubic kilometres, totalling about 60 cubic kilometres.

The solid precipitation is less than accumulation because the accumulation includes the drift snow and avalanches. The coefficient of concentration depends on morphological types of the glacier and its basin. Plotting the map of the snow line height, we have mostly used the big glaciers. According to our detailed field study in IHD-representative basins and according to the snow line deviation from other types, this coefficient is equal to about 1.25 on such glaciers. Thus, amount of solid precipitation varies similar to the accumulation from 2,000mm in wet areas and 400mm in the dry areas and is equal to 1,600mm along the southern slopes of Himalayas. The liquid precipitation at such heights everywhere are less, even far less than 20%. So the total precipitation over the alpine zone

changes from 2,400mm down to 400mm. According to the field experiments in the alpine zone, the runoff from total precipitation is equal to about 0.85, thus changing from 1,500-2,000mm in the wet to 350-500mm in dry areas. The total runoff from the alpine zone is about 400 cubic kilometres.

**Acknowledgement.** This investigation was supported by RFFI grant No. 93-05-9699.

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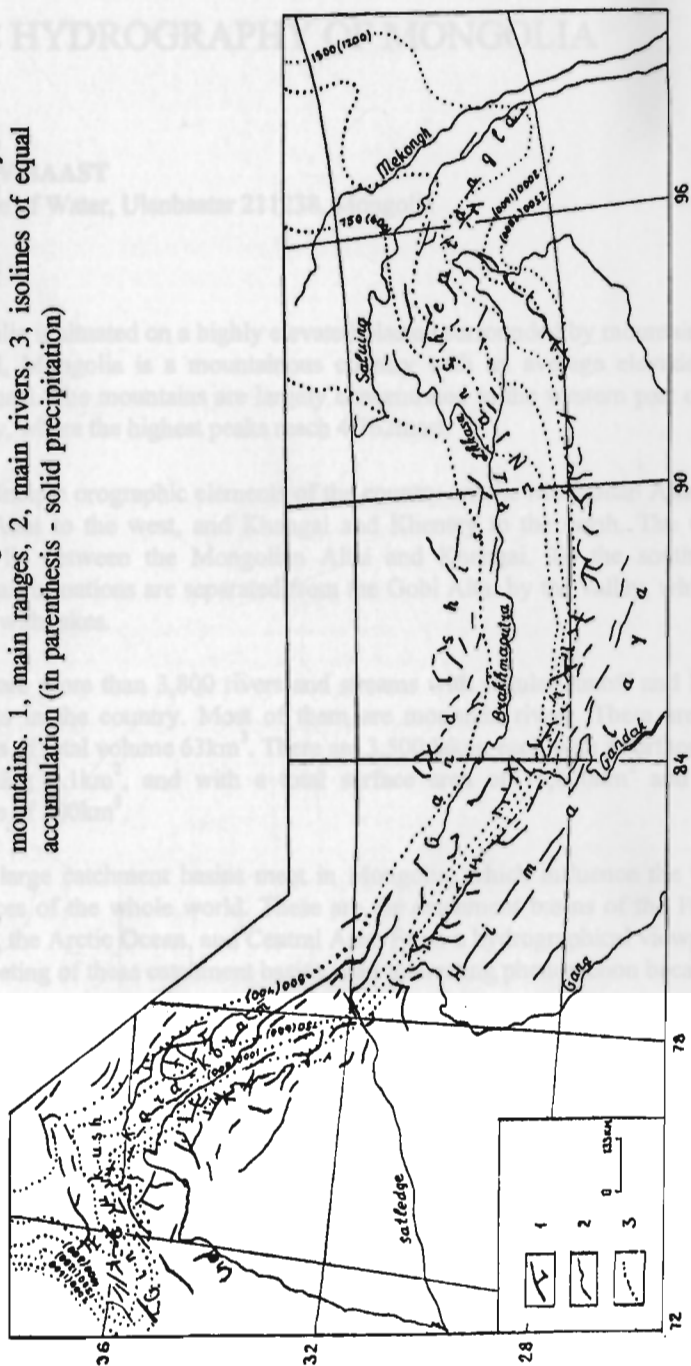
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Fig 1: The accumulation on the glaciers in the Hindu Kush-Himalayan mountains. 1, main ranges, 2, main rivers, 3, isolines of equal accumulation (in parenthesis - solid precipitation)



# THE HYDROGRAPHY OF MONGOLIA

## PUREV BAAST

Institute of Water, Ulanbaatar 211238, Mongolia

Mongolia is situated on a highly elevated plateau surrounded by mountains. In general, Mongolia is a mountainous country with an average elevation of 1,580masl. The mountains are largely concentrated in the western part of the country, where the highest peaks reach 4,362masl.

The principle orographic elements of the country are the Mongolian Altai and Gobi Altai to the west, and Khangai and Khentey to the north. The Gerat Lakes lie between the Mongolian Altai and Khangai. To the south, the Khangai formations are separated from the Gobi Altai by the valley, which is dotted with lakes.

There are more than 3,800 rivers and streams with regular runoff and 8,000 riverlets in the country. Most of them are mountain rivers. There are 187 glaciers of total volume  $63\text{km}^3$ . There are 3,500 lakes, each with a surface area exceeding  $0.1\text{km}^2$ , and with a total surface area of  $15,600\text{km}^2$  and total volume of  $500\text{km}^3$ .

Three large catchment basins meet in Mongolia, which influence the water resources of the whole world. These are the catchment basins of the Pacific Ocean, the Arctic Ocean, and Central Asia. From a hydrographical viewpoint, the meeting of these catchment basins is an interesting phenomenon because it rarely occurs on the mainland.

All of western Mongolia, approximately 35% of the total area of the country, is part of the catchment basin of Central Asia. Because this is a self-contained hydrological system, where the rivers do not flow out of their catchment area but mostly end in lakes, it is specially suited for investigating the water cycle. In such a system, a variety of eco-regions can be found close together - glaciers, tundra, forest, steppe, and desert, all situated alongside rivers.

# ON ECOHYDROLOGICAL INVESTIGATION OVER THE HIMALAYAS

**JAGDISH BAHADUR**

Department of Science and Technology, Government of India  
Technology Bhawan, New Delhi 110016, India

Calling the Himalayas the tallest water tower of the earth with the inherent characteristics of a natural environment and ecosystem, the need to evolve an appropriate mix of traditional with modern knowledge for rational water utilisation on a sustainable basis is outlined. The utmost cooperation of all concerned is needed to manage water resources with a full understanding of their spatial and temporal vagaries for sound management of the apex environment. The quantum of atmospheric moisture and interrelationship between cryosphere and atmosphere are outlined with regard to heat and water exchange. The role of extensive snow (over a million  $\text{km}^2$  in winter) and glacier cover (approximately 100,000  $\text{km}^2$  in summer) in moderating, modifying, and modulating the weather and climate of the region is brought out. The percentage of seasonal (June to September) to annual rainfall ranges from 45.9% for Jammu and Kashmir to 90.4% for Nagaland, Manipur, and Mizoram in different Himalayan meteorological subdivisions of India. This is discussed in this paper along with available hydrometeorological observations made at higher altitudes by Chinese investigators. Investigations on snow and glacial meltwater contributions from various Indian workers are given and their findings highlighted. It is estimated that from 400 to 800  $\text{km}^3$  flows down the Indus, Ganges, and Brahmaputra river systems every year. Studies of manmade water storage reservoirs higher than 100m, with 51  $\text{km}^3$  capacity at the base of the mountain system, are included, pointing out the need to increase the storage capacity for all round and longer availability of water in the higher mountain region and also to reduce downstream surface runoff and control loss of valuable soil necessary for environmental regeneration.

Case studies dealing with rainfall trends at Barapani for 31 years (1957-87) indicate no change in rainfall; water harvesting in the NE hill region with rain-runoff varying from 30.8 to 85%; runoff duration, from 240 to 1,293 hours; soil losses were from 3.62 to 22.5t/ha. The soil-water conservation measures

for increased agricultural production, temporal variation of rainfall which decreased by 120 to 206mm during last 100 years, and temperature rises at three locations in the Ganges basin are presented and discussed. Scenarios from various global climatic models upto 2100 A.D. and observations on CO<sub>2</sub> concentration are also incorporated for climatic change studies. The need for improved understanding of the ecohydrology of the Himalayan system, based on weather and climate, is emphasised. It is suggested that coordinated and planned land-surface atmospheric experiments should be conducted with the establishment of mesoscale and long-term flux measurements at selected sites, combined with hydrological and vegetation studies to provide meaningful inputs for developmental strategies. This needs local, regional, and international cooperation, adopting an inter-institutional and multidisciplinary approach for the highest mountain system in the world.

Calling the Himalayas the "water tower of Asia", the report stresses the need to evolve an understanding of a natural environment and ecosystem, the need to evolve an appropriate mix of traditional with modern knowledge for rational water utilisation as a sustainable basis is outlined. The utmost cooperation of all concerned is needed to manage water resources with a full understanding of the spatial and temporal variation for sound management of the apex environment. The question of atmospheric moisture and interrelationship between cryosphere and atmosphere are outlined with regard to heat and water exchange. The role of extensive snow (over a million km<sup>2</sup> in winter) and glacier snow (approximately 100,000 km<sup>2</sup> in summer) in moderating rainfall, and moderating the weather and climate of the region is brought out. The percentage of annual (June to September) to annual rainfall ranges from 45-50% for Jammu and Kashmir to 20-40% for Nagaland, Manipur, and Mizoram in different Himalayan meteorological subdivisions of India. This is discussed in the paper along with available hydro-meteorological observations made at higher altitudes by Chinese investigators. Investigations on snow and glacial meltwater contribution from various Indian waters are given and their findings highlighted. It is estimated that about 400 to 500 km<sup>3</sup> flows down the Indian Ganges, and Brahmaputra river systems every year. Studies of meltwater with storage reservoirs begin from 1950s, with 31 km<sup>3</sup> capacity at the base of the mountain system are included, pointing out the need to increase the storage capacity for all round and better availability of water in the higher mountain region and also to reduce downstream surface runoff and control loss of valuable soil necessary for environmental regeneration.

Case studies dealing with rainfall trends at Bhopal for 31 years (1957-87) indicate no change in rainfall; water harvesting in the NE hill region with runoff varying from 30.8 to 82.9% runoff duration from 240 to 1,293 hours; soil losses were from 1.63 to 22.2 t/ha. The soil-water conservation measures

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

**AMALAVA BHATTACHARYA AND RAM R. YADAV**

Birbal Sahni Institute of Palaeobotany, 53 University Road,  
Lucknow 226001, India

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 parameters 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

**GLEB E. GLAZYRIN**

Central Asia Research Hydrometeorological Institute,  
72 Obervatorskaja Str., Tashkent, 700052 Uzbekistan

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 parameters 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 ( $M$ , [ $\text{dm}^3 \cdot \text{km}^{-2} \cdot \text{s}^{-1}$ ]) 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.

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

It is easy to find

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

Let us have  $N_r$  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  $m(Z)$ .

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

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

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

or exponential

$$m = b_1 \cdot \exp((Z - b_2)/b_3),$$

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

The conditions are as follow.

- (a) In the Central Asian mountains,  $m = 0.5 / 1.0 \text{ dm}^3 \cdot \text{km}^{-2} \cdot \text{s}^{-1}$  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  $dm(\text{ELA})/dZ = 0$ . 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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# ECOHYDROLOGY OF RIVER BASINS OF NEPAL

**N.R. KHANAL**

Department of Geography, Tribhuvan University, Kirtipur,  
Kathmandu, Nepal

**A. POKHAREL**

Department of Hydrology and Meteorology, Babar Mahal,  
Kathmandu, Nepal

**S.R. CHALISE**

International Centre for Integrated Mountain Development,  
Jawalakhel, Kathmandu, Nepal

Temporal and spatial variations in the discharge from major river basins of Nepal have been examined on the basis of available records of discharge together with basin characteristics and meteorological data. The specific runoff of each basin has been calculated and mapped (Fig. 1). Downstream changes in the volume of flow, both annual and extreme, have been estimated in order to examine upstream-downstream linkages in the flow of water.

It is known that specific runoff varies generally with space and time, and the general trend in specific runoff in these basins indicates that it is comparatively higher in the central part of the country than in other parts. It is seen that specific runoff ranges from below 1,000mm in the Koshi basin in the east, to more than 1,500mm in the Gandaki basin in central Nepal, to slightly more than 1,000mm in the Karnali basin in the west. Although the total monsoon precipitation in the southern part of the Himalayas, in the Koshi basin (eastern Nepal), is comparatively high, yet a significant portion of the Koshi basin lies on the much drier northern side of the main Himalayas, which results in low specific runoff in this basin. Similarly, the Karnali basin in the west, which receives less precipitation than the central and eastern parts of the country, also has lesser specific runoff as compared to the Gandaki and Koshi basins. The influence of the high Himalayas on the precipitation and, consequently, on specific runoff is evident from the fact that rivers originating from the northern side of the main Himalayas, such as the Arun, Trishuli, Budhigandaki, Kaligandaki, Bheri, and Mugu Karnali, have lesser specific runoffs compared to the rivers originating from the southern side of the

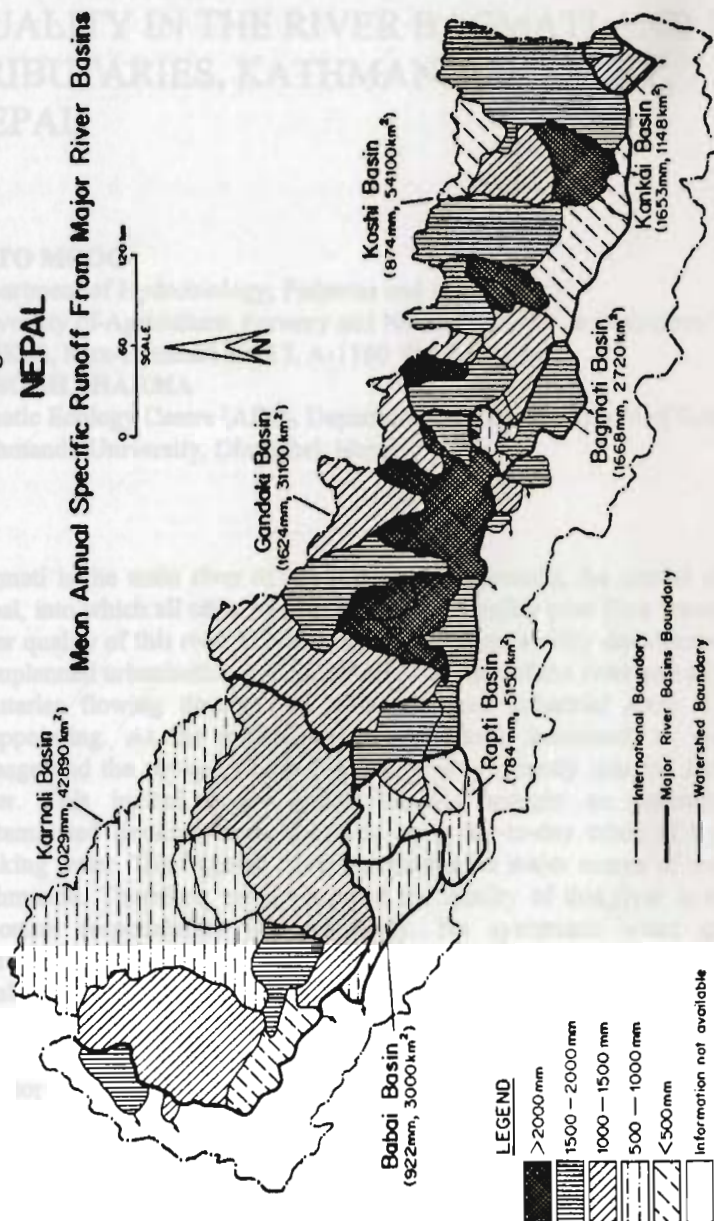
Himalayas, such as the Tamor, Dudhkoshi, Khimti, Likhu, Balephi, Chepe, Madi, Seti, etc. Similarly, the ratio of average maximum to mean average discharge as well as the ratio of maximum to minimum annual average discharge is comparatively higher in the rivers originating in the Siwalik hills in the south, indicating the very flashy nature of runoff in this region.

From the available data on the Koshi basin it is found that, although upstream utilisation and diversion of water are virtually nonexistent, the volume of water decreases in the downstream section near the Kampughat and Chatra areas. This anomaly in downstream discharge needs to be further investigated in order to understand the flow behaviour of these rivers and the causes of such anomalies. It has also been noticed that extreme discharge events generated either by heavy precipitation, landslide damming, or glacial lake outburst floods in the upstream areas are not directly connected with the floods in distant downstream areas.

The impact of intense rainfall events are found to be more damaging on microwatersheds compared to other watersheds. However, the existing network of meteorological stations in Nepal is not sufficient to record such events. Case studies of the impact of such events on microwatersheds could contribute to a better understanding of ecohydrological processes in such watersheds. It is also desirable to improve the existing monitoring network of hydrometeorological stations in the country in order to generate more reliable data.

Figure 1  
**NEPAL**

Mean Annual Specific Runoff From Major River Basins



# BIOLOGICAL ASSESSMENT OF WATER QUALITY IN THE RIVER BAGMATI AND ITS TRIBUTARIES, KATHMANDU VALLEY, NEPAL

**OTTO MOOG**

Department of Hydrobiology, Fisheries and Aquaculture  
University of Agriculture, Forestry and Natural Renewable Resources  
(BOKU), Max-Emanuel Str. 17, A-1180 Vienna, Austria

**SUBODH SHARMA**

Aquatic Ecology Centre (AEC), Department of Biology, School of Science  
Kathmandu University, Dhulikhel, Nepal

Bagmati is the main river of the valley of Kathmandu, the capital city of Nepal, into which all other streams draining the valley pour their water. The water quality of this river in Kathmandu Valley has swiftly deteriorated due to unplanned urbanisation and industries. The state of the river and adjacent tributaries flowing through the residential and industrial areas is very disappointing. As the population in Kathmandu increased, so did the garbage and the sewage which found their way directly into the Bagmati River. This invited severe health hazards brought on basically by contaminated drinking water followed by a day-to-day crisis of hygienic drinking water. The Bagmati River constitutes the major source of water in Kathmandu. Therefore, preservation of the quality of this river is a very important responsibility for everybody. No systematic water quality monitoring network has yet been developed in Nepal. The search for a suitable, cheap, and effective method of water-quality assessment is, therefore, very necessary. Bagmati River in Kathmandu Valley has been chosen as a model for adopting water quality management, especially to monitor the water quality of the heavily polluted sites.

The application of the saprobic method in the rapid field assessment of organic pollution is described in this paper. The importance of abiotic and biotic factors in deciding the saprobic state of a river is highlighted. The trophic interactions among the producers, consumers, and decomposers in

an aquatic ecosystem are taken into account. Besides macroinvertebrates, the indicator species concept, based on the observation of algae, diatoms, and macrophytes, is also considered. The phenomena occurring on a river site, such as the formation of iron sulphides beneath the stones, presence of iron ochre, generation of froth on the water surface, hydrogen sulphide gas in sediments etc, are looked into more deeply.

The water quality of the Bagmati River in Kathmandu is presented in coloured maps and is categorised into seven saprobic levels or water quality classes. The saprobic levels are best defined and described as *Oligosaprobic* (Water Quality Class: I, colour: blue), *Oligosaprobic to Beta-Mesosaprobic* (Water Quality Class: I-II, colour: blue-green), *Beta-Mesosaprobic* (Water Quality Class: II, colour: green), *Beta-Mesosaprobic to Alpha-Mesosaprobic* (Water Quality Class: I-III, colour: green-yellow), *Alpha-Mesosaprobic* (Water Quality Class: III, colour: yellow), *Alpha-Mesosaprobic to Polysaprobic* (Water Quality Class: III-IV, colour: yellow-red) and *Polysaprobic* (Water Quality Class: IV, colour: red).

The saprobic system of water quality assessment is extensively used in Central Europe, mainly Germany and Austria, and has been adopted by the neighbouring east European countries too. The significance and limitations of this method, based on the experiences shared on Austrian as well as Nepalese rivers, are discussed. This system has been briefly compared with other biological systems in the Nepalese context and suggestions are made for a better and more effective water management tool.



# VALUATION METHOD OF ECOHYDROLOGY CONDITIONS IN HIGH MOUNTAIN AREAS: AN EXAMPLE OF LAKE BAIKAL BASIN

**ALEXANDER PERTROVITCH KHAUSTOV**

Ecology Department, People's Friendship University, Marshall Zakharov St.,  
12-3-412, Moscow, 115569, Russia

**VALERY NIKOLAEVITCH ZYKOV**

Ecology Department, People's Friendship University, Marshall Zakharov St.,  
12-3-412, Moscow, 115569, Russia

## INTRODUCTION

One of the urgent problems of hydrological and ecological research in mountain countries is the evaluation of the condition of natural environment subjected to human impact and forecasting of its condition. It can be done on the basis of the analysis of carrier and transformation processes of polluting substances, as well as by revealing indicators of environmental conditions.

Representation of territorial Landscape Geochemical Systems (LGS) can serve as the basis of landscape hydrology division into districts possessing determined levels of geochemical immunity, i.e. self-regulation of migratory processes and "refining" technical genesis. It is necessary to note that the landscape is considered not only as the effect of interaction of natural processes, but also as a system carrying out the work of this interaction. Each such system is characterised by specific interaction of its elements or blocks: precipitation - vegetation - soils - mountain rocks, surface and underground waters, creating individual features characteristics for such a system of migration, transformation, and accumulation of weighted and dissolved substances. The identification of afore-mentioned processes is effectively revealed on the basis of spatial-temporal variability research of the contents of chemical elements in waters of the rivers, which are controlled by landscape structure pools, drained by a river network. According to its organisation it is possible to subdivide LGS into elementary and cascade. Elementary LGS form lower steps and represent lithologically similar territories, covered by the same types of soils and, hence, certain vegetation communities. Such territory

can be considered as an indivisible landscape-individual. The channels of communication between the components of an elementary landscape are migration flows, consisting of the carrier (moisture flows) phase and the dissolved or firm substances phase. Elementary LGS sets form cascade LGS, where each elementary landscape is part or block of a columbine system.

The flow formation in river pools is determined in general by two main processes, ensuring the transformation of atmospheric precipitation, and accumulation of moisture and its drainage. (Stepanov et al. 1987). The volumes of migration of dissolved substances and their chemical composition, can reliably indicate predominant types of vegetation communities, and soils for periods of mixing in river.

Information about space distribution of other area indicators were used, e.g. physical and mechanical properties of soils, geological formations, and thermal properties (temperature including those of frozen ground). Area characteristics are model predictors (arguments), on which spatial-temporal variability of flow characteristics depend on models for the evaluation of sizes of dissolved substances are discussed in detail in the paper based on the following relation.

$$\sum_{i=1}^n M_i \cdot F_{i,j} = q_{i,r}$$

where  $q_{i,r}$  = ionic flow with j-th of pool (mg/sec);  $M_i$  = module of ionic flow (mg/sec km<sup>2</sup>) with i-th vegetation communities;  $F_i$  = its area in j-th river pool, km<sup>2</sup>.

Data of 22 rivers falling into the lake Baikal are used, where study on the chemical composition of water is conducted. The majority of studied items are located at the mouths of the rivers. Therefore, the problem of revealing forming conditions of ionic structure of waters within the limits of various (LGS) parts becomes even more urgent. Sampling for separate months with the account of rivers' water drain value during selection of tests are conducted. Through normalisation method (Alekseev 1971) it was possible to establish correlation dependence, mineralisation and flow. On the basis of evaluations of equally assured (chance) sizes of these parameters monthly volumes of ionic flow were calculated. Such techniques of calculations are stipulated by security discrepancy of the average month charges of the rivers and mineralisation owing to nonlinear relations between them.

From the calculation it was possible to evaluate perennial middle size  $M_i$  and to calculate mineralisation flows in annual dynamics from 10 main types of floral communities. In all the cases the authentic solutions characterised by high coefficients of multiple correlation ( $R=0.96-0.98$ ) and steady factors in regression equations (Khaustov 1991) are received. The heaviest size's module of ionic flow are characteristic for larch-pine mountain-taiga forests and make 42.3 tonnes/year/km<sup>2</sup>, least from territories of meadow communities, in high mountains, and lowlands (2.74-5.38 tonnes/year/km<sup>2</sup>).

A significant role in the formation of river and ionic flow is played by dark coniferous mountain-taiga forests and their restoration asp-birch and larch-pine forests, appearing at human changes of natural complexes (e.g. radical vegetation on account of clearance, fires etc.).

Transformation of geochemical stability of a natural system is reflected in quantitative and qualitative alteration of geochemical properties of a water body, formed within the limits of landscape. If  $M_i$  with dark pine forests and their restoration series are comparable (19 and 13-15 tonnes/year/km<sup>2</sup>), mineralisation of this series sharply grows up to 109-126mg/l (for dark pine forests - 37mg/l). This fact is well traced in annual mode; in this connection there can be scheduled possible ways of forecasting hydrochemical landscapes mode changes as a result of economic activity.

The mineralisation calculation of waters is also conducted on the basis of offered model. The analysis of annual water flow for various LGS has revealed the tendency for water budget atrophy according to exponential rule, that corresponds to representations on drainage by the river network mechanism of the whole columbine.

In fig. 1 there are indicated hydrographes of river modules flow from territories of some predominant vegetation communities. Hydrograph with restoration series (Alekseev 1971) evidently reflects sharp reduction in maximum flow, its large dynamics at recession and low steady values in the cold period of a year. It is connected with the regulating ability of a landscape, because the heaviest scales of human factor in the pool of lake Baikal are connected with the clearing of forests. The suggested method enables us to evaluate the negative effect on quantitative parametres of water and ionic flow and to calculate possible economic damage from woods clearance.

For mineralisation values of river waters a sharp-cut seasonal course is observed, which consists of an available minimum (May-June), when inflows are formed by prevailing snow dissolved in water. Such minima correspond to vegetation communities of mountain tundra and dark-pine mountain-taiga forests in comparison with other communities. The mineralisation values here are close to those in atmospheric condensation, that testifies to the prevalence of surface genesis of waters in river flow with an extremely insignificant share of underground supply. The maximum mineralisation is observed in March, when atrophy of limited stocks of underground waters occurs.

For larch-pine vegetation communities, there exists higher mineralisation for minimum water amount, as well as for its maximum, that testifies to slowed-down character of water exchange within the limits of a territory of their distribution. The reason for this is the low hipsographical location of territories and increase of underground supply share. As a result of evaporation of  $M_i$  for a particular LGS, the data on sizes of ionic shown from hydrological unknown area of Lake Baikal were found out and are given in Table 1.

In relation to analysed metals, the received values can be submitted in a kind of number migration, Al-Fe-Cu-Cr-Pb-V, which do not correspond to standard circuit noncluster of chemical elements and vegetation of forest zones. However, this number reflects in the best way mobilisation of chemical elements in river waters of Baikal. The specified law is confirmed by the results of model calculation of the contents of listed elements (Table 2) by recalculating them according to sizes of concentration. Notwithstanding that for Pb and Cu increased accumulation in vegetable is characteristic, their presence in ionic flow can be explained by high clurk contents in soils and rocks of the region.

## RESULTS

The proposed method permits us to take into account annual variation of dissolved chemical elements and to obtain the solution effectively, not depending on site and vegetation community combinations; to effectively generalise data by a single hydrogeochemical definition, when it is necessary to present received materials for the control and forecast of geochemical landscapes conditions; to evaluate the role of landscape-geochemical complexes in the formation of integrated flow of dissolved substances; to reveal the most dynamic reaction on humidifying and anthropogenic load of LGS, to study distribution of macrocomponents in LGS and to establish the forms and ways of migration of all generically dangerous species, as well as

abilities for survival and maintenance of vegetation with the pupose of drawing up ecology-geochemical maps; to create base stations for background monitoring on representative sites of the main types of landscapes in mountain countries, to conduct searches of useful mineral on secondary aureole diffusion.

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Table 1. Mean flow (liters per second) of rivers in the mountain regions of the USSR (on the basis of 1961-1970 data).

| Region | Mountain edges |                |                |                | Total |
|--------|----------------|----------------|----------------|----------------|-------|
|        | Trans-Caucasus | Trans-Caucasus | Trans-Caucasus | Trans-Caucasus |       |
| I      | 1.0            | 4.3            | 7.2            | 4.2            | 16.7  |
| II     | 0.7            | 3.1            | 2.2            | 3.1            | 9.1   |
| III    | 0.8            | 3.3            | 3.8            | 3.3            | 11.2  |
| IV     | 1.2            | 4.8            | 8.8            | 3.0            | 17.8  |
| V      | 1.8            | 14.2           | 20.2           | 14.2           | 30.2  |
| VI     | 2.4            | 20.2           | 28.0           | 20.0           | 40.6  |
| VII    | 4.2            | 18.2           | 31.0           | 18.0           | 51.4  |
| VIII   | 4.4            | 18.2           | 32.4           | 18.0           | 52.8  |
| IX     | 4.2            | 16.2           | 30.2           | 22.4           | 42.8  |
| X      | 0.2            | 11.8           | 18.2           | 11.8           | 21.8  |
| XI     | 1.8            | 7.2            | 10.4           | 6.1            | 15.5  |
| XII    | 2.8            | 2.2            | 12.8           | 7.2            | 18.0  |
| Yam    | 11.8           | 128.2          | 228.4          | 127.4          | 495.8 |

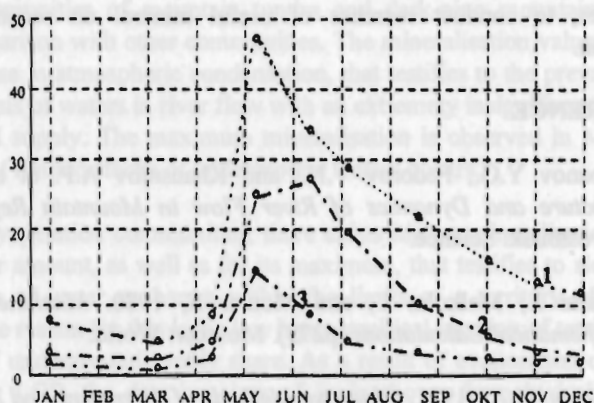
M<sub>i</sub>

Fig. 1. Hydrograph of river flow with the most representative floral communities of Baikal region [ 4 ]

1 - dark-pine mountain-taiga; 2 - larch- pine mountain-taiga;  
3 - birch restoration series from dark pine

Table 1. Ionic flow ( thousand ton per year) from unstudied territories to the lake Baikal ( on the data of floral communities ) [ 4 ]

| Months | Mountain edges |           |             |              |             | Total |
|--------|----------------|-----------|-------------|--------------|-------------|-------|
|        | Primorsky      | Baikalsky | Barguzinsky | Ulan-Burgasy | Hamar-Daban |       |
| I      | 1.0            | 4.3       | 7.5         | 4.3          | 4.8         | 21.9  |
| II     | 0.7            | 3.1       | 5.5         | 3.1          | 3.7         | 16.1  |
| III    | 0.8            | 3.3       | 5.8         | 3.3          | 4.0         | 17.2  |
| IV     | 1.3            | 4.8       | 8.8         | 5.0          | 4.7         | 24.6  |
| V      | 3.8            | 14.5      | 26.2        | 14.7         | 19.5        | 78.7  |
| VI     | 5.4            | 20.2      | 38.0        | 20.0         | 21.4        | 105.7 |
| VII    | 4.9            | 18.5      | 31.9        | 18.0         | 18.6        | 91.9  |
| VIII   | 4.9            | 18.7      | 32.4        | 18.6         | 19.7        | 94.3  |
| IX     | 4.5            | 16.5      | 30.3        | 25.4         | 16.1        | 92.8  |
| X      | 0.3            | 11.6      | 18.7        | 11.6         | 13.4        | 55.6  |
| XI     | 1.6            | 7.3       | 10.4        | 6.1          | 5.5         | 30.9  |
| XII    | 2.0            | 5.7       | 12.6        | 7.2          | 6.9         | 34.4  |
| Year   | 31.0           | 128.5     | 228.4       | 137.4        | 138.3       | 663.6 |

Table 2. Sizes of modules flow ( $\mu\text{g/s km}^2$ ) and their concentration ( $\mu\text{g/l}$ ) in flows ( under feature ) from the territory of the lake Baikal floral communities basin in October 1978 [ 4 ]

| №№ | Cu                  | Pb                 | Al                     | V                   | Cr                         | Fe                            |
|----|---------------------|--------------------|------------------------|---------------------|----------------------------|-------------------------------|
| 1  | <u>24.8</u><br>0.68 | <u>3.4</u><br>0.09 | <u>1440.0</u><br>39.7  | <u>1.4</u><br>0.04  | <u>6.5</u><br>0.21         | <u>770.0</u><br>21.5          |
| 2  | <u>2.1</u><br>0.84  | <u>0.4</u><br>0.16 | <u>307.0</u><br>124.0  | <u>0.3</u><br>0.12  | <u>1.4</u><br>0.57         | <u>173.0</u><br>70.0          |
| 3  | <u>12.7</u><br>0.68 | <u>1.8</u><br>0.1  | <u>830.0</u><br>44.9   | <u>0.7</u><br>0.04  | <u>3.6</u><br>0.19         | <u>428.0</u><br>23.1          |
| 4  | <u>24.7</u><br>1.17 | <u>6.7</u><br>0.32 | <u>5960.0</u><br>280.0 | <u>6.0</u><br>0.28  | <u>28.2</u><br><u>1.34</u> | <u>3360.0</u><br><u>159.0</u> |
| 5  | <u>6.8</u><br>1.28  | <u>4.0</u><br>0.75 | <u>3910.0</u><br>738.0 | <u>1.6</u><br>0.3   | <u>14.9</u><br><u>2.81</u> | <u>1770</u><br>334.0          |
| 6  | <u>0.1</u><br>0.1   | <u>1.0</u><br>0.3  | <u>1260.0</u><br>420.0 | <u>1.1</u><br>0.37  | <u>5.9</u><br>1.98         | <u>698.0</u><br>233.0         |
| 7  | <u>16.9</u><br>0.63 | <u>2.1</u><br>0.08 | <u>623.0</u><br>23.4   | <u>0.4</u><br>0.01  | <u>2.3</u><br>0.09         | <u>276.0</u><br>10.4          |
| 8  | <u>2.1</u><br>0.7   | <u>0.5</u><br>1.66 | <u>349.0</u><br>116.0  | <u>0.14</u><br>0.05 | <u>1.3</u><br>0.43         | <u>154.0</u><br>51.3          |

Note. 1 - mountain tundra; 2 - alpine meadows; 3 - dark pine thin forests on slope valley; 4 - dark pine mountain-taiga forests; 5 - larch-pine mountain-taiga forests; 6 - larch-pine series from dark pine forests; 7 - cedar brushwood; 8 - larch-pine mountain-hollow forests

# EFFECTS OF ALTITUDE ON ECOHYDROLOGICAL PROCESSES

**G. PESCHKE, C. SEIDLER AND U. FEISTEL**

International Graduate School Zittau, Markt 23, D-02763 Zittau, Germany

If ecological investigations are included in the consideration of hydrological problems, then the term ecohydrology is used. Attempts have been made to investigate interrelationships between plant cover and abiotic environmental factors such as temperature, moisture, radiation, precipitation, and wind and soil conditions. These environmental factors also significantly control the water cycle processes. They depend on the regional and local climate and soil conditions. Local climates in mountainous regions are highly dependant on altitude. Consequently, the interrelationship between vegetation cover and hydrological processes in mountain areas is greatly influenced by altitude. Of the moisture and heat fluxes at the atmosphere, soil, and vegetation interfaces, two general processes predominate in their effect on the local hydrology, the interception decreasing the moisture input into the soil and transpiration increasing the moisture extraction from the soil. The resulting soil moisture and precipitation reaching the soil surface through the plant cover determine the formation of different runoff components.

At two sites in the Erzgebirge mountain region, different in altitude, but similar in soil conditions and plant stand, measurements of the abiotic environmental factors mentioned above were taken. The gradients of these factors are in correspondence with results of the general climatic characterisation of this region. Furthermore, experimental investigations of the processes of interception, infiltration, runoff formation, soil moisture storage, snow-cover accumulation and depletion, and transpiration were carried out. Different methods, such as micro-meteorological, soil-physiological, and hydrological, were applied to investigate transpiration. The results of the experiment also provided all input variables and parametres required for the application of a mathematical model. The results obtained by experiments and models provide an insight into the complex and time-varying ecohydrological processes, dependent on the altitude of the investigation site. At higher elevations it is generally seen that, as a



consequence of higher precipitation and lower temperatures, the soil water availability for plants increases. However, the atmospheric evapotranspiration demand is often lowered and therefore the transpiration decreases. But, during different weather situations (e.g., inversions, foehn), reversed correlations were observed. Some other results from the comparison of ecohydrological processes at sites differing in altitude are discussed in detail in the paper.

Hydrological processes are included in the consideration of hydrological problems, then the term ecohydrology is used. Attempts have been made to investigate interrelationships between plant cover and abiotic environmental factors such as temperature, moisture, radiation, precipitation, and wind and soil conditions. These environmental factors also significantly control the water cycle processes. They depend on the regional and local climate and soil conditions. Local climate in mountainous regions is highly dependent on altitude. Consequently, the interrelationship between vegetation cover and hydrological processes in mountain areas is greatly influenced by altitude. Of the moisture and heat fluxes at the atmosphere, soil, and vegetation interfaces, two general processes predominate in their effect on the local hydrology, the transpiration decreasing the moisture input into the soil and transpiration increasing the moisture extraction from the soil. The resulting soil moisture and precipitation reaching the soil surface through the plant cover determine the formation of different runoff components.

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# WATER RESOURCES AND ECOHYDROLOGY OF THE HIMALAYAS: SOME SHARED EXPERIENCE[S]

**R. SAHU**

Centre for Himalayan Studies, University of North Bengal,  
Darjeeling: 734430, India

The changing scenario of ecohydrology and water resources of the Himalaya has caused serious concern for the planners and policy-makers of those countries who share a common interest in the region. In the light of this, the present paper seeks to address some of the important issues at the regional level and, at the same time, explores the possibility of finding out some tangible solutions to harnessing the enormous potential of water resources of the region. In order to achieve this goal, bilateral dialogues between the concerned countries are felt imperative to chalk out a common strategy that will go a long way in judicious utilisation and management of the water resources of the region.

A stable and balanced ecohydrology and judicious water resources' management of the Himalayas will definitely serve the common interests of the countries. There is no doubt about it. This goal can, however, be achieved if the problems are identified and solutions found within the framework of a spirit of regional cooperation in South Asia.

In this context, one can say that SAARC, which is emerging as a common forum to handle issues, has an important role in bringing about perceptible change and development in the entire South Asian Region.

# THE PARTICULARS OF TERRITORIAL DISTRIBUTION AND ANTHROPOGENIC RIVER RUNOFF VARIATIONS FOR THE MOUNTAINOUS AREA OF CENTRAL ASIA

**VENIAMIN SEMYONOV**

World Data Centre All-Russia Research Institute of Hydrometeoroinformation, 6, Korolev St., Obninsk, Kaluga Reg. 249020, Russia

Spatial distribution of runoff values for the rivers of Central Asia depends on elevation and orientation of the locality, and extension of mountain systems.

Time variations of runoff in the second half of the 20th century depend on the relationship between feeders. As for anthropogenic factors, irrigated farming affects runoff most of all. The influence of basins is determined by their size and latitudinal position.

Consideration is given to the particulars and general regularities in the spatial distribution of annual mean, maximal, and minimal runoff over the Altai and Sayan Mountains, Tian Shan, and the Pamirs. It has been established, with the help of complex geographical and hydrological studies, that the distribution of water balance elements and values of the rivers' runoff depend on elevation and orientation of the locality and the extent of the mountain systems. The size orientation and annual mean runoff of similar in basin areas (from 3,000 to 6,000sq.km.) and the mean elevations of basins (2,000-2,500m) are given in Table 1.

Complex statistical calculations of observation data for 100, 60, and 35-year periods suggest that, in the second half of the 20th century, negative variations prevail in the annual mean runoff over Central Asia. But, in rivers substantially fed by glaciers (more than 20%) and in snowmelt- and rainfed rivers in the outlying and northwestern areas of Altai, Sayan, Dzungarian

Ala Tau, the Pamirs, and Alai, positive variations are observed in annual runoff as well as runoff for flood and low-water periods.

In Fig.1, long-term smoothed runoff is shown for glacier- and snowmelt-fed rivers in the mountains of the Central Tian Shan area (r.Bolshoi Naryn) with a negative trend from April to September and positive runoff trends for the peripheral regions of Western Tienshan (r.Maidantal), Western Pamir, and Altai (r.Bartang, Zungar, Pasrut). The differences account for the amount of precipitation and icing.

Among the numerous kinds of domestic activity, the rivers' runoff over the Central Asia mountains is most affected by irrigated farming agriculture. Using the test method for trend, it was established that climate variations and increase of water loss during the irrigation period in the northern Tian Shan, Pamirs, and Altai areas resulted in a decrease in the annual mean runoff for the period from 1951 to 1990, which amounted to 0.04-0.06l/s for 1sq.km. per year. It was particularly great in the upper drift of the mountain rivers where filtration has sharply increased at the cost of irrigation, and a decrease in loss from evaporation and, sometimes, even a rise in runoff can be observed.

Water loss on evaporation from the water storage basin is determined by the size, latitudinal position, elevation, and orography of the place.

For example, the loss from the Chimkurgan reservoir on the Kashkadarya River(southwest of Central Asia) decreased the river runoff by 29%, and the loss from the Krasnoyarsk reservoir on the Yenisei River (north of Central Asia), only by 8%.

The total river runoff loss is so great on the rivers Amu-Darya and Syr-Darya (Fig.2) that it has worsened the ecological conditions of the Aral Sea and Lake Balkhash.

If some trend is detected in the runoff variations of high significance (more than 95% probability), the values of calculated runoff norms should be corrected according to the following formula.

$$q_{i\delta} \approx \bar{q} \pm nq, \quad \delta = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10$$

where

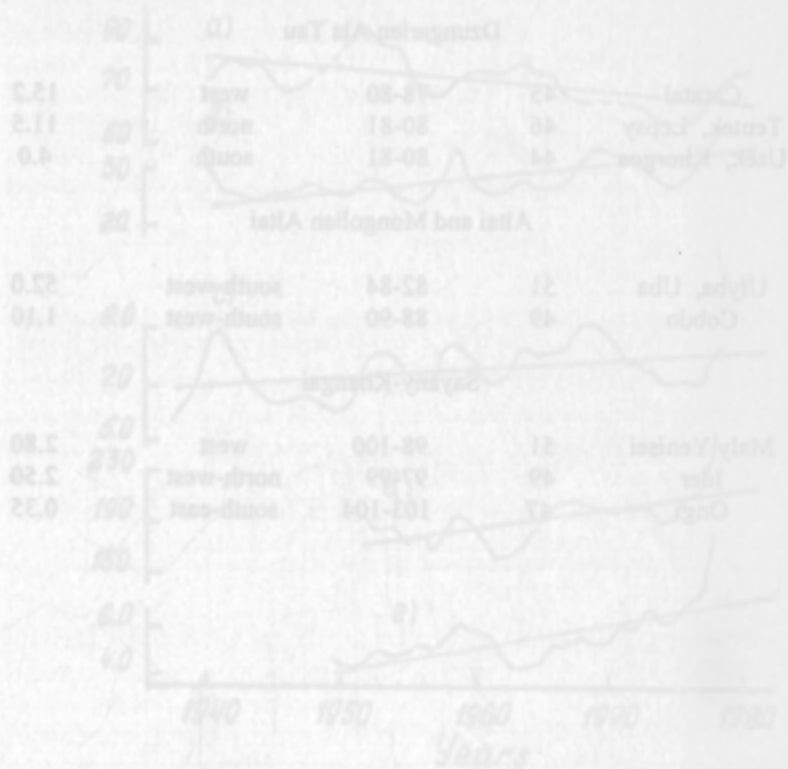
$q_{i\delta}$  = predetermined normal runoff,

$\bar{q}$  = normal runoff, calculated for the previous long-term period,

$n$  = period duration, and

$q$  = magnitude of the normal runoff variation (for a year) under the impact of climatic or anthropogenic factors.

Steady runoff variations and climate variations allow for prognosis of the amount of water resources at the beginning of the 21st century.



- a - r. Bolshoi Naryn - outlet;
- b - r. Maidantal - outlet;
- c - r. Pasrut - Pinnon;
- d - r. Bartang - Jindahang;
- e - r. Jyngar - outlet.

Table 1

| River basin               | Coordinates |         | General orientation | Module of annual mean runoff, l/s for 1 sq. km |
|---------------------------|-------------|---------|---------------------|--|
|                           | N           | W       |                     |  |
| Dzungarien Ala Tau        |             |         |                     |  |
| Caratal                   | 45          | 78-80   | west                | 15.2   |
| Tentek, Lepsy             | 46          | 80-81   | north               | 11.5   |
| Usek, Khorgos             | 44          | 80-81   | south               | 4.0  |
| Altai and Mongolian Altai |             |         |                     |  |
| Ulyba, Uba                | 51          | 82-84   | south-west          | 52.0   |
| Cobdo                     | 49          | 88-90   | south-west          | 1.10   |
| Sayany-Khangai            |             |         |                     |  |
| Maly Yenisei              | 51          | 98-100  | west                | 2.80   |
| Ider                      | 49          | 97-99   | north-west          | 2.50   |
| Ongi                      | 47          | 103-104 | south-east          | 0.35   |

If some trend is detected in the runoff variations of high significance (more than 95% probability), the values of calculated runoff series should be corrected according to the following formula.

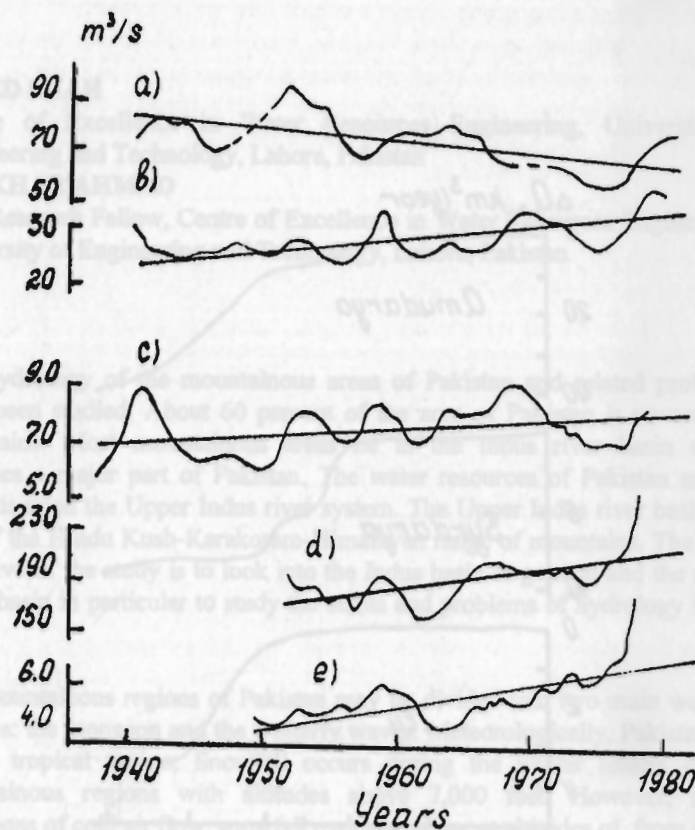
$$q = q_0 + \Delta q$$

where

$q_0$  = predetermined normal runoff,

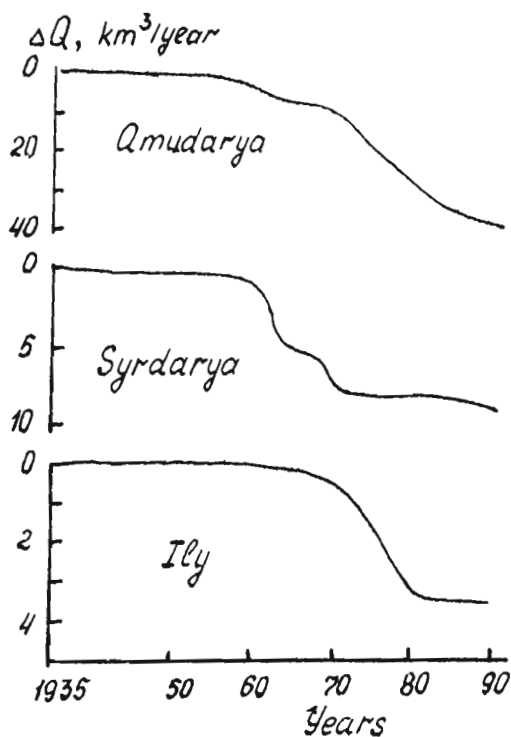
$q$  = normal runoff, calculated for the previous long-term period,

**Figure 1. Smoothed long-term runoff for glacier- and snowmelt-fed rivers for April to September**



- a - r. Bolshoi Naryn - outlet;
- b - r. Maidantal - outlet;
- c - r. Pasrut - Pinnon;
- d - r. Bartang - Jindzhang;
- e - r. Jyngar - outlet.

Figure 2: River runoff variations under the impact of economic activity of human beings





# PRESENT STATUS AND PROBLEMS OF HYDROLOGY OF THE MOUNTAINOUS AREAS OF PAKISTAN

## **SAEED SHAH**

Centre of Excellence in Water Resources Engineering, University of Engineering and Technology, Lahore, Pakistan

## **IFTIKHAR AHMAD**

PhD Research Fellow, Centre of Excellence in Water Resources Engineering, University of Engineering and Technology, Lahore, Pakistan

The hydrology of the mountainous areas of Pakistan and related problems have been studied. About 60 percent of the area of Pakistan is covered by mountains. Most mountainous areas lie in the Indus river basin which occupies a major part of Pakistan. The water resources of Pakistan mainly depends upon the Upper Indus river system. The Upper Indus river basin is a part of the Hindu Kush-Karakoram-Himalayan range of mountains. The main objective of the study is to look into the Indus basin in general and the upper Indus basin in particular to study the status and problems of hydrology in the area.

The mountainous regions of Pakistan may be divided into two main weather systems: the monsoon and the westerly waves. Meteorologically, Pakistan lies in the tropical region. Snowfall occurs during the winter season on all mountainous regions with altitudes above 7,000 feet. However, under conditions of cold air flow, snowfall may also occur at altitudes of from 4,000 to 5,000 feet. Snowfall on the mountains starts towards the end of November, and may continue till March at high altitudes only. However, at altitudes of more than 6,000 feet, snowfall may occur even during the summer months. The glacier cover of the mountainous headwater of the Indus is not more than 5 per cent. For the main streams (above Attock), it amounts to approximately 10 per cent. About 70 to 80 per cent of the annual flow of the Indus river is due to snow and glaciermelt.

The problems of Pakistan's mountainous regions resemble those of other countries in the region to a great extent. They are related to hydrological

disasters, poor accessibility, unfavourable climatic conditions, poor management, financial constraints, lack of technical support, etc. The study discusses these problems and their possible solutions.

The present status of mountain hydrology has been reviewed in detail. Various technical projects currently underway for the development of the area, initiated by different agencies in Pakistan, have been discussed. On the basis of this review, shortcomings and problems of the current projects are indicated and preliminary conclusions are drawn for the solutions to these problems. The study may provide guidelines for future planning and development in the mountainous areas of Pakistan.

# EFFECT OF GLOBAL WARMING ON THE STREAMFLOW OF A HIGH ALTITUDE SPITI RIVER

**PRATAP SINGH**

National Institute of Hydrology, Roorkee (U.P.) 247 667, India

Global warming is likely to change temperature and precipitation, which may affect the quantity and quality of freshwater resources. One of the most important impacts of future climatic changes is expected to be on the regional water availability, particularly the timing of magnitude and surface runoff and soil moisture fluctuations. Existing global models suggest that climatic changes will have dramatic impacts on water resources, leading to major alterations in regional water systems. The vulnerability of the Indian subcontinent to the impact of changing climate is vital because the major impact of climate change in this continent would be on the hydrology, water resources, and agricultural economy. The main river systems of the Indian subcontinent, namely the Brahmaputra, Ganges, and Indus, which originate in the Himalayas, are expected to be more vulnerable to climate change because of the substantial contribution of snow and glacier melt runoff to these river systems.

In the present study, the possible changes in snowmelt runoff, glaciermelt runoff, and annual streamflow due to expected changes in temperature and precipitation have been studied for the Spiti River. It is a high altitude Himalayan river located in the western Himalayan region. The Spiti basin covers an elevation range from about 2,900 to 7,000m and its area is about 10,000km<sup>2</sup>. This basin experiences very heavy snowfall during winter. Hypothetical scenarios of temperature and precipitation, based on the simulation of climate change over the Indian subcontinent by Hamburg, coupled with the Atmosphere-ocean Climate Model were adopted and used in the present study. The Hamburg Climate Model has demonstrated a good simulation for both climatology and hydrology over the Indian subcontinent. The UBC Watershed Model is used to simulate the hydrological response of the basin to changed climatic scenarios.

The study reveals that snowmelt runoff, glaciermelt runoff, and total streamflow vary linearly with increase in temperature. The most prominent effect of increase in temperature has been noticed on glaciermelt runoff. Results related to the influence of precipitation show that snowmelt runoff and total streamflow vary linearly with changes in precipitation, while glaciermelt runoff is inversely related to changes in precipitation. It was also found that snowmelt runoff is more sensitive than glaciermelt runoff to changes in precipitation. In general, the period of snow accumulation, snowmelt, and glaciermelt runoff, and timings of peak runoff are not influenced by changes either in temperature or precipitation for the scenario studied. The effect of various temperature and precipitation scenarios on total streamflow for a period of three years (1987/88, 1988/89 and 1989/90) is given in Fig. 1.

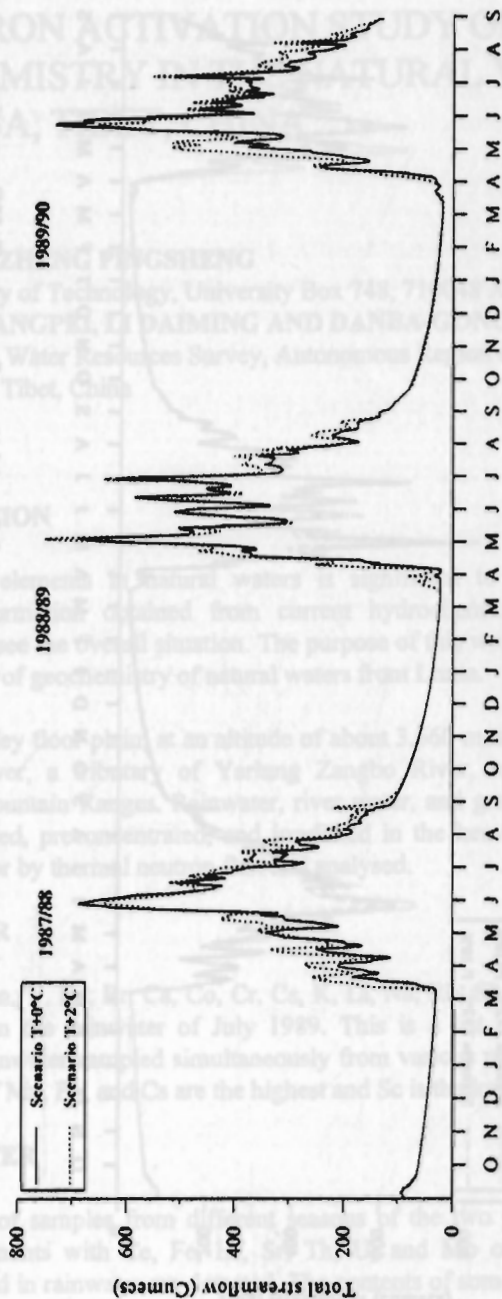


Fig. 1(a) : Effect of increase in temperature on daily total streamflow

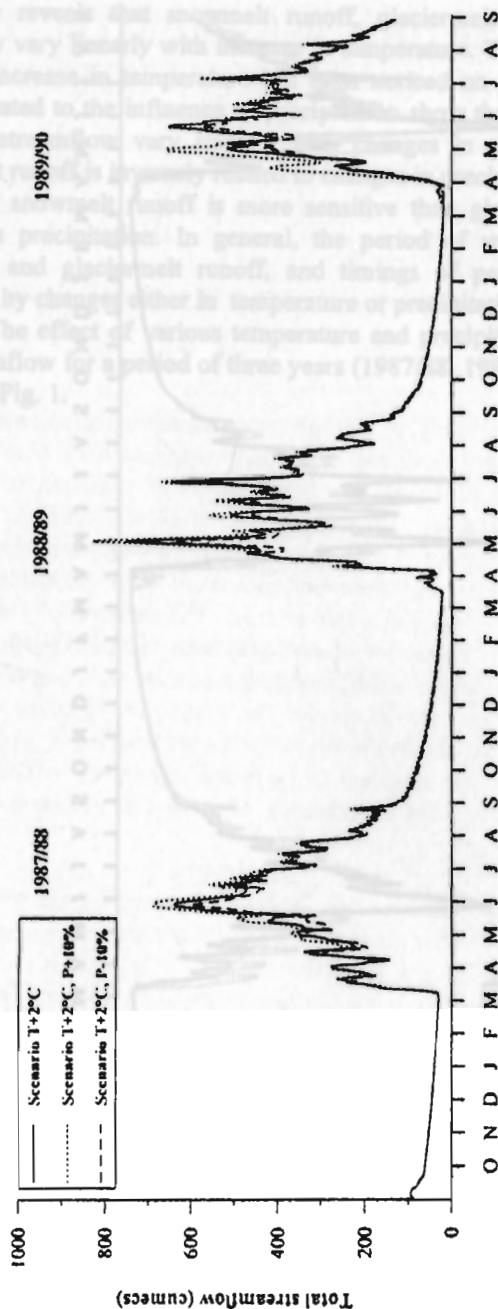


Fig. 1(b) : Effect of changes in precipitation on daily total streamflow over a T+2°C scenario

# **A NEUTRON ACTIVATION STUDY OF THE GEOCHEMISTRY IN THE NATURAL WATERS OF LHASA, TIBET, CHINA**

**GU WEI-ZU, ZHENG PINGSHENG**

Xi'an University of Technology, University Box 748, 710048 Xi'an, China

**TUDENG-XIANGPEI, LI DAIMING AND DANBA-GONGJUE**

Hydrology and Water Resources Survey, Autonomous Region of Tibet,  
850000 Lhasa, Tibet, China

## **INTRODUCTION**

The state of elements in natural waters is significant to ecohydrology. However, information obtained from current hydrochemical analyses is insufficient to see the overall situation. The purpose of this work is to provide an observation of geochemistry of natural waters from Lhasa.

The Lhasa valley floor plain, at an altitude of about 3,660 masl, is situated by the Lhasa River, a tributary of Yarlung Zangbo River, to the north of Himalayan Mountain Ranges. Rainwater, river water, and groundwater were sampled, filtered, preconcentrated, and irradiated in the heavy-water cooled nuclear reactor by thermal neutron flux and analysed.

## **RAINWATER**

Al, Cl, Mg, Mn, V, Ba, Br, Ca, Co, Cr, Cs, K, Li, Na, Rb, Sb, Sc, Sn and Zn are detected in the rainwater of July 1989. This is a list of the elements detected in rainwater sampled simultaneously from various regions of China. The content of Mn, Ba, and Cs are the highest and Sc is the lowest.

## **RIVER WATER**

As the mean of samples from different seasons of the two years 1988 and 1989, 26 elements with Ce, Fe, Hf, Sr, Th, U, and Mo other than those elements found in rainwater are detected. The contents of some elements, e.g., Zn, U, and Cs, have increased significantly in 1989. The annual mean content

of Cs, V, Ce, and Cr is somewhat higher than the mean reported content in world freshwater (Bowen 1979). The content of Cs and Cr is the highest in samples taken from 10 main rivers of China during the same period, which is four to eight times as high as that reported in world freshwater.

## GROUND WATER

It contains all the elements detected in rainwater and river water other than Nd and La. There are 15 elements with concentrations higher than the reported mean value as shown in Fig. 1. The content of rare and rare earth elements are influenced, in general, by the natural abundance in the earth's crust.

## COMPARISON BETWEEN WATERS

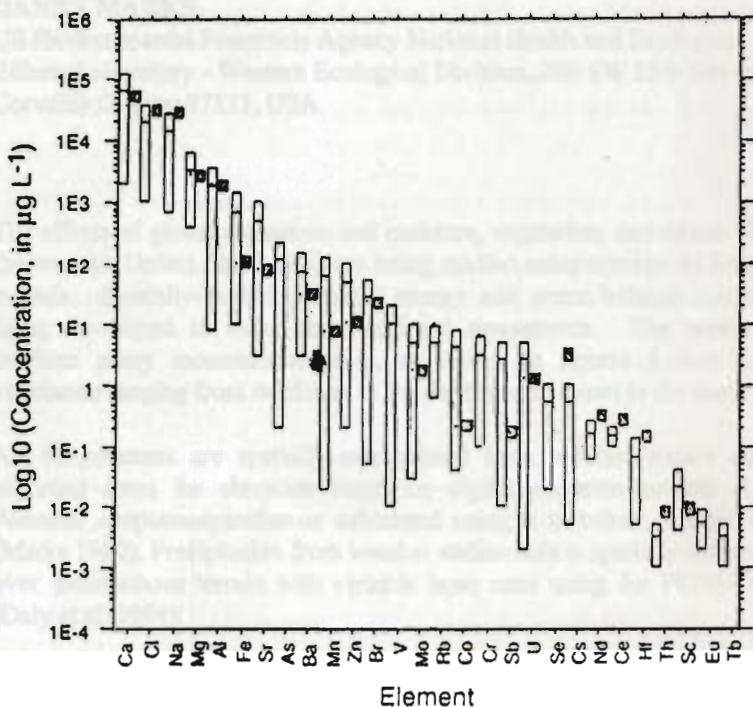
Concentrations of most elements in groundwater are higher than in river water and rainwater, especially of rare earth elements, such as Ce, La, Sc, Sm, etc. However, the content of Zn and Sb in rainwater is the highest. And the highest contents of elements in river water are of Al and Br. The content of various elements in rainwater, river water, and groundwater are compared and graded into eight groups, with concentrations from  $10^4 \mu\text{g/l}$  to  $0.01 \mu\text{g/l}$ .

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**Figure 1. Comparison of the variations of element concentrations determined by neutron activation of shallow groundwater samples in the vicinity of Lhasa (shaded boxes), with the ranges of world freshwater reported by Bowen (1979)**



# REGIONAL SCALE WATER BALANCE MODELLING FOR GLOBAL CHANGE STUDIES IN THE MOUNTAINOUS WESTERN UNITED STATES

**JEFFREY S. KERN**

ManTech Environmental Technology Inc.

**DANNY MARKS**

US Environmental Protection Agency National Health and Ecological  
Effects Laboratory - Western Ecological Division, 200 SW 35th Street,  
Corvallis Oregon 97333, USA

The effects of global change on soil moisture, vegetation, and stream flow in the western United States (US) are being studied using a series of integrated models. Spatially-explicit, coupled energy and water balance models are being developed to make these regional assessments. The western US contains many mountainous areas, as shown in figures 1 and 2, with vegetation ranging from rainforest in the northwest to desert in the south.

Air temperatures are spatially extrapolated from weather station data by adjusting them for elevation based on digital elevation models (DEM). Potential evapotranspiration is calculated using a turbulent transfer model (Marks 1990). Precipitation from weather station data is spatially extrapolated over mountainous terrain with variable lapse rates using the PRISM model (Daly et al. 1994).

The framework for linking soil infiltration and throughflow with subsurface flow is adopted from Wigmosta et al. (1994). Water is routed into two soil layers and a third groundwater/baseflow layer. Lateral subsurface flow in the third layer occurs in response to gravitational gradients and moisture gradients. Timesteps used during model development do not allow the use of detailed approaches such as the Richards' equation which requires many model iterations per minute (Šim\_ek et el. 1994). Even if the computing resources were available, the required input data are not. Simplified approaches to model the soil water balance on a spatial basis are being

developed. Similar to the Richards' equation, the subsurface flow model provides solutions for water flow but it is constrained by field capacity and wilting point. Despite the drawbacks of the concepts of field capacity and wilting point for modeling-specific processes such as solute transport, they are useful for broad-scale modeling with relatively long timesteps. We used the SWMS\_2D model, based on the Richards' equation for saturated and unsaturated flow (Šim nek et al. 1994), to explore the relationship between soil texture and field capacity.

Soil water retention is derived from pedotransfer functions using soil texture and organic matter data. Kern (1995) found that the functions developed by Rawls et al. (1982) were effective for a wide range of soils in the US. Estimates of hydraulics are made in a similar manner. Soil water holding capacity (i.e., the difference in water content between field capacity and wilting point), corrected for rock fragment content and soil depth, is shown in the figure.

Current research is examining ways to spatially characterise soil distribution. Methods are being developed to separate soils into hydrologically-significant groups based on their water storage and hydraulic conductivity. Specifying stream channels is being explored as a way to enhance the subsurface lateral flow routing and may be particularly useful in flat areas where the subsurface flow model tends to fail.

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Figure 1. Digital elevation model and soil-water holding capacity in the 0 to 150cm depth layer for the western United States

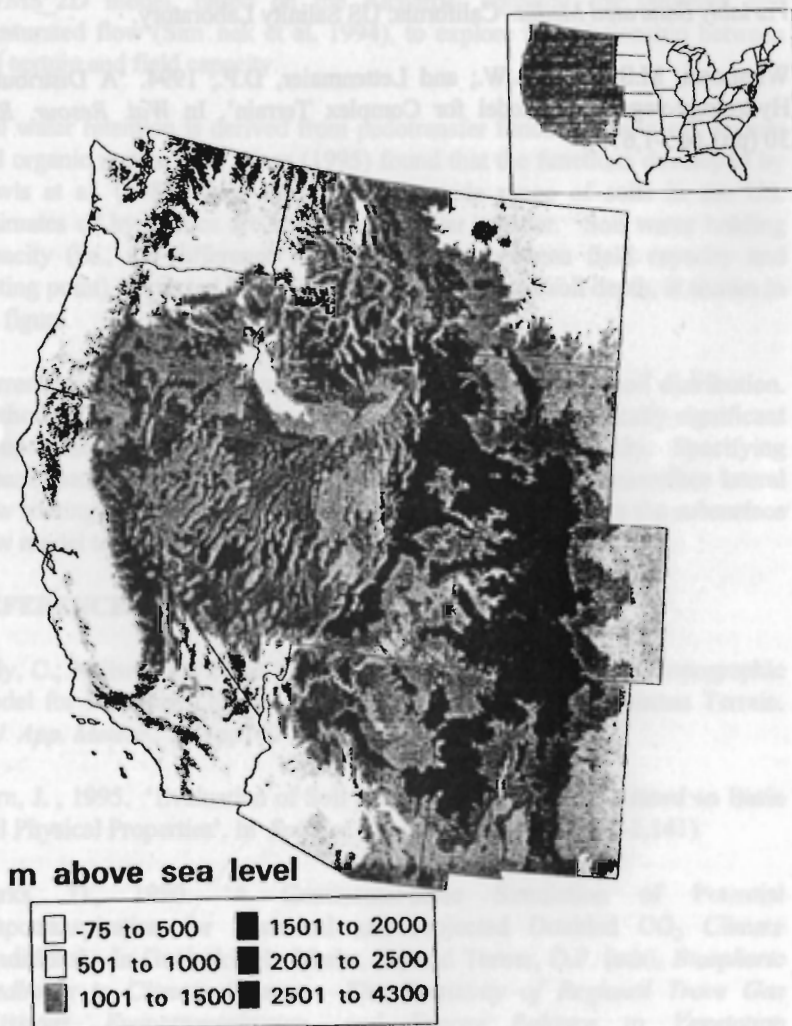
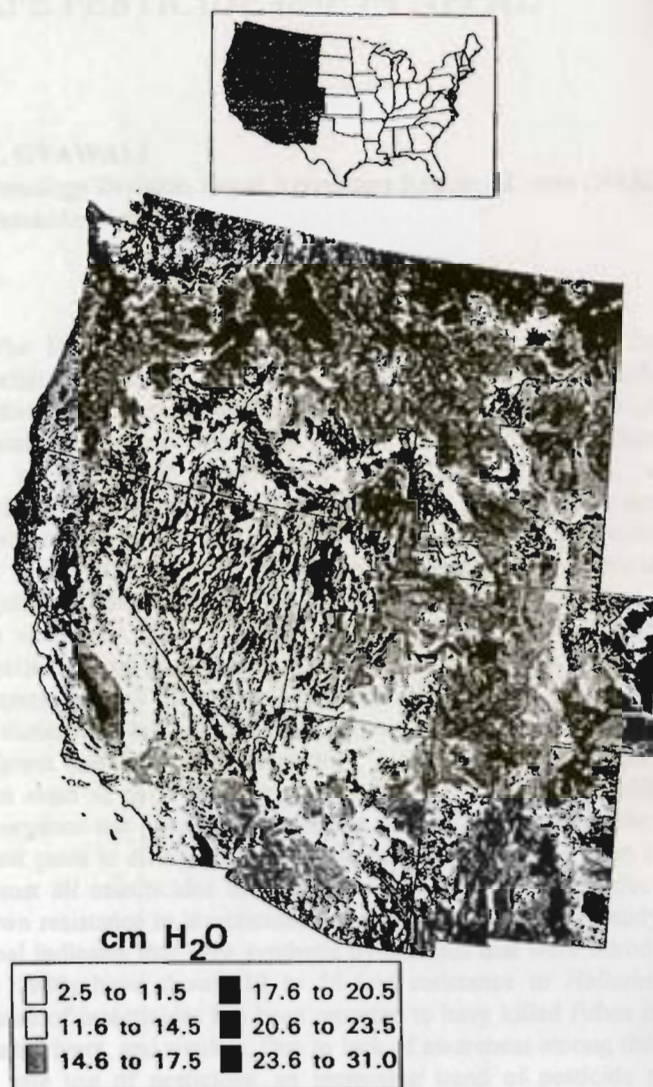


Figure 2. Digital elevation model and soil-water holding capacity in the 0 to 150cm depth layer for the western United States



# AN INTEGRATED PEST MANAGEMENT (IMP) APPROACH AS AN ALTERNATIVE TO SAFE PESTICIDE USE IN NEPAL

**B.K. GYAWALI**

Entomology Division, Nepal Agriculture Research Centre (NARC),  
Kathmandu, Nepal

In the last four decades, Nepal has introduced several categories of insecticides including organo-chlorine, organo-phosphates, carbonates, and synthetic pyrethroids. Most of the insecticides used were broad spectrum causing tremendous damage to human health and environment including soil microbes and water biota. These toxic chemicals, with higher persistence in nature, were chosen for longer period of pest control by the innocent users in the past. Some of these biological toxicants are still in use. The target species were insect pests of agricultural crops in agroecosystems, but, in the food chain, other beneficial natural enemies are also victimised. Besides agriculture, the Ministry of Health has also used insecticides against vectors of Malaria and Kala azar. Insecticides contaminated the major portions of the environment, killing the insects on the surface soil and under the soil and contaminated the water table, forming different metabolites. Consequently, biological magnification was traced from dead animals including fishes from the lakes of Pokhara Valley. Resurgence has already been noticed as overuse of insecticides has caused minor pests to change their status to major pests after a short colonisation. Almost all insecticides used in the past for three consecutive years have shown resistance to insecticides and produced biotypes. A study in western Nepal indicates that even synthetic pyrethroids that were introduced during late 1980s have shown 12 to 56-fold resistance to *Heliothis armigera*. Misuse of insecticides has been reported to have killed fishes in the ponds, canals, rivers, and rivulets. Due to lack of awareness among the users about the safe use of pesticides, an increasing trend of pesticide poisoning is observed in Nepal and there is also an increase in suicides through pesticide ingestion. Integrated pest management (IPM) approach is an alternative to safe pesticides use in Nepal.

# DEVELOPMENT IN A METHODOLOGY OF CLASSIFYING SEDIMENTS IN HIMALAYAN RIVERS

**R.C. JOHNSON AND R.P. COLLINS**

Institute of Hydrology, Wallingford, UK

The sediment loads of Himalayan rivers are among the highest in the world, resulting in national, regional, and local water resource problems, such as the siltation of reservoirs, blockage of river channels, quality of water supplies, transport of chemical pollutants, and the degradation of biological habitats. The major sources of sediments are considered to be glacial debris, landslides, and intensively-cultivated hill slopes, but little is known about the characteristics of the sediments from these sources, the movements into the river system, or their transportation down the rivers. Throughout the Himalayas the relative contributions from these sources, the type of sediments, and their transportation are likely to differ according to geology, topography, climate, and land use. The aim of the project is to develop a methodology for classifying sediments in the Himalayan rivers, including the full range of sources and methods of transportation, providing an essential information source for a future project to quantify the sediment loads of the rivers. Standardised methods of surveying sediments from first order rivers to the piedmont zone are being developed by field sampling and statistical analysis.

In addition, a GIS framework is being developed from two of the study river basins, the Upper Ganges in North West India and the Trisuli in Central Nepal. Comprehensive sets of attribute data, including geology, topography, river networks, land use, and sediment characteristics are being utilised to enable the analysis of the sediment in a spatially distributed manner on a river basin scale. The establishment of this framework will be fundamental in the quantification of both sediment supply from the main sources and the transportable load within the river channel.



# STRIVING TOWARDS ASSESSMENT OF MOUNTAIN WATER RESOURCES

**Z. W. KUNDZEWICZ AND D. KRAEMER**

World Meteorological Organisation, 41 Av. Giuseppe Motta, 1211 Geneva 2, Switzerland

A large portion of the earth's surface is covered by mountains and a larger portion of the global water resources originates from mountainous areas.

There is a consensus on the lack of knowledge of mountain water resources and hydrology of mountainous areas on a global scale. There are a number of reasons for that, such as difficult access to numerous drainage basins, sparse settlements with limited services (electricity, telephone, etc), and the harsh environment, hindering the development of hydrological observations in many mountainous regions. These conditions make it difficult to install and maintain instruments. Often a special, more expensive design of heavy duty instruments is needed which is capable of withstanding the harsh conditions. Field studies of water resources in the mountains are, therefore, far more difficult and demanding than most other hydrological activities.

WMO's Guide to Hydrological Practices (1994) recommends that, because of the heterogeneity of the mountain environment, observation networks in mountain regions should be denser than in most other areas. However, the results of WMO's Basic Hydrological Network Assessment Project (BNAP) show that hydrological networks in mountainous regions are less dense than elsewhere. In addition, the operation of existing networks has been affected by budgetary constraints, and, in some cases, has resulted in the abandonment of hydrological stations, sometimes with long-term series of valuable observations, due to lack of funds.

An additional problem in the assessment of mountain water resources is connected to the boundaries between countries. Many mountainous regions form frontiers between neighbouring countries. Sometimes relations between nations on either side of a mountain frontier may be quite hostile, hence there is no willingness to cooperate. But even if relations between neighbouring

countries are very good, it is not uncommon for the data from two neighbouring countries to be incompatible.

Remote sensing offers considerable potential for studying the hydrology of mountainous areas. Because of difficult access and the expensive operation of hydrological stations, radar or satellite data are particularly appropriate, but, of course, ground-truth data are indispensable in the calibration and verification of data obtained by remote sensing.

Summarising the research and operational needs, one can say that the creation of a systematic data collection network for measuring precipitation in mountainous areas is urgently required. Gathering data on the hydrology of different hillslope types under various precipitation patterns is recommended. Improvement of the hydrological monitoring of streams and rivers within mountains is necessary in addition to the monitoring of the same rivers in the lowlands, which is done with far greater accuracy. Studies of processes are needed with an emphasis on field experiments. It is of paramount importance to try and launch a GIS-supported assessment of freshwater resources in mountain areas and to estimate the contribution of these areas to global water resources. Recommendations on data and information activities in Chapter 13 of the Agenda 21 (1992) devoted to managing fragile ecosystems, and in particular, to sustainable mountain development, read:

*"...governments at the appropriate level, with the support of the relevant international and regional organisations; should ... maintain and establish ... hydrological ... monitoring, analysis and capabilities that would ... encompass ... water distribution of various mountain regions of the world,... build an inventory of different forms of ... water use ... and ... identify hazardous areas that are most vulnerable to erosion, flood, landslides, earthquakes, snow avalanches and other natural hazards".*

Yet the practical results of the implementation of these Agenda 21 recommendations are, to date, nonexistent.

# EVAPORATION OF INTERCEPTED SNOW - MODELLING OF THE AERODYNAMIC RESISTANCE

**ANGELA LUNDBERG**

Division of Water Resources Engineering,  
Luleå University of Technology, Luleå, Sweden

**RICHARD HARDING**

Institute of Hydrology, Wallingford, Oxfordshire, UK

## INTRODUCTION

Several papers during the last decade have emphasised the importance of evaporation of intercepted snow (Calder 1990, Schmidt 1991, Lundberg and Halldin 1994). When a substantial amount of snow is lost by evaporation, studies of the intercepted snow become important, and studies of this type are presented by Calder (1990), Schmidt (1991), and Lundberg and Halldin (1994).

Details of the modelling of aerodynamic resistance during snow conditions and a theoretical basis are presented in the paper. Data were collected intermittently during the winters of 1983-84 and 1984-85 at the experimental site in Queens Forest near Aviemore in the Highland Region of Scotland.

The results show that the maximum evaporation rate determined by the water budget method ( $0.56 \text{ mm h}^{-1}$  during 7 hours) is much higher than the maximum evaporation from a snow pack ( $0.06 \text{ mm h}^{-1}$ ) reported by Harding (1986) but it is in accordance with the rate ( $0.5 \text{ mm/h}$ ) reported by Calder (1990). The average evaporation rate ( $0.24 \text{ mm/h}$ ) is high. A disadvantage of determining evaporation as a residual term from water budget consideration is that the errors in the individual terms have to be added, resulting in a large possible maximum error. The total error estimate for the accumulated evaporation ( $E^{\text{acc}}$ ) for all periods (Table 1) was rather large ( $\geq 0.8 \text{ mm}$ ).

However, the relative error for the three-day period was small (13%) while the relative error for 30th March was large (26%). The agreement between the accumulated evaporation determined by the water budget method and the combination equation using the snow aerodynamic resistance was good for the three-day period (17th-19th March) and it was acceptable for the 28th and the 30th. The combination method and standard rain aerodynamic resistance greatly overestimated the evaporation for four out of five days. The snow aerodynamic resistance, 10 times higher than the rain aerodynamic resistance, simulates the evaporation far better than the rain aerodynamic resistance. Some of the snow at the highest branches may have melted. This may have masked any possible differences between new and old snow and possible differences in aerodynamic resistance as a function of canopy storage. A difficulty with determining the evaporation of intercepted snow using the combination equation is that the required accuracy in the determination of vapour pressure is difficult to achieve. This uncertainty might explain the discrepancy between the water budget method and the combination method. The eddy-correlation technique does not suffer from this weakness and has been successfully tested above both snow and forest. This technique may be suitable for future snow interception evaporation studies according to Lundberg and Halldin (1994). The transition from solid to liquid phase is very important when dealing with evaporation of intercepted snow and no existing method can directly be applied (Lundberg 1993) to measure the intercepted mass and to partition it into liquid and solid phases will require further investigation and will probably result in a combination of methods. The comparison of intercepted snow evaporation calculated by the water budget method and the combination method (Penman) using different aerodynamic resistance showed that evaporation of dry intercepted snow calculated by the combination method provided a much larger aerodynamic resistance ( $\approx 10$  times) than when rain aerodynamic resistance is used. The maximum evaporation rate ( $0.56\text{mm h}^{-1}$ ) was in accordance with the rate ( $0.5\text{mm/h}$ ) reported by Calder (1990). More accurate measurement of air humidity (at temperatures close to and below zero) and a way to separate liquid from solid interception are required to gain better knowledge of the intercepted snow evaporation process.

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Table 1. Estimates of Accumulated Evaporation (mm) with Water Budget Equation and with Combination Equation Using Different Aerodynamic Resistances, March 1985

| Term/Date                      | 17   | 18       | 19       | 17-19          | 28            | 30            | Average        |
|--------------------------------|------|----------|----------|----------------|---------------|---------------|----------------|
| $E_{WB}^{ACC}$                 | 5.0  | 1.3      | 4.5      | $10.8 \pm 1.4$ | $3.9 \pm 0.8$ | $3.1 \pm 0.8$ | 0.24<br>(mm/h) |
| $E_{raS}^{ACC}$                | 3.0  | 3.2      | 3.9      | 10.1           | 2.3           | 1.1           | 0.18<br>(mm/h) |
| $E_{raL}^{ACC}$                | 5.1  | 10.      | 12.      | 27.8           | 7.8           | 1.5           | 0.51<br>(mm/h) |
| $E_{raS}^{ACC} / E_{WB}^{ACC}$ | 0.60 | 2.4<br>6 | 0.8<br>6 | 0.94           | 0.59          | 0.35          |                |

$E_{WB}^{ACC}$  = calculated by the water budget method.

$E_{raS}^{ACC}$  = calculated by the combination equation and aerodynamic resistance for snow conditions.

$E_{raL}^{ACC}$  = calculated by the combination equation and aerodynamic resistance for rain  $r_{aL}$ .

# MEDIUM RANGE PREDICTION OF WINTER PRECIPITATION OVER NORTH-WEST INDIA FROM A GLOBAL CIRCULATION MODEL (T-80)

**NISHA MENDIRATTA, AKHILESH GUPTA, L.S. RATHORE AND J. BAHADUR**

National Centre for Medium Range Weather Forecasting,  
Department of Science and Technology, Mausam Bhavan Complex,  
Lodi Road, New Delhi 110003, India

The winter precipitation over NW India and the Himalayas under the influence of western disturbances (WD) is vital for the replenishment of water resources. Though the monsoon rainfall in the plains of Northern India may be less, they are very significant for *rabi* crops.

A critical evaluation of the performance of the Global Circulation Model, T-80 (L-18), operational at the National Centre for Medium Range Weather Forecasting (NCMRWF), New Delhi, in predicting the occurrence and passage of extra tropical systems in the westerlies over India, is carried out with a view to assess its skill in location-specific Medium Range Weather Forecasting (MRWF) over the region. Typical characteristics of the winter synoptic systems affecting the Indian subcontinent from December 1994 to February 1995 have been examined in detail.

During the winter (Dec-Feb) of 1994-95, there were ten epochs of precipitation over north-west India of which six were of moderate to active intensity. Day-to-day circulation features in the model analysis and 72 hours' forecast and associated precipitation were studied. The performance of the model in terms of prognostication for the beginning of the WD events, trend, pattern, and intensity of precipitation (both qualitatively and quantitatively), over space and time, over NW India were examined.

It has been observed that the model possesses reasonably good ability to predict the movement of the majority of winter disturbances at least three days

in advance. The average root mean square errors of positions of the low-pressure areas and troughs at 850hPa in the analysis and 72 hours' forecast were in the order of 2.0 and 3.4 degrees respectively. Though the distribution and trend of increase and decrease of the precipitation are well captured in the model's forecast, heavy to very heavy amounts of precipitation were generally underpredicted.



# HYDROLOGICAL STUDIES IN A HIMALAYAN CATCHMENT

**K.S. RAMASASTRI**

National Institute of Hydrology, Roorkee 247 667, India

Hydrological studies are carried out in representative basins for the intensive investigation of specific problems. The National Institute of Hydrology (NIH) has been carrying out hydrological studies in selected representative basins in different parts of India. One of the representative basins is located in the Western Himalayas. It is the sub-basin of Baira *nallah* upto Tissa in Himachal Pradesh.

The Baira *nallah* (rivulet) is a small tributary of River Siul which is a tributary of the River Ravi, one of the five rivers of the Indus system. The sub-basin is located about 150kms to the north of the town of Chamba in Himachal Pradesh (Fig.1). The sub-basin is located in the Pir Panjal range of the middle Himalayas and the elevation ranges from 2,450 to 4,500m. The sub-basin has an area of 585km<sup>2</sup> upto Tissa. The average annual precipitation of the sub-basin is 1,150mm. The sub-basin is partly covered by snow in winter (December-March). The natural vegetation is of forest type and the species are a form of pine (locally known as *Deodar*) and fir. Agriculture and horticulture are the main forms of land use.

To date, the following studies and investigations were carried out in the sub-basin.

- (i) Collection of hydrometeorological data, including snow water equivalent and snow depth
- (ii) Geomorphology of the sub-basin
- (iii) Determination of infiltration rates of different soils in the sub-basin
- (iv) Land cover and land-use classification
- (v) Mapping of seasonal snow cover
- (vi) Simulation of snowmelt

Geomorphological parameters were determined using a toposheet on a scale of 1:50,000. Some of the important linear, areal, and relief parameters are given in Table 1.

Table 1. Geomorphological Parameters

|                        |        |                  |                        |
|------------------------|--------|------------------|------------------------|
| Length of main channel | 33.5km | Drainage area    | 585km <sup>2</sup>     |
| Bifurcation ratio      | 4.51   | Drainage density | 2.91km/km <sup>2</sup> |
| Sub-basin eccentricity | 0.83   | Elongation ratio | 1.81                   |
| Basin perimeter        | 113km  | Basin relief     | 3.92km                 |

Data of precipitation and stream flow were not observed in the past. The Institute (NIH) established a hydrometeorological observatory at Tissa (elevation 2,450m) in the year 1992. Besides parameters like rainfall, temperature, humidity, evaporation and windspeed, snow water equivalent and snow depth are also monitored daily. In May 1995, an Automated Weather Station was installed at Tissa for recording the parameters at short intervals.

Point infiltration tests were conducted at 30 selected locations in the catchment using a double-ring infiltrometer. The tests were conducted under five different land-cover conditions. The results are presented in Table 2.

Table 2. Infiltration Rates under different Land-Cover Conditions

| Land Cover   | Final Infiltration<br>Rate cm/hr |
|--------------|----------------------------------|
| Barren       | 1.2 to 2.4                       |
| Grass        | 0.6 to 2.4                       |
| Agriculture  | 1.2 to 3.6                       |
| Forest       | 12.0 to 14.0                     |
| Mixed Forest | 8.4 to 12.5                      |

Mapping of the snow-covered area was done for five seasons, in 1984, 1985, 1989, 1990, and 1992. The satellite data of Landsat MSS and the Indian Remote Sensing satellite IRS 1A LISS 1 were used. The snow-covered area delineated by the analysis is presented in Table 3. Studies on simulation of snowmelt have been initiated and are in the preliminary stages.

Table 3. Snow Covered Area

| Month/Year | Snow Covered<br>Area (SCA) km <sup>2</sup> | SCA as Percentage<br>of Sub-basin Area |
|------------|--|--|
| Feb 1984   | 410.7                                      | 70.2                                   |
| Feb 1985   | 395.8                                      | 67.6                                   |
| Feb 1989   | 329.4                                      | 56.3                                   |
| Mar 1990   | 304.4                                      | 52.0                                   |
| Mar 1992   | 350.0                                      | 59.8                                   |



# HYDROLOGY IN AFGHANISTAN

**M. ISSMAEL SADIQ**

Irrigation Planning Department, Kabul, Afghanistan

## INTRODUCTION

For the development and extension of various aspects such as agriculture, industries, water transportation, and water resources, hydrological data and their collection are basic important factors.

The formulation of hydrological programmes and their implementation alone will not solve the main problems of a country but they have an important role in the prospective development of the country's national economy.

The study of hydrology is important, especially for countries with abundant water resources, and they should make long-term and short-term hydrological study programmes. Such programmes are also very important for Afghanistan where an effective programme was initiated in 1960 (1338). The following topics are considered in this paper.

- Description of the natural geographical situation and location of Afghanistan
- Climatic conditions and precipitation, particularly in the north, south, and southeast
- Main rivers which run through three regions
- Water resources and acceptable reservoir balance
- Utility for agriculture
- General management and development of resources in Afghanistan

The main Hydrology and Regulation of Water Resources Programme includes the following.

- Establishment of hydrological history data of the Hindu Kush

- Description of data from the hydrological stations by rivers in Afghanistan
- Hydrometric information of rivers on the Afghanistan Map
- Hydrometric stations on the Afghanistan Map
- Description of hydrological and hydrometric studies from 1979 (1357) to 1995 (1373)

The paper also includes information on the implementation of the programme for hydrology and on hydrological stations which were destroyed in the civil war of Afghanistan.

# TECHNIQUES FOR MAPPING HYDROMETEOROLOGICAL AND ECOLOGICAL INTERACTIONS AT VARYING SCALES IN THE DRAKENSBERG MOUNTAIN RANGE OF SOUTH AFRICA

**ROLAND SCHULZE**

Department of Agricultural Engineering, University of Natal  
Pietermaritzburg, South Africa

The Drakensberg mountain range in the Province of KwaZulu-Natal, 200km inland from the Indian Ocean and rising from plains at 1,200m through foothills at 1,800m to the high Drakensberg escarpment at 3,000m dividing Lesotho and South Africa, is a major source of runoff in a generally water scarce region. The complexities of physiography, including steep gradients of topography and variations in dominant aspect have produced complex attendant precipitation, radiation, temperature, and ecological and hydrological responses on both meso (1-10km) and local (0.1-1km) spatial scales.

The paper describes various digital elevation-based techniques used to map hydrometeorological and ecological interactions. Three, four, and five dimensional Trend Surface Analysis (TSA) applied to a grid is used to illustrate practical considerations in mapping rainfall in mountainous terrain, including problems associated with the use of higher order polynomials in TSA. Relationships between annual and monthly rainfall are established to map daily rainfall, numbers of raindays, rainfall erosivity, and extreme (design) rainfall amounts. Using data from 16 streamflow gauges, curvilinear rainfall-runoff relationships are established for mapping purposes, showing mean annual runoff generation to range from under 100mm/pa to over 1,000mm/pa within a space of 30km.

On a local scale, a 100m digital elevation model RADSLOPE is used to model topographical controls of the surface energy balance, including incoming solar radiation, temperature, and potential evaporation on sub-daily and daily time

scales. This model is used to explain striking differences in vegetation on north and south aspects at different altitudes, e.g., evergreen forest vs protea savanna on cool and warm slopes respectively at 1,200-1,700m; or macchia type vegetation vs temperate grasslands on cool vs warm aspects at 1,800-2,300m; or more subtle variations of grassland species with aspect.

The paper concludes with some thoughts as to where ecohydrological models should be headed in the future, also addressing the problem of the degree to which spatial disaggregation should take place.

The Drakensberg mountain range in the Province of KwaZulu-Natal, 300km inland from the Indian Ocean and rising from plains at 1,300m through foothills at 1,800m to the high Drakensberg escarpment at 3,500m dividing Lesotho and South Africa, is a major source of runoff in a generally water scarce region. The complexity of topography, including steep gradients of topography and variations in dominant aspect have produced complex climatic precipitation, radiation, temperature, and ecological and hydrological responses on both meso (1-10km) and local (0.1-1km) spatial scales.

The paper describes various digital elevation-based techniques used to map hydro-meteorological and ecological interactions. Three, four, and five dimensional Trend Surface Analysis (TSA) applied to a grid is used to illustrate practical considerations in mapping rainfall in mountainous terrain. Interpolating problems associated with the use of higher order polynomials in TSA. Relationships between annual and monthly rainfall are established to map daily rainfall, numbers of raindays, rainfall intensity, and extreme (design) rainfall amounts. Using data from 16 streamflow gauges, outflow (design) rainfall amounts are established for mapping purposes, showing mean annual runoff generation to range from under 100mm/yr to over 1,000mm/yr within a space of 50km.

On a local scale, a 100m digital elevation model RADSCAPE is used to model topographical controls of the surface energy balance, including incoming solar radiation, temperature, and potential evaporation on sub-daily and daily time



# ERROR SOURCES IN THE ASSESSMENT OF PRECIPITATION ALTITUDE RELATIONSHIPS

**BORIS SEVRUK**

Department of Geography, Swiss Federal Institute of Technology,  
ETH Zurich, Switzerland

It is generally accepted that altitude is the main variable governing the spatial distribution of precipitation in the mountains. The reason, in principle, is decreasing temperature and increasing condensation with altitude. This is the basic assumption on which nearly all regionalisation and mapping techniques of precipitation in the mountains are based. The effects of topography are generally not accounted for explicitly for the simple reason that there are not enough gauge sites to do this properly. Moreover, they are distributed in such a way as to meet the practical requirements of the national meteorological services rather than the scientific ones. The questions in the foreground, by order of importance, include: the general need, availability of an observer, good accessibility, connections, safeguards against avalanches, distance to the next gauge site, altitude zone, climate representativeness, hydrological aspects, etc. As a matter of fact, most gauges are located in the valleys and almost no gauges are available on slopes and near ridges. It is quite clear that such one-sided positioning of precipitation gauges, as practised generally by meteorological services, cannot sufficiently express the complex distribution processes of precipitation in the mountains. In addition to the already sufficiently complex situation pertaining to the assessment of precipitation-altitude relationships, the point-precipitation measurements, using common, elevated and can-type gauges, are subject to systematic error which is not regularly corrected.

In view of state-of-the-art precipitation measurement and network design in the mountains, it is not surprising that precipitation totals can vary considerably in the same altitude zone and the effect of altitude may not be evident at all. This is reflected in many cases by a great scatter in the precipitation-altitude plots or even by decreasing precipitation with

increasing altitude. Consequently, the question arises concerning the accuracy of precipitation maps and water balance computations in the mountains, which are based on such simplified precipitation-altitude relationships. Therefore, there is a need to analyse the error sources. They can be divided into two main groups.

**Group One** dealt with the systematic measurement error, particularly the losses due to wind, wetting, evaporation, and snow blowing, and with the specific problems of precipitation measurement on slopes using gauges with horizontal orifices. Investigations of corrections of systematic error have been made in Switzerland for almost 30 years. This includes field and laboratory tests, wind tunnel experiments, and simulation of wind-induced losses using computational fluid dynamics. Mean monthly corrections were assessed for the 30-year reference period from 1951 to 1980. The correction methods are based on simplified physical concepts (Sevruk 1986). The correction values increase with altitude, from approximately 5 to 25 % of the measured values. At lower altitudes, the wind speed tends to be low as a result of the greater roughness (forests and built-up areas) and the topographic barriers. The small fraction of snow and the substantial wind protection of the stations also have a positive effect. Compared to this, the correction values in the snow-rich and wind-exposed high alpine regions are excessively high. However, snow blowing into the gauge can cause the losses to result in a surplus of more or less the same magnitude. Yet, applying the suitable correction procedures, the systematic measurement error can be partly eliminated. Concerning the precipitation measurement on slopes, it is evident that gauges with orifices parallel to the slopes are better suited. But they are not used. Under extreme conditions, on the steep exposed slopes, the error magnitude during snow storms amounts frequently to up to 80-90 % (Sevruk 1972).

Errors in **Group Two** arise from the insufficient consideration in a given network of both the effects of topography on precipitation distribution, particularly the windward and leeward slopes and redistribution processes of precipitation by wind over the mountainous ridges. These errors are caused by the unsuitable design of gauge networks, particularly a small number of gauges, and the nonrepresentativeness of locations of gauge sites with respect to the topography and geometry of basins. What matters is a suitable network configuration over the entire area of the mountain, including, in sufficient numbers, gauges located on windward and leeward slopes and in valleys in all altitude zones. In this way, it is possible to differentiate precipitation-altitude relationships according to the main

topographic features. Therefore, the transect precipitation measurements along the main mountainous ridges and in valleys, as preferred for practical reasons until the present day, should rather be completed by more important transects across the mountains, including the highest regions, windward and leeward slopes, and ridges. As shown by Sevrük (1989), different values of vertical gradients in seasonal precipitation totals resulted for the three groups of storage gauges located in the valley, on the leeward and the windward slopes in the same small mountainous basin in the Swiss Alps. The greatest gradients were registered for the group of gauges in the valley and the smallest ones for those on the windward slopes. This indicates that the application of gradients on the slopes, based on precipitation measurements in valleys, can result in the overestimation of areal precipitation in the mountains. Additional errors can be caused by the small-scale precipitation variability induced by local topography.

The present report deals with error sources in the estimation of precipitation-altitude relationships in the Swiss Alps. Examples are presented and analysed based on precipitation data from 340 gauge sites, corrected for the systematic error of precipitation measurement. The correction methods used and results obtained are also discussed. The suitability of the gauge site distribution with respect to topography is being checked in large basins using the water budget computations. For this aim, the area-mean values of precipitation were assessed from the precipitation map of Switzerland and related to the mean basin altitude. The vertical gradients in annual area-mean precipitation of basins were compared with the corresponding runoff gradients. In the high alpine regions, precipitation gradients were frequently greater than the runoff gradients. This resulted in unrealistic great basin evaporation values. The reason is the overestimation of area-mean precipitation derived from the precipitation map. The latter is based on precipitation measurements from gauges situated almost exclusively in the valleys where most precipitation is accumulated and does not reflect the real precipitation conditions on the windward and leeward slopes.

The results show that the accuracy of precipitation maps in the mountains depends significantly on the correct assessment of precipitation-altitude relationships. Yet, the one-sided distribution of precipitation gauges and missing corrections for the systematic measurement error appear to be the limiting factor to a better understanding of the spatial distribution of precipitation in most mountainous regions.

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# COMBINED PARAMETERISATION OF OROGRAPHY-INDUCED PRECIPITATION AND RUNOFF FOR REGIONAL HYDROCLIMATIC STUDIES

**ANDREY B. SHMAKIN, ANDREY Y. MIKHAILOV AND SERGEI A. BULANOV**

Institute of Geography, Russian Academy of Sciences,  
Staromonetny St. 29, Moscow 109017, Russia

The processes of land-atmosphere interactions are strongly influenced by the orography from many aspects. The role of orography is suggested by scientific community to be among the most important factors which should be considered in hydroclimatic models and/or calculations.

In studies of energy/water exchange on the land-surface, it is necessary to take into account the spatial scales of orographic features most important for the processes. It is more or less known that the mutual disposition of main mountain ranges (or hill chains) and main valleys of the size of from 10 to nearly 100km results in the spatial distribution of precipitation fields. The runoff formation and secondary reflection/emission of radiation fluxes between relief slopes are mainly influenced by the structure of elementary valleys and water divides of the size of from 100m to 1km. In order to include these processes in hydroclimatic studies, one should:

- 1) have initial natural database containing information about relief features on a given scale; and
- 2) develop special parameterisation schemes describing the results of the processes action according to the external atmospheric/hydrologic conditions and internal land cover properties.

For the regional studies of energy/water exchange in mountainous areas, we used several sources of relief information. One is the ETOPO5 database obtained from UNEP/GRID. It consists of relief heights for the entire globe (including ocean depths) with a spatial resolution of 5x5 minutes, made by

polynomial interpolation from 10x10 minutes of measured data. In spite of some disadvantages (obvious mistakes in separate areas, height values being divisible by some numbers only), this database gives a good general view of the main ranges and depressions disposition which is useful for the calculations of orographic precipitation.

To include the elementary valleys information into the calculations, we propose the conventional relief image on an appropriate scale. It is suggested that the profile perpendicular to a valley consists of a V-form valley and water divide which is flat in general (in a rather dissected area, the divides can be drawn as sharp "hills" without any flat part between two valleys). It is also suggested that a terrain consists of a network of valleys perpendicular to each other. Almost all types of land relief can be presented with such an image. For its numerical characteristics on the given territory, it is enough to know three morphometrical parameters of relief dissection: mean depth of elementary valleys; mean length of elementary valleys per unit square; and mean fraction of the unit profile occupied by the flat water divide. The data set containing these parameters with the spatial resolution 1x1 degree was created specially for this work for the main territory of Eurasia (except for some peninsulas) through analysis of the topographical maps.

To describe the water transport by rivers and secondary replenishment of soil water storage by rivers in the lowlands, we also created two data sets of 1x1 degree resolution: the main runoff directions between grid cells, and the fractions of incoming river runoff which can penetrate the soil in considerable areas of the cells. We also used well-known land cover data and soil data sets (Matthews 1983, Wilson and Henderson-Sellers 1985).

In the parameterisation scheme used for the regional studies (Shmakin et al. 1993), we took into account all main processes typical for the hydrological cycle in mountains: orographic precipitation, runoff formation, evapotranspiration (considering all components of the energy budget), water transport by rivers, replenishment of soil water storage by rivers in the lowlands. They were described in the scheme by considering the key mechanisms for each of the processes (vertical wind speed as a result of relief blowing, influencing the precipitation field; soil water transfer along elementary slopes and formation of contributing areas, resulting in the runoff field, etc). The scheme allows one to reproduce the temporal course of main energy/water budget components for a territory with several contrasting land cover patches connected by rivers. So, the temporal and

spatial changeability of both land-surface features and heat/water fluxes is taken into account, while each patch is suggested to be spatially homogeneous yet (the land cover heterogeneity leading to the appearance of the ordered mesoscale fluxes within the atmospheric boundary layer is planned to be parameterised in future, at least for the territories without high mountains).

In this study, the scheme was realised for several mountainous territories in mean climatic regime. The average climatic values of precipitation, surface air temperature, and cloudiness, with a spatial resolution of  $0.5 \times 0.5$  degrees (Leemans and Cramer 1991), were used as forcing data. The solar and incoming infrared radiation as well as the radiation fluxes between relief slopes were calculated by the methods developed earlier (Krenke et al. 1991, Shmakin and Ananicheva 1991).

The results show that even with such poor forcing data (average climatic regime only, without weather changes within a month) and a rather simple calculation scheme, the main features of water and energy cycles were reproduced quite satisfactorily and some interesting conclusions can be made. The introduction of rather detailed relief data into the calculations by a parameterisation procedure allowed more detailed field of precipitation as well as more appropriate runoff and evapotranspiration values at every grid cell to be obtained. The role of temporal changeability of fluxes was partly played by their spatial inhomogeneity in this case. At the same time, some processes were parameterised too roughly (snow and glacier melting, intensive water penetration into the soil after heavy rains) due to poor temporal resolution. This is planned to be improved in future by the "weather generator" procedure.

Then, it was found that the spatial disposition of strongly dissected and not so dissected terrains can be very important for regional hydrological-climatic interactions. Territories with large relief dissection give much more runoff production due to more active slope water movements and larger fraction being occupied by valleys. Moreover, they are usually associated with rather high mountains where the precipitation is significantly more than on the plain. Nevertheless, the strongly rugged relief itself is not responsible for the enlarged role of the water cycle in the climate system. The mutual influence of hydrologic and climatic processes becomes much more intensive in the regions where rather dissected territories are adjacent to quite flat terrains (for example, the Himalayas and Ganges lowland). In such territories, precipitation is much more heavy if the main air flows are



directed from the lowlands to the mountains, as precipitation intensity is connected with upward wind speed along the slopes rather than with the absolute height of the mountains. Then, the intensive runoff processes in strongly dissected areas give rise to intensive evapotranspiration from the lowlands where a large part of the soil water is brought by rivers from uplands and mountains. The situation is even more interesting in the closed basins (e.g. in the Central Asia), where all precipitation from the mountains flows downstream and evaporates from adjacent lowlands as there is no means of water transport to the ocean there. At the same time, in other regions (for example, Scandinavia), where the intensive precipitation and runoff exist due to high and dissected mountains near the ocean, and there are no wide lowlands between them, one can see heavy precipitation and intensive runoff, too. Nevertheless, this water transfer from air to surface does not influence the climatic system so much because the evapotranspiration does not result from additional water inflow from the mountains.

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(*Vitex negundo* L.) Neem (*Azadirachta indica* A. Juss.)

His Majesty's Government of Nepal has recently passed the Pesticides Act-2048 B.S. (1991) and Pesticide Regulation - 2050 B.S. (1993). The regulation has been made effective since July 16, 1994.

# PESTICIDE USE AND ITS EFFECT ON THE ENVIRONMENT IN NEPAL

**KRISHNA K. SHRESTHA**

Plant Pathology Division, Nepal Agricultural Research Council, Khumaltar, Lalitpur, Nepal

Pesticides in Nepal are generally applied to control or kill well-targeted harmful living organisms, such as insects, organisms causing diseases, weeds on agricultural crops, ectoparasites of livestock, and insect vectors of human diseases, but they are more or less poisonous and hazardous to fresh water, groundwater, lakes, and ponds, threatening human health, and terrestrial as well as aquatic life. Pesticides have also been causing environmental degradation and poverty.

The sale of pesticides in the country through the Agricultural Input Corporation from 1994 to 1995 was about 781MT WP dust and 1,37,314 litres of liquid. Consumption of chemical pesticides in agriculture is increasing, and amounted to 54.3gm/ha in 1989. The import of agriculture-related pesticides in 1989 was worth Rs 42.394 million. In 1994, the estimated amount of DDT and Malathion used by the Ministry of Health was about 100MT and 270MT respectively.

Farmers in Nepal have also started using indigenous plant pesticides for the control of stored grain pests such as *Dampate* (*Thalictrum foliolosum* DC.), *Titepati* (*Artemisa vulgaris* L.), *Asuro* (*Adhatoda vasica* Nees), *Pire* (*Polygonum hydropiper* (L.) Spach), *Bakaino* (*Melia azedarach* L.), *Shimali* (*Vitex negundo* L.) *Neem* (*Azadirachta indica* A. Juss).

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# BIOGEOHYDROLOGICAL DATA AND GIS AS DECISION SUPPORT SYSTEM FOR NATURAL HAZARD MANAGEMENT IN HIMALAYAN WATERSHED

**R.B. SINGH**

Department of Geography, University of Delhi, Delhi-110007, India

The hydrological system as a linking element between mountains and plains is very sensitive to unsustainable and unadapted anthropogenic activities in the highlands as well as lowlands. There is no doubt that the Himalayas have undergone a most dynamic change in land use due to the rapid increase in population. Subsequently, natural hazards cause a great deal of harm and damage every year and they have generally increased over the last decade. The complexity of the problem arose due to declining land-man ratio, nonavailability of additional arable land, compulsion of increasing intensity of land use, and careless application of technology. The occurrence of hazards, such as landslides and other types of mass wasting, are becoming a common feature in the Indian Himalayas. It is very difficult to say that hazards are mainly produced by the natural fragility of the region or biotic degradation and land-use practices which are more significant for the hydrological processes. Thus, there is a need for process understanding by developing multidimensional and integrated biogeohydrological databases at micro-levels in order to understand complex geosphere-biosphere interaction. This includes the identification of key databases, such as geographical, glacial, hydrological, meteorological, geological, biospheric, anthropogenic, land use, and sociocultural. The standardisation and user-friendly format should be an integral part of such databases. The appropriate geoinformatic technology should be applied, providing the latest information about products and systems in the fields of space technology, image processing, GIS, GPS, and expert systems. High-resolution satellite data and low-resolution satellite data for specific purposes should be compiled in a multitemporal database to support local projects.

Ecohydrological studies are required to analyse phenomena, processes, and their interaction throughout space and time. The hydrological information system has to be considered as multidimensional, i.e. it should include attribute dimensions, spatial dimensions, and temporal dimensions. Geographical Information Systems (GIS) offer such capabilities as they integrate multisector, multi-level, and multiperiod databases. The present paper discusses the various components and principles of GIS. Subsequently, GIS can be used as a decision-support system, identifying, integrating monitoring, and predicting natural hazards, i.e. landslides, soil erosion, and floods, which are the major environmental risks. Natural hazards, the result of complex interaction between various natural systems, modify topographic gradients and anthropogenic activities on a spatio-temporal scale. Any change in the physical configuration of a watershed directly affects its environmental sustainability. The combination of type and casual processes is the basic condition for the classification of hazard risks and critical zones in a watershed.

The degree of criticality is determined by the magnitude, frequency, and type of hazard/risk. Most of the risk zones are confined to the slopes with less vegetative cover and densely populated regions. Few of the important particularities are high steep slopes, rapid bioclimatic gradients, local avalanches, lithologically weak structures, population density, irrigated and terrace agriculture, tourism-based economies, and construction activities. Some severe hazards are considered moderate because they occur away from human habitation. Human-induced hazards are prominent around excavation works for construction activities. Construction especially causes erratic runoff making the area locally prone to mass wasting. The paper also suggests that GIS technology should become an integral part of the decision-support system in mountain disaster monitoring and mitigation studies, on the basis of empirical evidence, using the ERDAS system for predicting soil erosion hazards and suitability for various land uses such as agriculture. Similarly, the model and method may be applied for the study of other similar watersheds.

# **CALIBRATING A WATER YIELD MODEL FOR THE DEVELOPMENT OF HYDROLOGIC PARAMETERS OF UNGAGED SMALL WATERSHEDS IN MOUNTAINOUS TERRAIN OF TROPICAL MONSOON REGION**

**SAHID SUSANTO**

Department of Agricultural Engineering, Faculty of Agricultural Technology, Gadjah Mada University, Yogyakarta, Indonesia

## **INTRODUCTION**

In order to ameliorate the environmental degradation in Indonesia, particularly in Java, the Indonesian government has implemented many rehabilitation programmes related to watershed management for conserving water resources, such as reforestation, soil conservation measures, etc, but the rate of degradation still exceeds that of the success of the programmes. An innovative hydrological calculation is still needed for predicting water yields in a simple way.

This report deals with predicting water yields from ungaged watersheds using a water balance approach. A five parameters' water yield model developed by Van Der Beken and Byloos (1977) was used to study water yield from eight small watersheds in the mountainous terrain of the tropical monsoon region, Central Java, Indonesia.

## **THE MODEL**

Rainfall and evapotranspiration are the model's inputs. These inputs are used by a series of equations that relate to the different hydrologic processes, such as infiltration, evapotranspiration, surface runoff, percolation, and groundwater return.

Before this model can predict water yield from a specific watershed, five parameters must be determined. They are:

$a1$  = evapotranspiration ( $a1 \geq 0$ ),  
 $a2$  = base flow ( $0 \leq a2 \leq 1$ ),  
 $a3$  = surface run-off ( $0 \leq a3 \leq 1$ ),  
 $a4$  = percolation rate ( $a4 \geq 0$ ), and  
 $a5$  = channel seepage ( $a5 \leq 0$ ).

These parameters cannot be directly measured for a particular watershed. For gaged watersheds, the optimum values for these parameters are obtained by minimising the sum of the squares of the differences between observed and simulated monthly runoff. Trial and error was used for optimising the parameters. For watersheds with no runoff records, alternate methods for estimating the five model parameters had to be found. In this study an attempt was made to relate the five model parameters to measurable watershed characteristics.

The objective of this study was to develop a reliable method for estimating the five parameters of the water yield model for small ungaged watersheds in the mountainous terrain of the tropical monsoon region. Equations for predicting the parameters were developed on one set of gaged watersheds and tested on a second independent set of ungaged watersheds. This testing gave a reliable check on the accuracy of the prediction.

Other studies on the relationships between the parameters of mathematical hydrological models and the watershed characteristics have been carried out. Five small-gaged watersheds were used for optimising the parameters model in this study. Optimum parameters were regressed on the watershed characteristics. They are the average slope of the watershed (S), gradient of the main river (G), percentage of total area of the watershed to forest area (AF), percentage of total area of the watershed to rice field area (AR), percentage of total area of the watershed to rainfed or upland area (AU), and percentage of total area of the watershed to settlements area (AS). The relationships were tested by comparing observed and simulated runoff records from three watersheds that were not contained in the five calibrated watersheds. Three years of monthly data were used in this study.

## RESULTS

Table 1 shows the characteristics of the watershed studied. The first group of five-gaged watersheds, denoted as calibration watersheds, was used to develop the regression equations for predicting the model's parameters. The

other three ungaged watersheds were retained to be used in testing the calibrated model. The result of the regression analysis was a prediction equation for each of the five model parameters. These equations are as follow.

$$\begin{aligned}
 a1 &= -0.0262 - 0.0194 S - 0.0055 G - 0.0229 AF - 0.0090 AR - 0.1110 AU - 0.0023 AS \\
 a2 &= -0.5637 - 0.3589 S - 0.1852 G - 0.2966 AF - 0.6701 AR - 0.3445 AU - 0.0672 AS \\
 a3 &= +1.4244 - 0.3715 S - 0.3572 G - 1.0807 AF + 0.2723 AR - 1.3867 AU - 0.9663 AS \\
 a4 &= -1.7086 - 0.4100 S + 0.5377 G + 1.7489 AF + 1.7931 AR + 1.7520 AU + 2.0823 AS \\
 a5 &= +0.7666 - 3.1007 S + 5.6446 G + 5.1660 AF + 9.3965 AR + 3.4369 AU + 11.5243 AS
 \end{aligned}$$

Using the equations, a typical result of the model's performance presented by comparing observation and simulated water yield for the Duren watershed is shown in Figure 1. Optimum parameter results together with evaluation of the model on the basis of four statistical measures is presented in Table 2.

## CONCLUSION

Optimum parameters for a five parameter monthly water yield model has been obtained on five small gaged watersheds in the mountainous terrain of the tropical monsoon region, Central Java, Indonesia. These optimum parameters were then regressed on watershed characteristics. Prediction equations were derived for each model parameter. These equation were used to calculate the model parameters for the other three watersheds from the watershed characteristics. By using these calculated parameters, simulations of runoff in these ungaged watersheds were made. Comparisons were made between the simulated and observed runoff. Graphical and statistical indicators were used to identify the accuracy of the model's performance. The method of developing the parameter prediction equations should not be used on watersheds greater than 3,500ha in area.

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**Table 1. Watersheds Studied**

| No | Watershed | A<br>(ha) | S<br>(%) | G<br>(%) | AR<br>(%) | AF<br>(%) | AU<br>(%) | AS<br>(%) |
|----|-----------|-----------|----------|----------|-----------|-----------|-----------|-----------|
| 1. | Duren     | 163       | 24       | 6.3      | 13        | 28        | 37        | 22        |
| 2. | Wader     | 202       | 40       | 19.0     | 17        | 47        | 23        | 13        |
| 3. | Wungu     | 203       | 46       | 18.5     | 27        | 6         | 63        | 4         |
| 4. | Plawatan  | 261       | 24       | 5.0      | 4         | 40        | 46        | 10        |
| 5. | Padas     | 3485      | 34       | 0.6      | 13        | 12        | 59        | 16        |
| 6. | Ngunut I  | 596       | 18       | 3.0      | 21        | 7         | 27        | 27        |
| 7. | Ngunut II | 186       | 9        | 7.0      | 12        | 0         | 46        | 42        |
| 8. | Tapan     | 184       | 41       | 12.2     | 5         | 59        | 30        | 5         |

Notes: A : watershed area; S : average slope of watershed; G : gradient of main river; AF : percentage of total area of the watershed to forest area; AR: percentage of total area of the watershed to rice field area; AJ: percentage of total area of the watershed to rainfed area; AS : percentage of total area of the watershed to settlements area

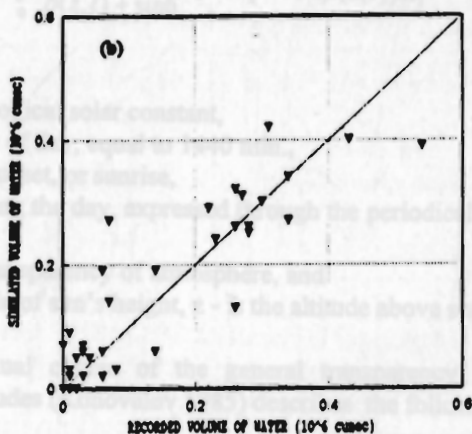
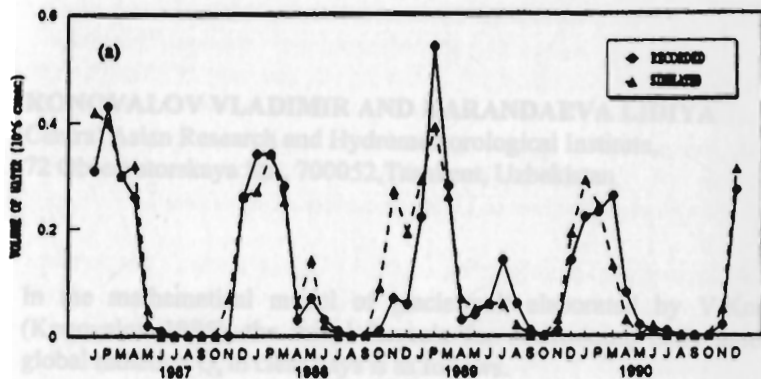
**Table 2. Parameter Values and Statistical Measures for Each Watersheds Studied**

| No | Watershed | a1    | a2    | a3   | a4    | a5 | SR   | CD   | CC   | MB   |
|----|-----------|-------|-------|------|-------|----|------|------|------|------|
| 1. | Duren     | 0.006 | 0.30  | 0.10 | 0.40  | 10 | 0.82 | 0.73 | 0.88 | 0.15 |
| 2. | Wader     | 0.002 | 0.15  | 0.33 | 0.10  | 7  | 0.96 | 0.76 | 0.88 | 0.09 |
| 3. | Wungu     | 0.005 | 0.05  | 0.33 | 0.40  | 6  | 1.78 | 0.64 | 0.83 | 0.06 |
| 4. | Plawatan  | 0.005 | 0.30  | 0.33 | 0.06  | 6  | 1.45 | 0.86 | 0.93 | 0.03 |
| 5. | Padas     | 0.010 | 0.03  | 0.08 | 0.01  | 5  | 3.60 | 0.72 | 0.87 | 0.05 |
| 6. | Ngunut I  | 0.001 | 0.06  | 0.08 | 0.01  | 6  | 0.13 | 0.55 | 0.79 | 0.12 |
| 7. | Ngunut II | 0.001 | 0.08  | 0.01 | 0.90  | 10 | 0.39 | 0.60 | 0.86 | 0.18 |
| 8. | Tapan     | 0.001 | 0.065 | 0.04 | 0.001 | 5  | 0.33 | 0.57 | 0.82 | 0.03 |

Notes: SE : standard error; CD : Coefficient determination; CC : coefficient correlation; MB : mass balance

Fig. 1. Typical results of simulated and recorded runoff at the Duren watershed

(a) Time-series diagram, (b) Scatter diagram



# REGIONAL METHODS OF COMPUTATIONS OF MEAN SUMMER TEMPERATURE AND INTRAANNUAL COURSE OF GLOBAL RADIATION WITHIN CENTRAL ASIA

**KONOVALOV VLADIMIR AND KARANDAEVA LIDIYA**

Central Asian Research and Hydrometeorological Institute,  
72 Observatorskaya Str., 700052, Tashkent, Uzbekistan

In the mathematical model of glacier melt elaborated by V.Kononov (Kononov 1985), the initial formula for determining daily amounts of global radiation  $Q_s$  in clear days is as follows.

$$Q_s = J_s T_1 / \pi * \int_0^{\tau_s} \frac{\sinh z}{\rho(z, t) + \sinh z} [\sinh z + 0.38 \rho(z, t)] dt \quad (1)$$

Where

$J_s$  = meteorological solar constant,

$T_1$  = duration of day, equal to 1440 min.,

$\tau_s$  = time of sunset, or sunrise,

$t_1$  = time during the day, expressed through the periodical function of hour's angle,

$r$  = general transparency of atmosphere, and

$h_s$  = the angle of sun's height,  $z$  - is the altitude above sea level.

The intraannual course of the general transparency of atmosphere at different altitudes (Kononov 1985) describes the following expression.

$$\rho(z, t) = 0.383 - 0.068z + (0.036 + 0.031z - 0.084z^2) * \cos [2\pi(t - 373 + 59.5z - 11.7z^2) / T_2] \quad (2)$$

Here,  $T_2 = 365$  days. Analysis of the formula (2) showed that  $\rho(z, t) > 0$  at 0 5.19km. For practical applications it was accepted that, at  $z > 5.19$  km,  $\rho$  is constant equalled in value to  $z = 5.19$ km.

After some mathematical transformations, it is not difficult to derive analytical formulae for determining the underintegral expression in the right part of (1). Those formulae were used for the calculation of

$$Q_s = Q_s(z, t, j)$$

within Central Asian by means of a special computer's routine. This routine also envisages the calculation of incoming  $Q_s$  on slopes of different inclination and exposition, taking into account the actual conditions of cloudiness. For some points within Central Asia,  $Q_s$  was calculated with measurements of global radiation. The relative deviations between measured and calculated values of  $Q_s$  are presented in the Table 1.

To develop the regional method of calculation of mean summer temperature as a function of altitude  $z$ , latitude  $j$ , longitude  $l$  were used the data of 198 meteorological points, located inside of altitudinal range from 0.3 km till 4.9 km above sea level. Twelve points on glaciers were also included in this set of data.

Ultimately, for the calculation of mean summer air temperature within Central Asian territory the following expression was derived.

$$\Theta_s = 70.56 - 0.517 \cdot 10^{-2} z - 0.407 \cdot 10^{-6} z^2 - 1.102 j + 0.0409 l, \quad (3)$$

where

$\Theta_s$  = summer mean temperature, °C,

$z$  = altitude, masl,

$j$  = latitude, and

$l$  = longitude.

The correlation relationship for (3) equalled 0.98 and the root mean square error was 1.37°C. The calculations' quality according to (3) were estimated by comparing  $\Theta_s$  values derived by the proposed formula, with the same characteristics determined by the well-known method of A. Krenke (1982). These values are presented in the Table 2. As anybody can see, the correspondence between the compared characteristics is rather satisfactory. That permits us to recommend our simple and effective method for wide application.

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Table 1. Relative Deviations (%) between Measured and Calculated Monthly Sums of Global Radiation

| Points           | z<br>kmasl. | I   | II  | III | IV  | V  | VI | VII | VIII | IX | X   | XI  | XII |
|------------------|-------------|-----|-----|-----|-----|----|----|-----|------|----|-----|-----|-----|
| Chardjou         | 0.188       | -10 | -9  | -3  | 0   | 2  | 3  | 6   | 0    | -4 | -13 | -14 | -12 |
| Ashgabat         | 0.227       | -5  | -6  | 1   | 4   | 7  | 9  | 11  | 8    | 5  | -6  | -7  | -3  |
| Termez           | 0.309       | -9  | -6  | 1   | 2   | 6  | 4  | 5   | 3    | -2 | -8  | -11 | -12 |
| Kairak-kum       | 0.347       | -8  | -11 | -3  | 1   | 3  | 7  | 8   | 5    | -1 | -10 | -11 | -9  |
| Tashkent         | 0.478       | -9  | -10 | -3  | 3   | 7  | 5  | 6   | 7    | 0  | -8  | -10 | -9  |
| Fergana          | 0.578       | -1  | -8  | -7  | 4   | 7  | 7  | 8   | 4    | 0  | -7  | -11 | -10 |
| Samarkand        | 0.689       | -5  | -3  | 3   | 7   | 8  | 5  | 9   | 5    | 3  | -6  | -9  | -7  |
| Bishkek          | 0.756       | -12 | -10 | 0   | 3   | 7  | 9  | 8   | 6    | 1  | -10 | -12 | -12 |
| Alma-Aty         | 0.847       | -6  | -5  | 2   | 4   | 7  | 8  | 8   | 7    | 1  | -9  | -9  | -7  |
| Kyzylcha         | 2.076       | -15 | -18 | -8  | -10 | -4 | -3 | -2  | 0    | -3 | -12 | -14 | -15 |
| Big Almaty Lake  | 2.516       | 0   | -11 | -4  | -3  | 1  | 5  | 6   | 6    | 2  | -9  | -11 | -22 |
| Tianshan         | 3.610       | -7  | -6  | -3  | -2  | 1  | 3  | 4   | 1    | -2 | -8  | -12 | -10 |
| Lednik Fedchenko | 4.169       | -5  | -5  | -5  | -2  | -1 | 2  | 4   | 2    | 0  | -8  | 2   | -3  |

Table 2. Comparisons of  $\Theta_s$  Calculations by Formula (3) and Krenke's Method, °C

| Z<br>kmasl | $\varphi$<br>NL | $\lambda$<br>EL | $\Theta_s$<br>by<br>(3) | $\Theta_s$<br>by<br>Krenke | Differen<br>ce, °C | Z<br>kmasl | $\varphi$<br>NL | $\lambda$<br>EL | $\Theta_s$<br>by<br>(3) | $\Theta_s$<br>by<br>Krenke | Differen<br>ce, °C |
|------------|-----------------|-----------------|-------------------------|----------------------------|--------------------|------------|-----------------|-----------------|-------------------------|----------------------------|--------------------|
| 3.96       | 39.0            | 66.8            | 3.6                     | 3.4                        | 0.2                | 3.98       | 38.2            | 65.3            | 4.0                     | 4.1                        | -0.1               |
| 4.04       | 39.1            | 67.3            | 3.3                     | 2.7                        | 0.6                | 3.82       | 38.1            | 64.8            | 4.9                     | 5.5                        | -0.6               |
| 3.89       | 39.3            | 67.3            | 3.9                     | 3.7                        | 0.2                | 3.76       | 38.1            | 64.5            | 5.4                     | 6.0                        | -0.6               |
| 4.10       | 39.1            | 67.9            | 2.8                     | 2.2                        | 0.6                | 3.85       | 37.1            | 67.7            | 5.3                     | 6.3                        | -1.0               |
| 4.10       | 39.2            | 68.8            | 2.6                     | 2.1                        | 0.5                | 3.83       | 37.8            | 65.3            | 5.1                     | 5.8                        | -0.7               |
| 4.10       | 39.9            | 69.6            | 3.1                     | 1.4                        | 1.7                | 3.95       | 37.6            | 65.5            | 4.6                     | 5.0                        | -0.4               |
| 4.26       | 39.5            | 70.4            | 1.9                     | 0.5                        | 1.4                | 3.95       | 37.8            | 65.6            | 4.5                     | 4.8                        | -0.3               |
| 4.36       | 39.6            | 71.1            | 1.1                     | -0.5                       | 1.6                | 3.77       | 38.0            | 66.1            | 5.6                     | 6.1                        | -0.5               |
| 4.29       | 40.1            | 71.8            | 1.4                     | -0.4                       | 1.8                | 3.91       | 38.0            | 67.0            | 4.9                     | 5.0                        | -0.1               |
| 4.35       | 39.9            | 72.3            | 1.3                     | -0.7                       | 2.0                | 3.67       | 38.5            | 68.8            | 6.1                     | 6.5                        | -0.4               |
| 4.05       | 40.4            | 73.6            | 3.0                     | 1.4                        | 1.6                | 3.94       | 38.4            | 67.9            | 4.4                     | 4.3                        | 0.1                |
| 4.15       | 40.7            | 74.3            | 2.0                     | 0.3                        | 1.7                | 3.85       | 38.7            | 68.7            | 5.0                     | 4.8                        | 0.2                |
| 4.09       | 38.9            | 68.8            | 3.1                     | 2.5                        | 0.6                | 3.83       | 38.7            | 69.2            | 5.0                     | 5.0                        | 0.0                |
| 3.98       | 38.3            | 67.6            | 4.2                     | 4.1                        | 0.1                | 4.03       | 39.2            | 70.3            | 3.6                     | 2.8                        | 0.8                |
| 3.97       | 38.0            | 65.6            | 4.1                     | 4.4                        | -0.3               | 4.23       | 39.3            | 70.4            | 2.1                     | 1.0                        | 1.1                |

# PERFORMANCE OF HYDROMETEOROLOGICAL INSTRUMENTS UNDER HARSH ENVIRONMENTAL CONDITIONS IN THE NEPAL HIMALAYAS

**O.R. BAJRACHARYA, K. SHARMA AND T. ADHIKARI**

Department of Hydrology and Meteorology, Babar Mahal, Kathmandu, Nepal  
**W. GRABS.**

Global Runoff Data Centre, Kaisein-Augusta-Anlagen 15-17,  
56068 Koblenz, Germany

Reliable input data are necessary for the Snow and Glacier Hydrology Project (SGHP) of the Department of Hydrology and Meteorology to assess and predict snow and glacier melt runoff.

The paper outlines the rationale for the instrumentation of the six hydrometeorological stations in the Nepal Himalaya and discusses the data recovery rate under the influence of the harsh environmental and human activities.

The paper shows that, in general, conventional and semi-automatic instruments have a better performance record because of a more robust design and easier maintenance under the conditions in Nepal than fully automatic instruments and stations. Automatic stations are reliable and have a high data recovery ratio when observed frequently. However, due to long repair times, the periods of data losses are longer than for comparable conventional equipment.

For the most commonly used instruments of the SGHP, the average data recovery rates are given together with an identification of the reason for data losses. The experiences gained during an eight-year technical cooperation project show that environmental factors such as climate and catastrophic events, together with acts of vandalism, account for the largest proportion of data losses from the instruments.



The paper further discusses countermeasures of the SGHP to minimise data losses by optimised maintenance and calibration schedules and improved spare part supply and reporting routines for instruments.

O.R. BALACHANDRAN, K. SRINIVAS AND T. ADHIKARI  
Department of Hydrology and Meteorology, Indian Meteorological Service, India  
W. GRAIS  
Global Remote Data Centre, Karlsruhe Institute of Technology, Germany

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# ADAPTATION OF A HIGH ALPINE GAUGING STATION (VERNAGTBACH, OETZTAL ALPS/AUSTRIA) TO GREATLY ENHANCED GLACIAL DISCHARGE

**OSKAR REINWARTH AND LUDWIG N. BRAUN**

Commission for Glaciology, Bavarian Academy of Sciences,  
Marstallplatz 8, D-80539 München, Germany

In 1973, the gauging station "Pegelstation Vernagtbach" was constructed at an elevation of 2,640m, draining a basin of 11.44km<sup>2</sup> with a glacierisation of approximately 80%. Discharge has been monitored since then at a temporal resolution of one hour, which allows a detailed analysis of the processes governing the glacial runoff regime. Remarkable glacier mass loss since the mid 1980s has led to increased mean runoff values. Connected with this glacier shrinkage, the extent of the firm region of Vernagtferner has been greatly reduced to less than one tenth of its original size. As a result, temporary storage of meltwater in the firm has greatly diminished, and the diurnal fluctuations of discharge have increased dramatically during the past five years. The measuring capacity of the gauging station, of 10m<sup>3</sup>/s, was repeatedly surpassed by 50% in the summer of 1994, causing damage to the station and the first significant data loss. An adaptation of the gauging station to these altered runoff conditions was attempted in fall 1995, which should have increased the measuring capacity without having to enlarge the cross-sectional area of the measuring channel.

# SOIL MOISTURE MEASUREMENTS WITH AN IMPROVED TIME DOMAIN REFLECTOMETRY SYSTEM (TRIME)

**ROBIN FUNDINGER AND KURT KOEHLER**

IMKO Micromodultechnik GmbH, Im Stöck 2, 76275 Ettlingen, Germany

**MARKUS STACHEDER**

Institute of Applied Geology, University of Karlsruhe, Kaiserstr. 12,  
76128 Karlsruhe, Germany

## INTRODUCTION

Water content measurements are the crux of all hydrological studies. Standard methods such as oven drying, neutron moderation, or gamma reduction, involve a lot of disadvantages, such as being time-consuming, destruction of test sites, and use of hazardous radioactive sources. The relatively new Time Domain Reflectometry (TDR) technique (Topp et al. 1980) avoids these disadvantages and is gaining more and more acceptance.

## METHOD

The determination of volumetric water content is based on the reflection of a high-frequency electromagnetic pulse on metallic rods embedded in the soil, with which the dielectric constant, mainly a function of water content in moist soil, can be determined and a suitable calibration function then yields the water content. But conventional TDR systems developed for electrical engineering to detect cable damages and adopted by soil scientists for water content determination are not very convenient for field application. The expensive, complex, and heavy hardware; high power consumption; and need for graphical waveform interpretation pose several problems.

We have developed a new TDR technique (Stacheder et al. 1994), the "TRIME method", which avoids the need for a high-frequency (HF) pulse generator, a sampling oscilloscope or a cable tester. The use of sophisticated application-specific analog and digital integrated circuits (ASIC), new

waveform-processing hardware, and algorithm allow the production of devices with small dimensions and the construction of probes that are independent of HF-cable length. The measuring time and power consumption are considerably reduced. The new probes can be interlinked by a digital two-wire bus and located along a serial data network up to 3km in length. The measurement values can be logged by a PC or the probes can be connected to a datalogger. For the first time, the use of small rod-probes (0.05 m) to measure water content (<5%) by volume and the construction of a TDR tube probe that allows the measurement of a water content profile in the soil via a glass fiber access tube are possible.

## RESULTS

The new technique was tested with several soils ranging from fine sand to heavy clay (Table 1) and a universal relationship was established. The reference method was the oven-drying technique (at 105°C). The mean absolute accuracy for water content determination was about  $\pm 1.5\%$  by volume, and the new system had a repeatability of  $\pm 0.5\%$  by volume.

The possibility of determining soil bulk electrical conductivity with the new system has also been investigated, which makes TDR an interesting new tool in subsurface solute transport investigations.

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**Table 1** Characteristics of Materials Used for Soil Water Content Determinations

| Material    | Organic material (%) | Clay (< 0.002mm) | Texture (%)         |                 | Bulk density range, g/cm <sup>3</sup> |
|-------------|----------------------|------------------|---------------------|-----------------|---------------------------------------|
|             |                      |                  | Silt (0.002-0.05mm) | Sand (0.05-2mm) |                                       |
| Fine sand   | -                    | -                | 2                   | 98              | 1.4-1.6                               |
| Glass beads | -                    | -                | -                   | 100             | 1.6                                   |
| Bentonite   | 4.7                  | 68               | 27                  | 5               | 0.5-1.3                               |
| Rendoll     | 12.8                 | 6                | 66                  | 28              | 0.7-1.2                               |
| Loess loam  | 4.9                  | 19               | 61                  | 20              | 1.0-1.5                               |
| Kaolin      | 3.4*                 | 38               | 60                  | 2               | 1.0-1.4                               |

\* Loss on ignition determined at 400°C

To simulate and predict snow and glacier melt runoff, an existing conceptual snow and glacier melt runoff model operation with daily time steps has been adapted from Alpine to Himalayan conditions (Lang et al. 1992, Brown et al. 1993, Hottel et al. 1993). A schematic description of its individual model components is shown in Fig. 1. The paper demonstrates some of the major differences between Alpine and Himalayan runoff simulation and prediction and the adjustment of the parameters in the model for its operational use in Nepal.

# ADAPTATION AND CALIBRATION OF A CONCEPTUAL SNOW AND GLACIER MELT RUNOFF MODEL FOR OPERATIONAL PURPOSES IN THE NEPAL HIMALAYA

## **C. HOTTELET**

Wissenschaftlicher Mitarbeiter, Kommission für Glaziologie der Bayerischen,  
Akademie der Wissenschaften, Marstallplatz 8,  
D - 80538 München, Germany

## **L. BRAUN**

Commission for Glaciology, Bavarian Academy of Sciences,  
Marstallplatz 8, D - 80539, München, Germany

## **W. GRABS**

Global Runoff Data Centre, Kaisein-Augusta-Anlagen 15-17,  
56068 Koblentz, Germany

## **O. BAJRACHARYA**

Department of Hydrology, Babar Mahal, Kathmandu, Nepal

For the development of the hydropower potential of Nepal in the context of a distributed power generation scheme, the assessment of the water available for safe energy production is essential for site selection, design, and economic operation of the planned and implemented hydropower schemes. Runoff from the snow and glacier fields of the high Himalayas is hereby the primary source of river runoff in the dry season (Grabs et al. this issue).

To simulate and predict snow and glaciermelt runoff, an existing conceptual snow and glaciermelt runoff model operation with daily time-steps has been adapted from Alpine to Himalayan conditions (Lang et al. 1992, Braun et al. 1993, Hottel et al. 1993). A schematic description of its individual model components is shown in Fig. 1. The paper demonstrates some of the major differences between Alpine and Himalayan runoff simulation and prediction and the adjustment of the parameters in the model for its operational use in Nepal.

Amongst the differences between Alpine and Himalayan conditions are the different treatment of evaporation in the adapted model and the necessary model changes to reproduce the sensitivity of debris-covered glaciers in Nepal versus the mostly blank ice glaciers in the Alps with respect to changes in temperature and runoff generation. The paper discusses methods to adjust the model parameters to different basins, namely the Langtang, Imja, and Modi *Khola*, where the model has been successfully applied (Fig. 1). The threshold temperature between liquid and solid precipitation is discussed together with different temperature gradients experienced during the dry and the monsoon season.

In this regard, it is also necessary to use information from ungauged basins as input in the model to allow runoff simulation under different terrain and environmental conditions; a task which is important but for which the first concepts for Nepal are just emerging.

The model has been further adapted to cope with data losses and allow the necessary correction of precipitation data to represent the basin conditions as a generalisation of the gauge measurements. In the simulation phase, the quality of the model results is checked against precision discharge measurements using fluorescence-tracer techniques (Spreafico and Grabs 1993). The paper also discusses the steps necessary to shift from the simulation mode to the prediction mode.

The model runs on a stand-alone PC-basis where the data is transferred from the database of the Snow and Glacier Hydrology Project (SGHP). The development of the model to a user-friendly tool has required extensive work which is briefly reported in the paper.

While the simulation mode is sufficient for site selection and design of hydropower schemes, the prediction mode requires enhanced near-real time data transmission and improved areal information about the snow coverage for the economic operation of the hydropower scheme and the prediction of general electrical energy.

The paper discusses the operational aspects of the model and use of the model's results for the operation of a run-of-the-river hydropower scheme.

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Figure 1. Schematic overview of the HBV3-ETH snow and glacier melt runoff model

Figure 2. Simulation of discharge of the Modi *Khola* (1987/88), Langtang *Khola* (1989/90) and Imja *Khola* (1989/90) basins





Figure 1. Schematic overview of the HBV3-ETH snow and glacier melt runoff model

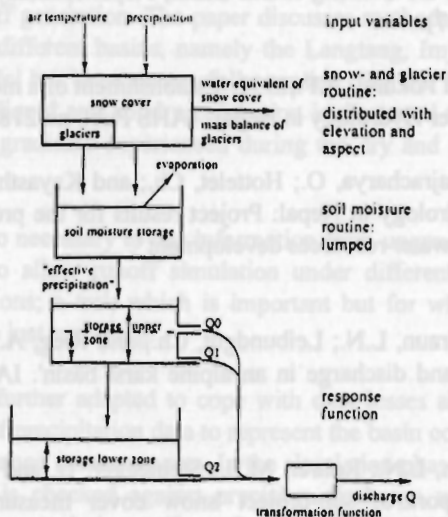
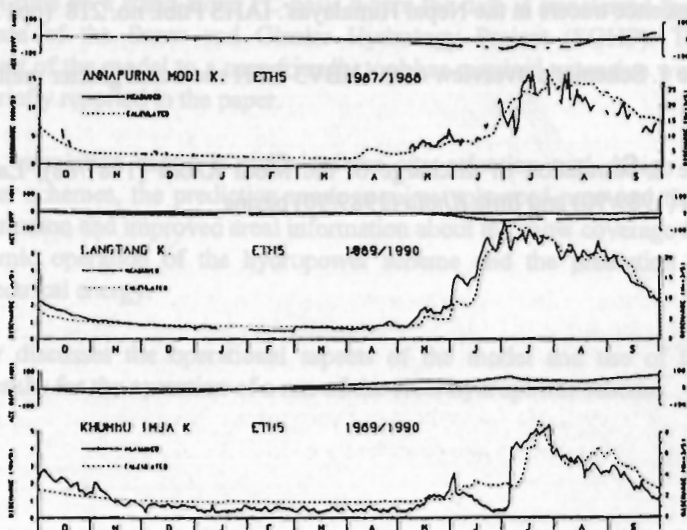


Figure 2. simulation of discharge of the Modi Khola (1987/88), Langtang Khola (1989/90) and Imja Khola (1989/90) basins



# HYDROLOGICAL APPROACH TO ENVIRONMENTAL IMPACT ASSESSMENT IN HIMALAYAN RIVERS: A CASE STUDY OF THE K HIMTI RIVER IN NEPAL

**PRAVIN KARKI**

Butwal Power Company Ltd., Pulchowk, Kathmandu, Nepal

## INTRODUCTION

Water is Nepal's greatest natural resource. In a drive to utilise this resource, the 60MW Khimti Hydropower Project is being constructed. Khimti basin (area 443sq.km.) has a biologically diverse and rich ecosystem, including some endangered species. Construction of any major hydropower projects could significantly affect this special ecosystem. With this in mind, low flow studies were initiated in 1992.

The primary objective of the low flow studies has been to identify the problems which might arise in the Khimti *Khola* following the diversion of water at the proposed intake site and to suggest measures that would mitigate the negative impacts.

The 60MW Khimti Hydropower Project will be of the run-of-the-river type, and a 2m-high diversion weir at the intake site will divert Khimti's water for power generation.

## INVESTIGATION AND RESULTS

Figure 1 shows the mean monthly hydrograph. The flows have a tendency to increase in April and May due to snowmelt and premonsoon rains. In June, the flows increase rapidly with the onset of the monsoon. The design flow of  $10.6\text{m}^3/\text{s}$  is available for only about six months during the monsoon period and this has been taken into consideration when designing the scheme.

Spanning over two years, the field investigations concentrated on low flow hydrology, fisheries, and water users.

It was important to establish a design curve which would give a fair indication of how much water would be available below the proposed intake in a typical dry year and to use this Design Curve as a basis to examine the various environmental impact considerations associated with the diversion of Khimti at the proposed intake site.

The February 1994 field programme offered the best data set of low flows. In February 1994 Khimti was gauged at the proposed intake site. The flow ( $4 \text{ m}^3/\text{s}$ ) was corresponding to a low flow return period of four years in the Low Flow Frequency Curve, similar to the return period of the rainfall recorded at that time.

Though February 1994 was in fact a month drier than average, a design return period had to be selected which would represent a relatively dry year, yet not an extreme. Therefore, a 10 year return period low flow was selected to establish the Design Curve. The February 1994 data were used to derive the Accumulated Flow Curve. The curve is drawn with straight lines between measured points. Figure 2 shows the accumulated flow curve. The curve gives us a clear picture of the accumulated flows resulting from the various tributaries. The February 1994 accumulated flows then had to be adjusted accordingly to produce a 10-year Design Curve.

This design curve gives a basis for analysing different low flow project operation scenarios. We chose two sets of flow scenarios.

Figures 3 and 4 show two low flow scenarios. Scenario No.1 (Fig. 3) shows the negative effect on the downstream water users, especially on fisheries in zones 3 and 4. Flow scenario No.2 (Fig. 4) shows that a compensation release of  $500 \text{ l/s}$  will have less negative effect. Fishes in zones 3 to 5 will have water from the release and the tributary inflow. Mitigation measures include compensation release, monitoring programmes, control of water pollution, and other measures.

Figure 1. Mean Monthly Hydrograph

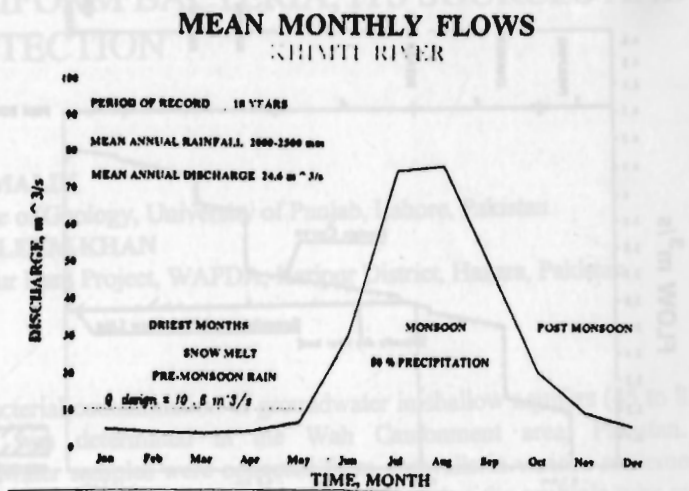


Figure 2. Accumulated Flow Curve

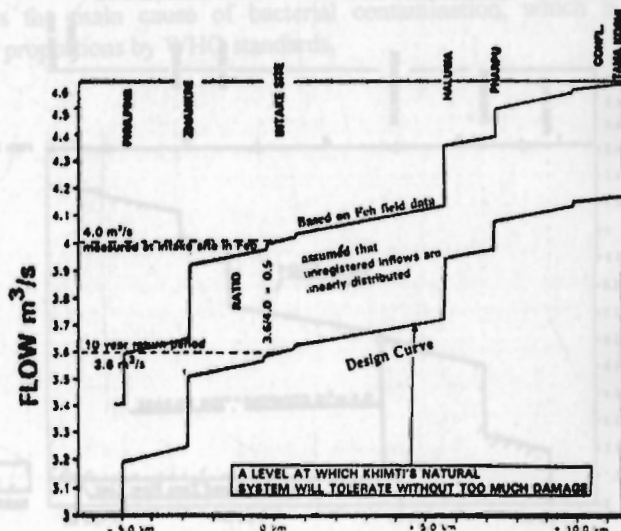


Figure 3. Low Flow Scenario No. 1

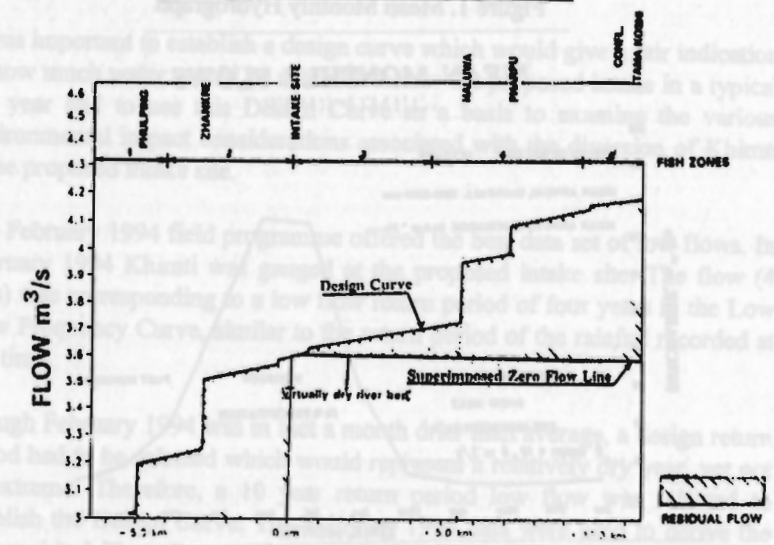
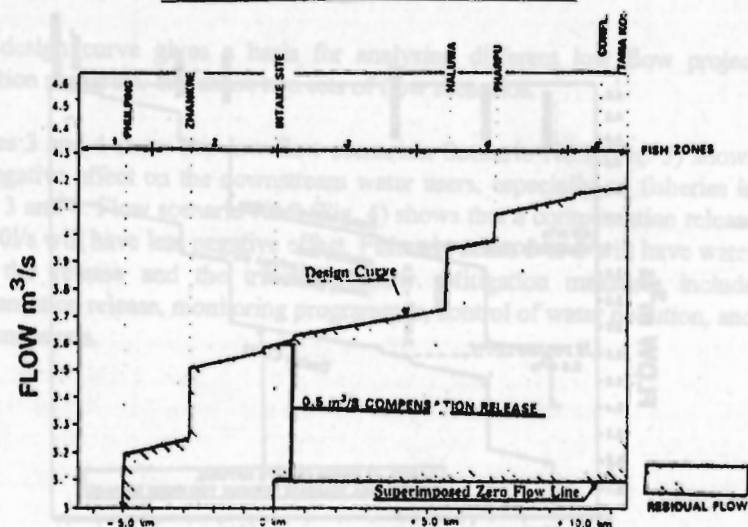


Figure 4. Low Flow Scenario No. 2



# GROUNDWATER POLLUTION DUE TO MIGRATION OF COLIFORM AND FAECAL COLIFORM BACTERIA, ITS SOURCES AND PROTECTION

**M.H. MALIK**

Institute of Geology, University of Punjab, Lahore, Pakistan

**M. SALEEM KHAN**

Khanpur Dam Project, WAPDA, Haripur District, Hazara, Pakistan

The bacterial contamination of groundwater in shallow aquifers (45 to 85 feet depth) was determined in the Wah Cantonment area, Pakistan. The groundwater samples were collected from dugwells in various settlements in private sector. The samples were analysed by using the multiple tube method for estimating coliform and faecal coliform bacteria.

The groundwater of shallow aquifers has been found highly polluted due to bacterial contamination. The disposal of sewage waste through the dugwell system is the main cause of bacterial contamination, which is reaching alarming proportions by WHO standards.

# SHAPE DEPENDANT MANNING ROUGHNESS

**WITOLD G. STRUPCZEWSKI**

Institute of Geophysics, Polish Academy of Sciences,  
Ksiecicia Janusza 64, 01-452 Warsaw, Poland

**ROMUALD SZYMKIEWICZ**

Department of Hydrotechnics, Technical University of Gdansk,  
Majakowskiego 11/12, 80-952 Gdansk, Poland

To get a general assessment of the model's applicability, it is not sufficient to check whether each underlying physical assumption sounds conclusive and has been tested empirically, but it is necessary to confront the model's output for various realistic initial and boundary conditions with our knowledge of the nature of the modelled process. Unfortunately, our understanding of the majority of natural processes may be too poor for such confrontation. The only hope, then, is to make such an assessment by analysing the results obtained by applying the model in different natural conditions. As, usually, there are several factors which may influence the values of the parameters of the model, it is not an easy task to derive them physically if only a passive type of experiment is available. The steady state flow process in an open channel modelled by the Chezy Uniform Flow Formula, with Manning friction, may serve as an example where both active and passive experiments are possible for verification and improvement of the formula. Hydraulic techniques and numerical models used in mountain-river studies are generally unverified for high gradient rivers because they have been developed for lower gradient rivers.

The Chezy model is the element of the majority of 1-D models of processes in a river network. Since unsteady flow friction is assumed to be the same as the friction for steady flow, all 1-D models of flood-routing are based on the Chezy model. Apart from hydrology and hydraulic engineering, there are many other water-related disciplines such as water quality, fluvial geomorphology, and sediment transport, which require an accurate determination of the hydraulic characteristics of rivers, e.g. shear stress, flow resistance, velocity distribution, velocity, and discharge. The longitudinal dispersion of both active and passive pollutants, either conservative or nonconservative, in the flowing aquatic environment of a prismatic channel

under both steady and unsteady flow conditions is described by the 1-D model built on a flow model. There is a need for hydraulic engineers and scientists in related disciplines to apply sound hydraulic methods; hydraulic research during last three decades has been limited. Funding has been diverted to more complex studies on a catchment, regional, or global scale. For a proper orientation of research programmes in hydrology, the present aspiration needs to be put into action with necessary research tools at disposal.

In spite of incorporating theoretical fluid-mechanics for better flow resistance, the Manning formula has not been superseded by a theoretically-based formula developed from modern fluid mechanics. Yen (1989) indicated that the Manning formula's longevity was a mixed blessing. He questioned whether the formula was fundamentally sound and practical or if it merely reflected lack of progress.

Chow (1959) named several factors affecting the variability of the Manning  $n$ , stating that *"there is no evidence about the size and shape of a channel as an important factor affecting the value of  $n$ "*. Here, based exclusively on the analysis of the Manning equation, it will be demonstrated that the Manning  $n$  is dependant on the channel shape and  $n$  varies with flow depth. It will be done by determination of the channel shape above an initial level for given

- (1) depth-discharge curve and
- (2) area-discharge curve.

By solving the inverse problems of the Manning equation it will be shown that neither of two steady flow axioms, i.e.

- (1) increase of flow depth causes increase in flow discharge and
- (2) a widening of a channel increases its flow capacity,

is fulfilled by Manning formula with constant  $n$ .

The idea for this came directly from practice when the senior author tried to apply the Manning formula on deep and narrow channels of Liberian rivers for depth-discharge rating curves estimation with a few measurements only.

The paper is addressed to research and practising hydraulic engineers, mathematical modellers, scientists, and students in water-related disciplines to show them the deficiency of one of the basic research tools. It provides guidelines for a research programme on the shape dependant  $n$ . The computer



# RELATIONSHIP BETWEEN CLIMATE AND VEGETATION IN THE HIGH ATLAS MOUNTAINS OF WESTERN MOROCCO

**MOHAMED ALIFRIQUI**

Laboratoire d'Ecologie Végétale, Faculté des Sciences-Semlalia,  
BP S/15, Marrakech, Maroc

**RICHARD MICHALET, JEAN PAUL PELTIER**

Université Joseph Fourier, Centre de Biologie Alpine,  
BP 53, 38041 Grenoble cedex 9, France

## INTRODUCTION

Le Maroc est très largement soumis à des flux dépressionnaires atlantiques en provenance du nord-ouest qui dépendent de l'activité saisonnière du front polaire. Le Haut Atlas occidental est, et à l'instar de tout le Maroc, une chaîne méditerranéenne, caractérisée par un climat extratropical à sécheresse estivale (Daget, 1984). Le Haut Atlas occidental constitue un véritable carrefour climatique, botanique et géographique, entre une zone franchement méditerranéenne au nord et une zone encore méditerranéenne mais à forte influence tropicale au sud. La répartition de la végétation sur les deux versants du Haut Atlas occidental se trouve ainsi, et en grande partie, dépendante de cette opposition de versant. Les différences d'aridité, essentiellement estivale, des deux versants du massif paraissent être à l'origine d'une coupure chorologique fondamentale que constitue l'axe de la chaîne dans cette région. L'apparition d'une végétation continentale dans les profondes vallées internes abritées constitue le second élément capital de la particularité climatique de cette chaîne.

La présente communication tend à montrer les conséquences biologiques qui découlent de la particularité climatique du Haut Atlas occidental, notamment sur la répartition de la végétation dans les différentes dimensions considérées : altitude, continentalité, exposition aux courants perturbés. Un schéma-modèle synthétique de la relation **climat-végétation** sera présenté. Il se base sur les résultats de plusieurs approches d'investigations climatiques, présentées succinctement ci-dessous avec les traits majeurs du

climat et sa variabilité dans cette marge méridionale de la région méditerranéenne.

## CLIMATE CLASSIFICATION AND CHARACTERISTIC (FIG. 1)

L'originalité du Haut Atlas occidental tiens au fait qu'il est soumis à différents types de courants perturbés (Peyre, 1983; Alifriqui, 1986 ; Delannoy, 1988) :

- sur le versant nord, ce sont les trajectoires à composante nord qui dominent, elles affectent la chaîne en hiver avec la descente du front polaire, et se prolonge pendant tout le printemps.
- sur le versant sud, ce sont les trajectoires à composante sud, qui sont en partie d'origine méridionale, et affectent la chaîne en automne et en hiver.

Dans le Haut Atlas, ce sont les hautes crêtes de la chaîne axiale partout supérieures à 3000 m d'altitude, qui modifient la dynamique verticale aérologique, d'où la dissymétrie de la couverture nuageuse selon les versants. En général, au fur et à mesure que l'on s'éloigne de la source génératrice des courants perturbés, il se crée à cause de l'orographie des secteurs en position d'abri, correspondant à des vallées internes (Alifriqui et *al.*, 1992). Cette caractéristique dynamique de la circulation des masses d'air engendre l'individualisation de domaines climatiques (externe, intermédiaire et interne) au fur et à mesure de la proximité de l'axe de la chaîne.

Ce sont là des particularités climatiques capitales pour la compréhension du fonctionnement climatiques et biologiques des écosystèmes naturelles du Haut Atlas occidental marocain. Par l'observation des types de temps (Peyre, 1983; Alifriqui, 1986), de la distribution saisonnière des précipitations, de l'utilisation des angles de Gams saisonniers (Gams, 1932 ; Izard et *al.*, 1985 ; Michalet, 1991; Alifriqui et *al.*, 1992) et par l'étude spatio-temporelle de la variabilité pluviométrique, on va tenter de mettre en évidence et caractériser les éléments déterminants du climat dans le Haut Atlas occidental marocain.

## VEGETATION (FIG. 2)

Le Haut Atlas est un véritable carrefour botanique où s'affrontent les espèces méditerranéennes atlasiques du nord et les espèces macaronésiennes méridionales du sud. Les principales successions végétales de cette partie du Haut Atlas occidental ont été récemment étudiées (Peltier, 1982 ; Alifriqui, 1986; Jaafar, 1994), en relation avec les différents domaines climatiques et

étages de végétation. Par ailleurs, plusieurs synthèses essentiellement phytosociologiques ont été réalisées (Barbéro *et al.*, 1981, 1982 ; Quézel & Barbéro, 1981). Notre schéma-modèle de la relation climat-végétation est un système à double entrée, intégrant l'ensemble de nos observations et investigations sur les étages et domaines climatiques de montagne (Ozenda, 1975), et les étages de végétation correspondants dans le Haut Atlas occidental marocain. On peut y distinguer quatre catégories végétales, correspondant à des stratégies adaptatives particulières :

- 1- Des communautés végétales de feuillus sclérophylles ou laurifoliées sur les zones frontales bien arrosées ;
- 2- Des communautés végétales de conifères cupressacées, caractéristiques des zones semi-internes ou intermédiaires dans le sens d'une continentalité croissante ;
- 3- Des communautés végétales dominées par des endémiques locales, sans couverture arborée, caractéristiques des vallées internes les plus encaissées et les plus lumineuses ;
- 4- Des espaces franchement asylvatiques sur les hautes altitudes, dominés par des espèces ligneuses en coussinets spécifiques de la haute montagne nord-africaine, et marocaine en particulier.

Ces communautés se repartissent différemment sur les deux versants de la chaîne du Haut Atlas.

La bonne corrélation qui existe entre la limite climatique mise en évidence et la limite chorologique observée dans le Haut Atlas occidental est révélatrice de l'existence d'un seuil bioclimatique essentiel pour la flore de la région étudiée. Les espèces méridionales ont développé des stratégies adaptatives leur permettant de résister à une saison sèche considérable. Sur le versant nord, l'importance des pluies de printemps permet l'installation d'espèces plus exigeantes dominés par l'élément méditerranéen, les endémiques méridionales sont alors éliminées par la concurrence.

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Figure 1. Position of the two transects in the Western High Atlas and orientation of river courses

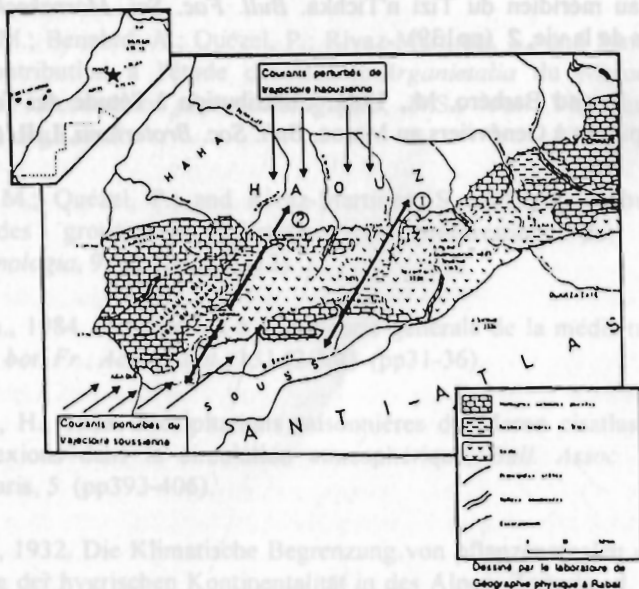
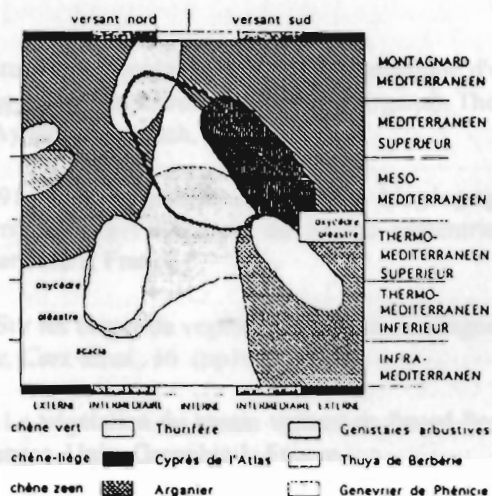


Figure 2. Position of principal species on the low slopes of the Western High Atlas in relation to climatic and vegetative conditions



# LAND-ATMOSPHERE INTERACTIONS IN MOUNTAINOUS REGIONS

**RONI AVISSAR**

Department of Meteorology and Physical Oceanography,  
Rutgers University, Cook Campus, New Brunswick, New Jersey 08903,  
USA

Heat and mass fluxes associated with mesoscale circulations generated by relatively large topographical features and other landscape discontinuities are typically stronger than turbulent fluxes. As a result, they contribute significantly to subgrid-scale fluxes in large-scale atmospheric models (e.g., GCMs), but are omitted in these models. Avissar and Chen (1993) developed a set of prognostic equations for large-scale atmospheric models, which accounts for both turbulent and mesoscale subgrid-scale fluxes. They also developed prognostic equations for these mesoscale fluxes, which present a closure problem, thus implying the need to develop appropriate parameterisations.

For the purpose of developing such a parameterisation, several experiments were conducted.

1. Using the Fourier Amplitude Sensitivity Test (FAST) with a state-of-the-art land-surface scheme for atmospheric models, Collins and Avissar (1994) found that mostly five land-surface characteristics affect the energy fluxes near the ground surface: stomatal conductance, soil surface wetness, surface roughness, leaf area index, and albedo. Li and Avissar (1994) found that under unstable atmospheric conditions the spatial variability (at the canopy scale) of stomatal conductance and leaf area index have the most significant effect on the spatially-integrated energy fluxes from vegetated land. Correspondingly, in bare land, the spatial variability of soil-surface wetness is most important. Under stable atmospheric conditions, the spatial variability of surface roughness seems to have the predominant effect on spatially-integrated fluxes from the ground surface. The spatial variability of albedo has only a small impact

on the energy fluxes from the ground surface, indicating that a mean value can be used confidently in atmospheric models.

2. A Large-Eddy Simulation (LES) model was used to evaluate the impact of landscape heterogeneities created by small topographical features (Avisar and Zeng 1995) and by mosaics of land patches (Avisar and Smith 1995) with different sensible heat fluxes, on the structure of the Atmospheric Planetary Boundary Layer (APBL) and, in particular, on the domain-averaged turbulent heat fluxes. These LESs indicate that as long as the characteristic horizontal length scale of the heterogeneity (i.e., the patch size) is smaller than about 2km, and as long as the topographical feature is smaller than about 200m, the APBL that develops above a heterogeneous domain as well as a homogeneous domain are very similar. Therefore, under such conditions, these results support the approach of the "mosaic of land patches" suggested by Avisar and Pielke (1989) to represent heterogeneous domain in atmospheric models.

3. A state-of-the-art mesoscale atmospheric model (namely the Regional Atmospheric Modeling System [RAMS] developed at Colorado State University) is currently used to study the impact of various topographical features (i.e., different inclinations and orientations, with different vegetation coverage) on mesoscale and turbulent heat fluxes, as well as on clouds and precipitation. Preliminary results indicate that very strong mesoscale circulations can develop as a result of relatively large topographical features, but that unstressed vegetation can significantly reduce these circulations. Clouds and precipitation are affected by the presence of vegetation and vice versa. This investigation complements preliminary experiments summarised by Pielke and Avisar (1990).

Lynn et al. (1995) used the similarity theory to develop a preliminary parameterisation of mesoscale fluxes induced by landscape patchiness. For this purpose, they used the Buckingham Pi Theory, a systematic method for performing dimensional analysis, to derive a set of dimensionless groups, which describes the large-scale atmospheric background conditions, the spatial variability of surface sensible heat flux, and the characteristic structure of the landscape. These dimensionless groups were used to calculate the coefficients of a fourth-order Chebyshev polynomial, which represents the self-similar vertical profiles of dimensionless mesoscale heat fluxes obtained for a broad range of large-scale atmospheric conditions and different landscapes. This parameterisation will be extended to include the impacts of topography, clouds, and precipitation. As a first step towards that



objective, Liu and Avissar (1995) studied the relative importance of the various clouds and precipitation parameters included in the RAMS microphysical scheme, as well as the impact of atmospheric dynamics on this scheme. As expected, this study revealed that the vertical component of the wind, which is very sensitive to the model grid resolution, is the most important dynamical parameter. This implies that only high-resolution models can be used for this type of study, until an appropriate parameterisation is developed.

The various issues related to modelling land-atmosphere interactions in complex terrain (including landscape heterogeneities) and their parameterisation in large-scale atmospheric models have been discussed by Avissar (1995a and 1995b). They will be presented and discussed at the conference, together with recent research progress.

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# SPATIAL DISTRIBUTED MODEL APPROACHES TO HYDROLOGIC PROCESSES AND RIVER FLOW FROM MOUNTAINOUS REGIONS

**A. BALTENSWEILER, J. GURTZ, H. LANG AND J. SCHULLA**  
Geographisches Institut, ETH Zurich, Winterthurestr. 190,  
CH-8057 Zurich, Switzerland

As a result of the pronounced topography, river basins in mountain regions are characterised by strong 3-dimensional variations of all land-surface characteristics (soil type, soil depth, vegetation) and all meteorological elements (air temperature, precipitation, radiation components, vapor pressure, wind velocity). In the assessment of possible impacts of climate variations on the water flow and water resources, a more physically-based model has to be employed, which takes into account these spatial variabilities.

In the development of a corresponding river basin model for the whole alpine/pre-alpine basin of the river Rhine/Rheinfelden (34,000sq.km.) at first the efforts were focussed on the smaller scales of the sub-basins of the Rietholzbach (3sq.km.) and of the Thur/Andelfingen (1,703sq.km.). These basins are located in the northeastern part of the Swiss part of the Rhine basin and have an elevation ranging from 400m to 2,500masl. A considerable part of the Thur basin is high mountain area, some of it above the tree line, and a greater part of the basin has a distinct snow cover during the winter season.

In the hydrologic distributed modelling, the digital terrain model (DTM) and land-use information as given by a GIS were consequently introduced in two approaches: a) a grid-oriented approach; and b) an approach based on the principle of hydrologic subareas (hydrotopes) with the assumption of similar hydrologic behaviour within the hydrotopes. For the spatial interpolation of the meteorological input variables, various methods were employed. The structure of the model components for snow accumulation and melt, interception, soil water, storage and uptake, evapotranspiration,

runoff generation, and flow routing is described, including a discussion on the assessment of the various parameters with respect to their time dependency.

The results for each of the hydrologic components are discussed with respect to the different subareas and altitudinal zones. Finally, some general conclusions and an outlook on the further endeavours in hydrologic modelling in mountain areas are presented.

# RAINFALL-RUNOFF DATA AND MODELLING IN THE LIKHU KHOLA CATCHMENT, NEPAL

**DAVID BOORMAN, ALAN JENKINS AND ROBERT COLLINS**

Institute of Hydrology, Wallingford, Oxon, UK

Population growth in the Himalaya region has led to increasing demand for food which has been met by increasing use of fertilisers and expansion of agricultural land. These changes modify the quality and quantity of river flows downstream from the affected areas and therefore have a regional as well as local impact. To investigate such changes requires good quality hydrological data on the appropriate spatial scale and temporal resolution. To enable such a study, flow and rainfall, volume and quality, together with other meteorological data, have been collected from five subcatchments of the Likhu *Khola* in the Middle Hills of Nepal. This paper describes the rainfall and runoff data collected from these sites, analyses of this data, and results from a rainfall-runoff model used to simulate catchment response.

Data were collected at seven sites, listed in Table 1, between 1991 and 1994. Five of these are flow-sites where the stage and rainfall (along with other parameters) were recorded at 30-minute intervals; for these sites, a simple land-use classification of the catchment area is also shown in Table 1. At both other sites, an automatic weather station (AWS) was installed to record rainfall and other meteorological data on an hourly basis. Because not all gauges were installed at the start of the project, and there were a number of technical and operational problems leading to loss of data, the data sets are by no means yet complete.

The annual rainfall at the AWS sites for the very nearly complete year starting in October 1992 was just over 2,000mm, of which over 90% fell in the wet season between 1st April and 30th November. Note that this "wet season" corresponds to both the monsoon and premonsoon periods, and this term will be used throughout this paper to refer to this period. At the nearby, but higher, Kakani Long-term Meteorological Station, the long-term

average rainfall is greater, 2,804mm for the period from 1962 to 1991, but it has an almost identical seasonal pattern.

Of the study sites the Chinniya, which is the highest site and on a north-facing hillside, has the greatest rainfall, roughly 25% more on an average than on the sites in the valley bottom. The Gerogaon site, also on the north-facing slope, receives an average of about 10% more than the other lower sites. Therefore, tentative conclusions are that rainfall increases with altitude and is greatest on the north-facing side of the valley. The latter is expected as most storms arrive at the catchment from the south or southeast. However, on other sites in Nepal, a more complex relationship of rainfall with altitude is reported.

An analysis of the rainfall data on an hourly basis shows that the sites are very similar. The following are some examples.

- i. The diurnal variation of rainfall shows that rainfall is least likely between 08.00 and 12.00, and most likely between midnight and 04.00.
- ii. Average storm durations are between six and eight hours, but frequently contain short periods with no rainfall.
- iii. Average intervals between storms are either less than two days or greater than four days.
- iv. Storms usually cause rainfall at all sites, although rainfall totals can vary greatly between sites.
- v. Most rainfall occurs in low-intensity bursts, e.g. at Jogi, 80% of the rainfall occurred in bursts of less than 10mm and only 5% in bursts of 40mm or more.
- vi. Within storms, there were very high-intensity bursts of short duration, the maximum being a rate of over 2mm/minute.

To derive flows from the stage records requires a stage-discharge relationship for each site. None of the sites had a formal structure and therefore these relationships had to be developed from spot gaugings. These were obtained by dilution gauging, which was ideally suited to the turbulent (well-mixed) conditions in the stream. Unfortunately, not enough high-flow gaugings were made to produce reliable stage-discharge relationships for all sites; the best was for the Bore *Khola*, with 27 gaugings.

Two features of the flow data are common to all catchments. Firstly, flows outside the wet season are very low and even fairly intense rainfall at this

time causes little or no increase in flow. Secondly, during the wet season, flows are maintained at higher levels and there is a very rapid but short-lived response to all rainfall events. Clearly, at the onset of the wet season, most of the rainfall is stored by the catchment and rain falling later is on a (partially) saturated catchment and runs off quickly.

While some general conclusions can be drawn from separate analyses of these data (i.e., flow, rainfall, and potential evaporation [PE]), it is far more revealing to examine them together within the framework of a rainfall-runoff model. The disadvantage of such an approach is that it requires all three data types to be available for the same period. For three of the catchments (Bore, Chinniya, and Bhandare) the period from 3<sup>rd</sup> March 1992 to 9<sup>th</sup> October 1993 is fairly complete and has been used to help fit a rainfall-runoff model. This modelling exercise has been carried out using daily data.

The model chosen was based on the probability distributed storage principle in which the soils of a catchment are represented by a continuous set of stores with capacities ranging up to a maximum value  $S_{max}$ . Between time steps, water redistributes between stores to maintain a constant volume of water across all stores. The model has been applied successfully to data from the UK in a number of studies.

In applying the model to the catchments it became clear that there were substantial losses from the catchments. On the Chinniya catchment for example, rainfall was 4,970mm compared to the total flow of 1,746mm and potential evaporation of 1,694mm, so that even if the potential evaporation was fully satisfied, 1,530mm (30%) rainfall was "lost" from the catchment. As actual evaporation is less than the potential rate, the true losses will be even greater. While within the Bore and Bhandare catchments this loss could be through irrigation diversions onto flooded terraces, the Chinniya is a natural catchment with no such diversion and the loss is most likely through groundwater leakage. This loss was represented in the model by a drain from the groundwater component of the model. The PE, rainfall, and observed and simulated flow for the Chinniya catchment are shown in fig. 1; the simulation successfully reproduces the different patterns of observed flows during the two wet seasons.

The same model can be applied to the other two catchments with the adjustment of only one parameter, the maximum soil depth  $S_{max}$ . The values of  $S_{max}$  are 314mm, 560mm, and 438mm for the Chinniya, Bore,

and Bhandare catchments respectively. The lower value for the Chinniya is physically realistic since it is located on thinner soils at higher elevations than the other catchments.

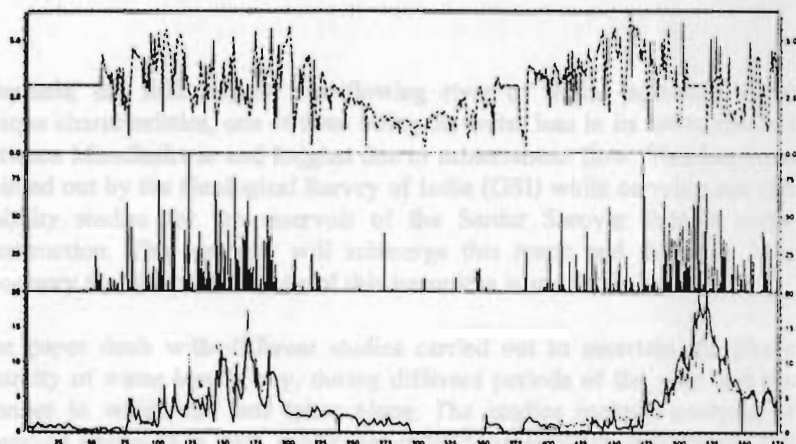
It is interesting to note that simulations on the other two catchments show some underestimation of the flows for a period of some two months at the end of the wet season. A possible explanation for this is that some of the "lost" water is in fact stored on the catchment in the flooded terraces and is only returned slowly to the river channel.

Table 1. Characteristics of the Study Sites

| Name<br>(flow sites only) | Type | Altitude<br>(m) | Aspect<br>(facing) | Catchment Characteristics  |          |            |       |
|---------------------------|------|-----------------|--------------------|----------------------------|----------|------------|-------|
|                           |      |                 |                    | Area<br>(km <sup>2</sup> ) | Land Use |            |       |
|                           |      |                 |                    |                            | Forest   | Cultivated | Grass |
| Baseri                    | AWS  | 700             | S                  |                            |          |            |       |
| Bhandare                  | Flow | 700             | N                  | 1.43                       | 9%       | 90%        | 1%    |
| Bore                      | Flow | 700             | N                  | 4.23                       | 60%      | 39%        | 1%    |
| Chinniya                  | Flow | 1300            | N                  | 1.14                       | 83%      | 17%        | 0%    |
| Dee                       | Flow | 800             | S                  | 2.64                       | 15%      | 59%        | 26%   |
| Gerogoan                  | AWS  | 800             | N                  |                            |          |            |       |
| Jogi                      | Flow | 700             | N                  | 2.35                       | 2%       | 96%        | 2%    |



Figure 1. PE (top), rainfall (centre), observed and simulated flows (bottom, solid and dotted lines respectively) for the Chinniya *Khola* for the 575-day period from 3rd March 1992. The abscissa scale is in days, ordinate scales all in mm.



# WATER LOSS STUDIES IN MANDLESHWAR-RAJGHAT REACH OF NARMADA BASIN

**S.A. CHAR, R.S. VARADARAJAN AND N.K. BHANDARI**

Narmada Control Authority, Indore, India

Narmada, the fifth largest west-flowing river of India, possesses some unique characteristics, one of them being the water loss in its lower reaches between Mandleshwar and Rajghat due to subterranean flow. This has been pointed out by the Geological Survey of India (GSI) while carrying out rim stability studies for the reservoir of the Sardar Sarovar Project under construction. The reservoir will submerge this reach and therefore it is necessary that the phenomenon of this water loss is studied in detail.

The paper deals with different studies carried out to ascertain the likely quantity of water loss, if any, during different periods of the year and the manner in which the loss takes place. The studies include analysis of observed stream flow data, simultaneous field measurement at upstream and downstream locations, hydrological studies, and tracer studies. A brief description of these studies is given below.

The recorded flow data of Central Water Commission of the Narmada river at Rajghat site from 1972-90 and for Mandleshwar site from 1971-92 were analysed on a monthly and yearly basis to ascertain whether there was any water loss.

Field measurements for estimating water loss were carried out for two different seasons, i.e. pre-monsoon and post-monsoon, for two reaches, one between Mandleshwar and Jalkoti and the other between Bhogaon and Ghatwara Dharampuri. Studies were carried out between 4<sup>th</sup> to 6<sup>th</sup> June 1993 and 6<sup>th</sup> to 15<sup>th</sup> February 1994.

Hydrogeological studies were carried out at selected locations of the Dharampuri and Talkoti sites, to identify geologically-weak features responsible for the water loss, if any.

The Tracer studies were undertaken at the Dharampuri site to estimate water loss, if any, from the river bed or banks, through the rim of the reservoir. The studies were divided into three groups: (1) water level measurement in the existing dugwells on the river banks; (2) river channel and borehole water-level measurements in the river bed; and (3) nuclear logging of boreholes in the river beds.

From the studies carried out, it was found that the quantity of water loss appeared to be confined to the basin and not out of the basin. However, further studies are being carried out for final confirmation.

# STREAMWATER ACIDIFICATION IN RESPONSE TO ANTHROPOGENIC POLLUTION INPUTS AT FORESTED AND CULTIVATED CATCHMENTS IN THE MIDDLE HILLS, NEPAL

**ROBERT COLLINS, ALAN JENKINS AND DAVID BOORMAN**

Institute of Hydrology, Wallingford, Oxon, UK

**PAUL WHITEHEAD**

Department of Geography, University of Reading, UK

The sustainable use of land, water, and agricultural resources is an essential component in the future development of Asian third-world countries, and especially those regions bordering the Himalayas where the rapid population growth is predicted to continue. This population pressure results in an intensification of agriculture through multiple annual crop rotations, supported by large applications of inorganic and organic fertilisers and the expansion of cultivated land to steeper hill slopes and previously forested areas. Continued and excessive application of mineral and organic fertilisers in order to increase crop yields may, however, result in detrimental effects in the form of soil and water acidification as well as potential downstream eutrophication. The problem may be exacerbated by the deposition of acidic oxides from fossil fuel burning; and it is predicted that the rapid industrialisation of many Asian countries will increase air polluting emissions in the future.

The Land Use, Soil Conservation and Water Resource Management Project was established in 1991 by the Institute of Hydrology, UK; the Royal Geographical Society, and the Department of Soil Science, His Majesty's Government of Nepal. The study focussed on the Likhu *Khola* watershed in the middle hills of Nepal. One aim was to quantify the impact of anthropogenic pollution on stream chemistry. The watershed is located approximately 10km north of Kathmandu and industrial emissions emanating from Kathmandu Valley cause acidic deposition. In addition, terraced agricultural land throughout the watershed is treated with

substantial applications of both mineral and organic fertilisers. Urea and ammonium sulphate are the main forms of mineral N fertiliser used, with c.140 - 200kg ha<sup>-1</sup> applied to each rice crop with normally two crops per year. Additionally, six to eight tonnes per year of farmyard manure are applied to the rainfed terraces.

Stream chemistry samples were taken at high frequency over a period of five days during storms in the monsoon season of 1992. The stream chemistry response to rainfall in a north-facing subcatchment comprised of c. 50% terraced agriculture and 50% second generation, mixed deciduous hardwood forest in its headwaters (fig. 1). The storms monitored were relatively moderate in magnitude and intensity, resulting in peak flows of only c.1m<sup>3</sup> s<sup>-1</sup>. The stream chemistry response to rainfall was characterised by rapid decrease in base cation concentrations. Base cations are predominantly derived from the weathering of gneissic bedrock so that a relatively constant source becomes diluted by the increased flow. This decrease in cations is accompanied by a concomitant increase in anions, predominantly fertiliser-derived SO<sub>4</sub> and NO<sub>3</sub>, triggering a reduction in stream pH and significant decreases in bicarbonate alkalinity with each new storm event, although the streams quickly recover to mean concentrations. Continuous monitoring of pH was also carried out at the study catchments over four years, and, at this site, shows that acidic episodes with pH falling below 6.0 are common. In general, the geology of the watersheds imparts a strong buffer capacity to the streams to ensure that acidification is only transient although the data indicate a susceptibility to anthropogenic pollution in the form of inorganic fertilisers, the input of which is likely to increase in the future in line with the increasing population and demand for food.

In contrast to the agricultural catchments, a relatively pristine forested catchment demonstrates constant pH throughout the year. However, a storm event in July 1992 (Figure 2) demonstrates a clear sensitivity to acidification as the pH drops to a level consistent with the episodic acidification response observed in the cultivated catchments. During this single event the pH dropped rapidly from 7.0 to 5.5, indicating a potential for biologically-damaging acidic episodes in pristine forested catchments. Since fertiliser usage is minimal within this catchment, this event must have been driven by high concentrations of acidic anions in the rain, indicating an underlying vulnerability of both forested and cultivated catchments to predicted increased levels of acidic deposition in the future. Acidic episodes

of this type are known to be biologically damaging to aquatic biota and have been identified as precursors to longer-term chronic acidification.

In conclusion, both forested and cultivated catchments in the middle hills are susceptible to episodic acidification. The acidic inputs driving this acidification are atmospheric deposition and application of inorganic fertilisers. In the case of acidification caused by fertilisers, it is clear that the method of application could be changed to ameliorate the most severe effects. At forested sites, a reduction or slowing in the rate of emission of acidic oxides would stabilise the situation. Remedial measures to reverse soil and surface water acidification in NW Europe and N America were implemented too late to prevent losses of biological and economic resources, largely because the precursors to chronic acidification went unnoticed. In the Himalayas, an early indication of a potential problem has been observed and this provides the opportunity for remedial measures to be adopted without long-term loss of, or damage to, natural resources.

Figure 1. Stream chemistry response to rainfall in a north-facing subcatchment comprised of c. 50% terraced agriculture and 50% second generation mixed deciduous hardwood forest

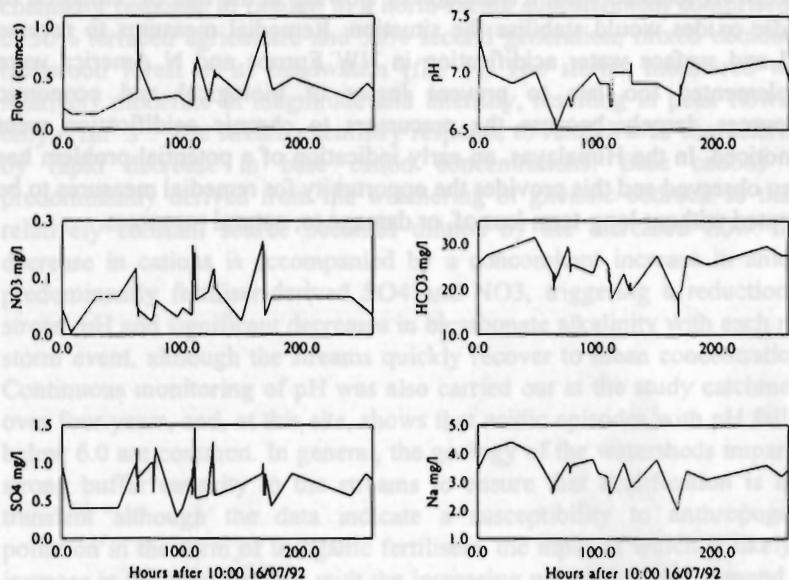
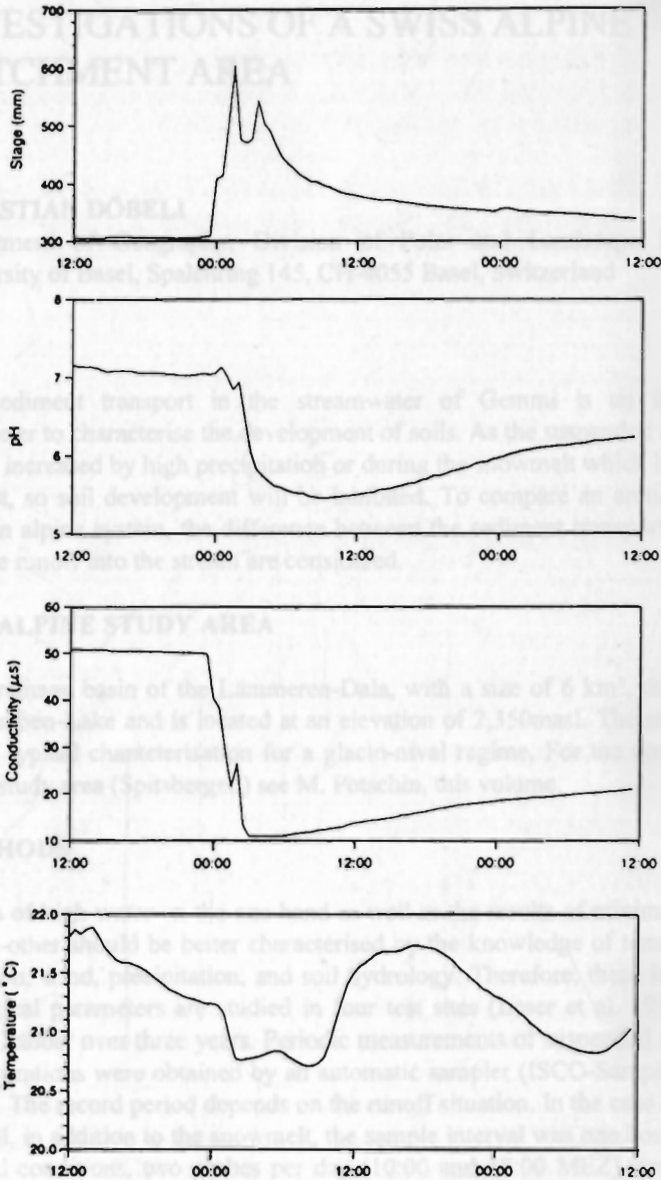


Figure 2. The stream stage, pH, electrical conductivity, and water temperature response to a rainfall event in July 1992 at a 100% forested catchment





# THE SIGNIFICANCE OF RUNOFF AND WATER CHEMISTRY MEASUREMENTS WITHIN THE LANDSCAPE ECOLOGICAL INVESTIGATIONS OF A SWISS ALPINE CATCHMENT AREA

**CHRISTIAN DÖBELI**

Department of Geography, Division of Polar and Landscape Ecology,  
University of Basel, Spalenring 145, CH-4055 Basel, Switzerland

The sediment transport in the streamwater of Gemmi is an important parameter to characterise the development of soils. As the suspended sediment flux is increased by high precipitation or during the snowmelt which lasts until August, so soil development will be inhibited. To compare an arctic system with an alpine system, the difference between the sediment transport and the surface runoff into the stream are considered.

## THE ALPINE STUDY AREA

The drainage basin of the Lämmeren-Dala, with a size of 6 km<sup>2</sup>, drains into the Dauben-Lake and is located at an elevation of 2,350masl. The study area shows typical characterisation for a glacio-nival regime. For the comparable arctic study area (Spitsbergen) see M. Potschin, this volume.

## METHODS

Events of high water on the one hand as well as the results of minimal runoff on the other should be better characterised by the knowledge of temperature, radiation, wind, precipitation, and soil hydrology. Therefore, these landscape ecological parameters are studied in four test sites (Leser et al. 1990) from June-October over three years. Periodic measurements of suspended sediment concentrations were obtained by an automatic sampler (ISCO-Sampler, Mod. 2700). The record period depends on the runoff situation. In the case of heavy rainfall, in addition to the snowmelt, the sample interval was one hour. Under normal conditions, two probes per day (10:00 and 18:00 MEZ) were taken.

According to the events (snowmelt, precipitation, high radiation), the sediment concentrations were classified into different types (snowmelt-type, rain-type, fair weather-type, bad weather type).

## RESULTS

At this point, it does not seem adequate to present long-term results. 1995 will achieve a complete record of suspended sediment flux. The corrected and analysed data will be presented at the conference itself.

In general, the suspended sediment concentrations never exceeded 1.3g/l . Concentration of 1.15g/l are measured during snowmelt by a flood of 1 Mio l/min. The maximum values in fair weather with rain (mainly during the night) vary between 0.2-1.28g/l and average 0.3g/l when no storms are recorded (compare Table 1).

Table 1. Suspended Sediment Concentrations in Different Situations

| Date       | Character                       | Sediment flux (g/l) per day |              |
|------------|---------------------------------|-----------------------------|--------------|
|            |                                 | <i>average</i>              | <i>range</i> |
| 26.06.1995 | Snowmelt                        | 0.78                        | (0.17-1.15)  |
| 14.07.1995 | Fair weather with rain by night | 0.51                        | (0.21-1.28)  |
| 20.07.1995 | Fair weather without rain       | 0.07                        | (0.02-0.16)  |

## PREDICTIONS

As a result of a strong snowmelt, higher sediment flux was recorded at the beginning of measurements (end of June). As it has not been snowing so much in the basin of Lämmeren-Dala since 1980, a different climatic scenario (Global Change) will be discussed.

## SIMILARITIES AND CONTRASTS BETWEEN ARCTIC AND ALPINE SEDIMENT FLUX

The results of suspended sediments in the arctic drainage basin (Liefdefjorden, NW-Spitsbergen, 80°N) were recorded by the research group of Heidelberg (Barsch et al. 1992). The characteristics of amount and nutrient composition of the arctic Kvikkåa-runoff (Leser et al. 1992) will be compared with the alpine Lämmeren-Dala. For this interpretation temperatures, radiation and soil hydrology (Döbeli, 1995) are considered. The varied mountain topography has an influence on sediment processes (Clark, 1987). The high relief energy

in the Alps and the higher precipitations contribute to a higher sediment transport. The comparison of both systems will be discussed in detail at the conference.

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Immense potential of aquatic ecosystems typical for alpine locations above the timberline.

Alpine aquatic ecosystems support characteristics of microbial communities which have been naturally selected for the particular conditions of high mountain environments. The organisms, constantly challenged by extreme and extremely-variable living conditions, are well adapted. Some of them have to survive for more than half a year in the dark and cold under snow or under a thick snow cover. But within a few days after snowmelt, they begin to grow and propagate. Some have to survive the

# THE MICROBIOTA OF ALPINE LAKES AND PONDS AS AN INDICATOR OF CHANGES IN THE HYDROLOGICAL CONVEYOR BELT

**KURT HANSELMANN AND KONSTANZE MEZ**

Institute of Plant Biology, University of Zürich, Zollikerstr. 107,  
CH-8008 Zurich, Switzerland

**JOSEF NIEDERBERGER AND HANS-RUDOLF PREISIG**

Institute of Systematic Botany, University of Zürich, Zollikerstr. 107,  
CH-8008 Zürich, Switzerland

**MARKUS BAUMGARTNER**

Institute of Inorganic Chemistry, University of Zürich,  
Winterthurerstr. 190, CH-8057 Zürich, Switzerland

**DONAT HÜGL**

Laboratory for Atmospheric Physics, ETH-Honggerberg,  
CH-8093 Zürich, Switzerland

**HANS-PETER NÄGELI**

Institute for Veterinary Pharmacology and Toxicology,  
Winterthurerstr. 260, CH-8057 Zürich, Switzerland

## INTRODUCTION

Neither the predicted  $\text{CO}_2$  increase as such nor the "small" globally-assumed temperature increase will regulate aquatic ecosystems in alpine regions but rather the hydrological events, and the availability and supply of nutrients (N,S,P, Fe). The present study illustrates the dynamics and homeostatic potential of aquatic ecosystems typical for alpine locations above the timberline.

Alpine aquatic ecosystems support characteristics of microbial communities which have been naturally selected for the particular conditions existing in high mountain environments. The organisms, constantly challenged by extreme and extremely-variable living conditions, are well adapted. Some of them have to survive for more than half a year in the dark and sometimes under anoxia under a thick snow cover. But, within a few days after snowmelt, they begin to grow and propagate. Some have to scavenge the

necessary nutrients for growth from an extremely-dilute aqueous medium and they might experience frequent oligotrophic stress. During the growing season, they are heavily influenced by rapid hydrological changes after storms, during snowmelt, and during periods of dryness. It is through these events that populations get destroyed and nutrients are diluted or replenished. Environmental variations are thus reflected as rapid changes in the community composition, as physiological shifts, or in the form of structural adaptations of certain populations. The microbial populations seem to be well adapted to cope with the kind of environmental fluctuations typical for these extreme environments.

We studied the microbiota of alpine lakes and ponds with the aim of defining their sensitivity toward change in the hydrological cycle. Can these ecosystems adapt rapidly enough to manmade environmental changes, to enlarged nutrient loads, to acidification, and to pollutant emissions?

## METHODS

We followed the development and response of phototrophic microorganisms in alpine ponds above the timberline in the Misox valley and in the Tambo Lakes (Southeastern Swiss Alps). Automatic registration of the local meteorological forcing parameters (wind, air and soil temperature, irradiation, and precipitation) were correlated with hydrological and biological response parameters (water temperature, pH conductivity, and oxygen concentration). Alterations in water constituents ( $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{HPO}_4^{2-}$ ,  $\text{NH}_4^+$  and several cations) were determined with the aid of modern analytical methods. Changes in the composition of the microbial community (population diversity) were observed microscopically and its physiological behaviour (e.g. cyanotoxin production) was followed employing the protein-phosphate inhibition assay and HPLC.

## RESULTS

*Overall Biomass Distribution:* Oligotrophic ecosystems are comprised of a low biomass content, but they contain a sizeable species diversity mostly consisting of unicellular and filamentous prokaryotes and eukaryotes. Several of the alpine lakes have recently been found to contain microbial mats comprising filamentous cyanobacteria, mostly *Oscillatoria* spp. or *Phormidium* spp. These mats represent locally-high biomass concentration and the mat communities might be responsible for the major portion of energy flow from the atmosphere to the hydrosphere as well as for the

nutrient cycling into biomass and within the ecosystem. The mats are probably the driving force for a tightly-coupled microbial loop which regulates the nutrient economy of the entire ecosystem (Laybourn-Parry et al. 1991).

*Community Composition:* The species must be well adapted to the particular nutrient environment. Much of the observed diversity can thus be attributed to the changing nutrient status, as it has been shown for antarctic inland waters by Heywood (1984). The main genera of cyanobacteria found at the alpine sites include *Coelosphaerium*, *Merismopedia*, *Anabaena*, *Lyngbya*, *Oscillatoria*, *Phormidium*, *Pseudanabaena*, *Scytonema*, and *Tolypothrix*, in certain cases in association with mass developments of diatoms and the flagellated eukaryotic green algae, *Chlamydomonas botryopara*, *Chloromonas pumilio*, *Hefniomonas reticulata*, *Scenedesmus* spp. and *Haematococcus pluvialis*.

*Nutrient Limitation:* The organisms live in waters with low nutrient concentrations but they are exposed daily to high irradiation intensities. Photosynthesis already becomes limiting under these conditions during morning hours, which forces the phototrophic microorganisms into metabolic stress. The consequences are seen to be most severe after a few days of repeatedly high solar irradiance.

*Metabolic Stress* (toxin production): Although low nutrient concentrations do not normally support blooms of planktonic cyanobacteria, we follow the hypothesis that cyanotoxin production is induced as a consequence of nutrient imbalance. In high alpine environments, toxin production might be induced after short periods of excessive growth once the nutrients have become limiting.

*Nutrient Replenishment:* The high ion concentration present in rain water can change the conductivity of pond water dramatically. Only the very first rain fractions and only rain after a longer dry period contain a high ion content. Initial nutrient concentrations tripled within a very short time span, short enough to be certain that inputs into the pool due to soil leaching could be excluded. Rain constituents thus represent a substantial nutrient input into these alpine ecosystems.

*Homeostasis:* When nutrients had been increased following a rain event, they were consumed again within the following days. The community

composition which collapsed as a consequence of the rain re-established itself within a short period of time.

## DISCUSSION

*Homeostasis:* Microbial communities in alpine lakes and ponds respond rapidly to environmental changes, they normally have a vital regenerating ability after catastrophic events (high homeostatic potential), and some of them show characteristic stress expression behaviour.

*Response to Environmental Variability:* Although cyanobacterial toxins are known to occur worldwide in natural and manmade aquatic systems, it was not known until recently that cyanobacteria in alpine aquatic ecosystems also produce them. This does not mean that all cyanobacteria present in alpine lakes and ponds produce toxins all the time (Mez et al. 1996). Toxin concentration per cyanobacterial cell as well as toxin production in the course of a day or a few days can vary greatly. We consider toxin production by cyanobacteria as one of the most rapid and most sensitive responses to short term environmental variations. Following this biological signal concurrently with a detailed registration of the development of short term environmental changes will probably teach us more about the rapid responses and adaptability of the biota to environmental variability. The synthesis of these toxins is supposed to be induced or at least enhanced by certain, not yet known, combinations of environmental conditions. A recent study describes a positive correlation between iron concentration in the water and toxin content in the cells (Utkilen and Gjoime 1995). This could lead to an increase in cyanobacterial toxicity in iron-rich alpine ponds.

*Ecosystem Dynamics:* Since organisms and ecosystems respond to the integrated action of a multitude of environmental factors, an observation once made can never be repeated under exactly the same combination of environmental influences, and repetitions and proper control experiments cannot be made. Microbial ecology can still come to meaningful conclusions from field measurements if patterns and events are observed with the proper time resolution.

*Patterns:* Nature continuously offers experiments under slightly different conditions. If the variability of natural conditions can be defined with a high degree of time resolution, and if these variabilities can be correlated to biological responses, one might be able to draw conclusions about the environmental regulation of organismic and ecosystem activities.

**Events:** Strong natural events, mostly hydrological ones, such as dryness, rain, or flooding, are common in mountain environments. They normally disturb an ecosystem's "steady state" behaviour, interrupt organismic interactions, and temporarily change habitat conditions or destroy populations. The recovery phase will teach us about routes and rates of restoration and thus about the homeostatic potential of these high mountain microbial ecosystems.

## CONCLUSIONS

Our results contribute to a better understanding of how today's alpine aquatic ecosystems function and respond toward nutrient fluxes, loads, and imbalances, and they further our understanding of the bio-accessibility of nutrients in oligotrophic ecosystems. We have extended the scope of traditional aquatic community ecology by introducing cyanotoxin production as a biomolecular indicator for a particular metabolic stress and as a specific and rapid physiological sensor for environmental changes (Mez et al. 1994).

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# HYDROCHEMICAL CHARACTERISTICS OF HEADWATER STREAMS IN THE MIDDLE HILLS AND HIGH MOUNTAINS OF THE NEPAL HIMALAYAS

ALAN JENKINS, JEREMY WILKINSON, AND ROBERT COLLINS  
Institute of Hydrology, Wallingford, Oxon., UK

The impact of anthropogenic pollution from industrial and agricultural sources on water chemistry has concerned environmentalists and scientists for the past two decades. Consequently, the chemistry of headwater streams, lakes, and lowland rivers has been monitored widely in Europe and North America, in an effort to define and quantify these anthropogenic impacts. An understanding of how anthropogenic pollutants affect water chemistry and hence the ability to predict the location and severity of potential impacts, can be achieved only through knowledge of hydrochemical processes in pristine waters with similar physico-chemical characteristics. If a sufficiently detailed knowledge of pristine or baseline water chemistry is available, the effects of local pollution stemming from land use and land management, and of regional pollution from atmospheric deposition of acidic oxides, for example, can be quantified. This study presents the first wide-scale surveys of the chemistry of medium to high-altitude first-order streams in the Nepal Himalaya.

The data is reported from seven regions of the Nepal Himalaya, situated around significant river basins (fig. 1), namely the Everest region (Dudh Kosi), Annapurna region (Modi *Khola*), Langtang region (Langtang *Khola*), Makalu region (Arun and Barun *Khola*), Simikot region (Mugu and Humla Karnali), Dunai region (Churto *Khola*), and Nuwakot region (Likhu *Khola*). Sampling was carried out during February and March 1992 in the Everest, Annapurna, Langtang, and Nuwakot regions and during November and December 1994 in the Dunai, Simikot, and Makalu regions. A repeat survey of the Langtang region was carried out in 1994 and the hydrochemical data is consistent between the two surveys of the region. At both times, flows were low at all elevations. Sampling at low flows, during a prolonged dry

season, was chosen primarily to reduce the variance in stream chemistry due to high flow events; this would produce regionally comparable data sets. However, an important consideration during this period was ease of access.

Detailed geology of these areas is poorly documented and the dominant bedrock geology is reported to consist of pre-Cambrian gneiss (Figure 1). Large areas of low-grade metamorphic green schist were noted in the field in all the sampling regions. The Central Himalayan Thrust fault is associated with a calcareous formation and outcrops in many of the regions. Natural vegetation in all the regions is strongly zoned by altitude and so reflects a north (high mountains characterised, above the tree line but below the zone of permanent snow cover, by juniper, rhododendron shrubs, and grassland) to south (middle hills dominated by terraced cultivation and grazing land) gradient.

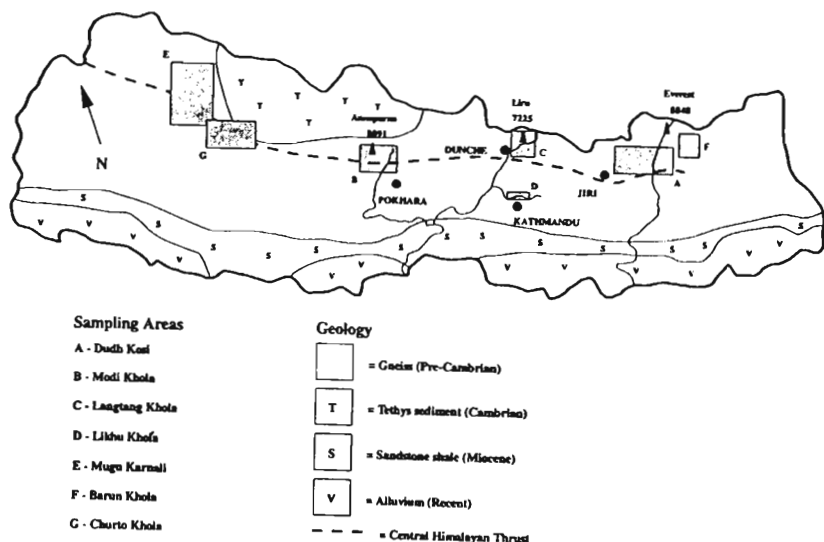
Results show that stream chemistry in mid-high altitude Himalayan mountain streams is well buffered, with pH generally in the 7.0-8.5 range. A number of sites within each region may, however, be sensitive to acidification with pH in the 5.5-6.5 range. Bicarbonate is the dominant anion and Ca and Mg the dominant cations, but there exist significant hydrochemical differences among the seven regions (Figure 2). Bedrock geology is the main influence on water chemistry, both among and within regions. Ion concentrations tend to decrease with altitude, reflecting differences in land use, land management, natural vegetation, and atmospheric deposition, all of which are correlated to altitude. Terraced agriculture also contributes significantly to differences in chemistry, both between and within regions. Water-draining agricultural catchments have higher concentrations of acid anions ( $\text{Cl}$ ,  $\text{SO}_4$ ), probably as a result of mineral fertiliser inputs and trace metals (Fe, Al, Ba, Sr, Mn, Si, and F), due to increased weathering. Locally high concentrations of trace metals were common in all high mountain regions.

In general, the high-altitude forest and alpine scrub-covered catchments in the Himalaya are unlikely to be sensitive to the atmospheric deposition of acidic pollutants. Many of these streams are fed by glacial meltwater. The waters from these catchments generally have high background concentrations of  $\text{SO}_4$  derived from weathering sources. High pH indicates that a large buffering capacity exists within the system and that further additions of anthropogenic  $\text{SO}_x$  will be readily buffered. However, these systems already show significantly high concentrations of  $\text{NO}_3$ . This is probably a result of the low biological requirements, given the poor

vegetation and cold temperatures at high altitudes. Clearly a future increase in atmospheric  $\text{NO}_x$  deposition could exacerbate the situation and promote yet higher concentrations. While this is unlikely to cause acidification of these upland streams, and the biological implications of increased  $\text{NO}_3$  concentrations are not known, downstream eutrophication problems may occur.

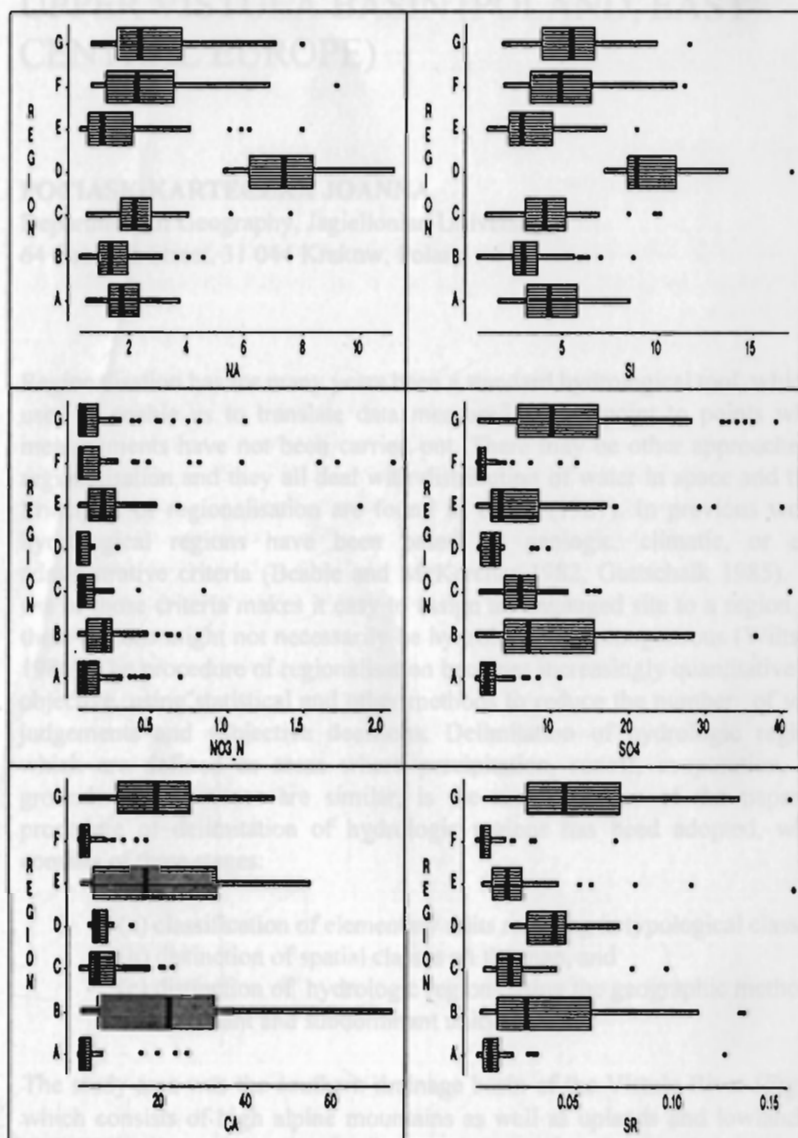
The close links reported between the stream invertebrate community structure and stream chemistry in these environments and land-use changes could have biological consequences through changes in water chemistry. Future surveys of water chemistry and biology are required in similar Himalayan environments to provide the necessary baseline data so as to assess the damage caused by anthropogenic influences; in particular, the impact of land use and land cover on stream chemistry should be quantified so that the sensitivity of these systems to anthropogenic pollution can be assessed. This is particularly important, given the desire to maintain ecosystem stability and biodiversity in the face of the continued development of these areas, in response to increasing population pressure in the middle hills and increasing tourist pressure in the high mountains. •

**Figure 1.** Location of the seven regions - sampled and simplified regional geology



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**Figure 2.** Hydrochemical characteristics of each region - mean concentration, range of the mid 50% of values, interquartile range, and outliers/extremes



# PRINCIPLES OF HYDROLOGICAL REGIONALISATION AN EXAMPLE OF THE UPPER VISTULA BASIN (POLAND, EAST-CENTRAL EUROPE)

**POCIASK-KARTECZKA JOANNA**

Department of Geography, Jagiellonian University,  
64 Grodzka Street, 31 044 Krakow, Poland

Regionalisation has for many years been a standard hydrological tool, which is used to enable us to translate data measured at one point to points where measurements have not been carried out. There may be other approaches to regionalisation and they all deal with distribution of water in space and time. Principles of regionalisation are found in Grigg (1967). In previous works, hydrological regions have been based on geologic, climatic, or even administrative criteria (Beable and McKerchar 1982, Gottschalk 1985). The use of those criteria makes it easy to assign an ungauged site to a region, but these regions might not necessarily be hydrologically homogeneous (Wiltshire 1986). The procedure of regionalisation becomes increasingly quantitative and objective, using statistical and other methods to reduce the number of value judgements and subjective decisions. Delimitation of hydrologic regions, which are defined as areas where precipitation, runoff, evaporation, and groundwater resources are similar, is the main purpose of the paper. A procedure of delimitation of hydrologic regions has been adopted, which consists of three stages:

- (a) classification of elementary units resulting in typological classes,
- (b) distinction of spatial classes on the map, and
- (c) distinction of hydrologic regions using the geographic method of dominant and subdominant units.

The study area was the southern drainage basin of the Vistula River (Fig. 1), which consists of high alpine mountains as well as uplands and lowlands. It seems advantageous to examine a new method of regionalisation in various physiographic areas. The investigated area was divided into regular grid cells

independent of basin boundaries. There is the possibility of storage and use of various data sets lie in the grid-cells system (Simo 1986). The distance between grid lines varies according to the following relationship (Simmers 1984).

$$0.05 A \leq l \leq 0.1 A$$

where

$l$  = grid spacing and

$A$  = total investigated area.

Units can be of any size, and characteristics chosen for discriminants between regions should be directly related to the purpose for which regionalisation is to be carried out.

Ward's taxonomy was used for classification of elementary units in the Upper Vistula Basin. The similarity between objects was measured by the Euclidian distance coefficient. The choice to stop grouping was not made arbitrarily; dendrograms which are statistical measures of the efficiency of grouping and spatial distribution of classes on the map, were taken into consideration. The spatial classes can neither be too detailed nor too general and should refer to the purpose of regionalisation. The dominant and subdominant method is based on the internal structure of spatial classes and dominant elementary units belonging to some class demonstrating the highest percentage of area or greatest frequency. A region is assumed to be an area where elementary units belong to one dominant typologic class. There may also be other subdominant elementary units of another typologic class or classes.

Altogether 27 hydrologic regions were identified in the Upper Vistula Basin (Fig. 1). They differ mainly in surface water and groundwater resources.

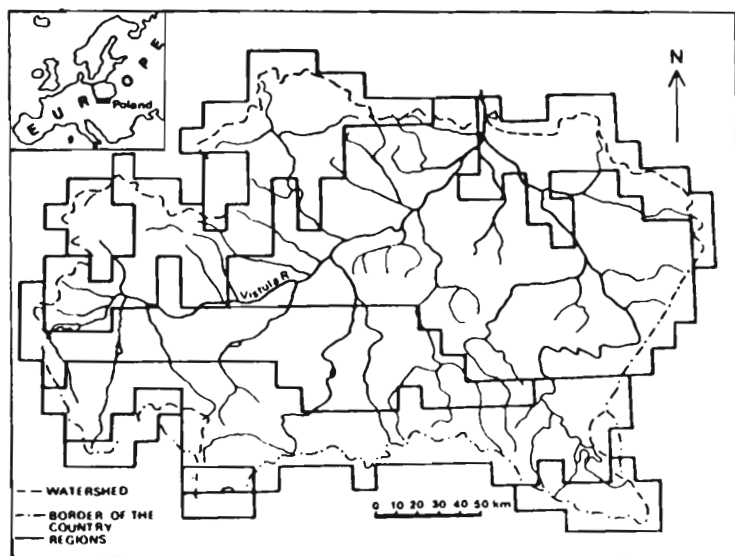
It is believed that the regionalisation procedure presented in this paper could be useful in practical hydrology, e.g. within network planning, physiographic evaluation of the investigated area, and generalisation of results from the representative basin. Taxonomy greatly facilitates interpretation of data sets. The presented procedure of regionalisation can be useful for all types of terrain in the world.



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Figure 1. Hydrologic regions in the Upper Vistula Basin



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# SPATIAL VARIATIONS OF DAILY EVAPORATION RATES IN A HIGH ALPINE VALLEY

**CARMEN DE JONG AND PETER ERGENZINGER**

B.E.R.G.(Berlin Environmental Research Group), Geographisches Institut, Grunewaldstr. 35, Freie Universität Berlin, Berlin 12165, Germany

The spatial and temporal variations of evaporation in high mountain valleys are not very well known. Due to the many problems associated with direct evaporation measurement and the very heterogeneous topography, soil types, vegetation, and climatological gradients in such catchments, very little regional information is obtainable on the subject. The aims of the study are, therefore, to examine the spatial variations of evaporation for an alpine valley, beginning with the snowmelt season, through the summer season and late autumn, from 1st June to 15th September. Twelve sites ranging in altitude from 1,600 to 2,800m, form the basis of the study. The sites are representative of wet valley floor meadows, high alpine meadows, high alpine pastures, and different categories of alpine shrubs as well as a high periglacial site. Each site was established in a representative region, with aspect and gradient typical for each slope. It is important to emphasise that for such a large regional study it is not sufficient to rely solely on valley floor measurements and to neglect the upper valley slopes. The valley provides an interesting contrast of NE and SW-facing valley slopes which substantially influence insolation and sunshine patterns. The catchment has been subdivided into a valley floor with rich meadows on well-developed soils; slopes covered by forest, over approximately 1/10 of the valley, with intermittent high altitude pastures also on well-developed soils; a predominant zone of alpine shrubs, consisting mainly of *rhododendron ferrugineum*, etc and growing on poorly-developed soils with a high amount of humus; and a pronounced zone of short alpine grassland on a very stony underground. Above this zone there are mainly scree slopes and fresh moraines, with periglacial activity, including both active and inactive block glaciers and active glaciers. Wet zones, including lakes and moors, are not only predominant on the valley floor but also in remote side valleys and in high-altitude corries.

Evaporation was measured daily at 12 sites (Fig. 1), integrated within a lower and upper valley profile, one within and above the forested area, the other near the glacier in the shrub zone. The other sites were located within the valley floor, and the highest at 2,800m adjacent to the glacier in a pass. Both direct and indirect evaporation was measured. Indirect measurements included meteorological variables while direct measurements included evaporation pans and lysimeters. The sites were divided into three main categories. The main sites included wind direction and velocity, radiation, soil and air temperature, precipitation and humidity measurements, and direct evaporation instruments; secondary sites included lysimeters and evaporation pans as well as wind, temperature and precipitation measurements; and tertiary sites included only evaporation pans, totalisors, and temperature measurements. At each site, additional daily wind, albedo, and air and soil gradients were obtained. In addition, changes in vegetation were incorporated into the measurements. Vegetation growth was monitored at the selected sites in relation to the surrounding vegetation types. During the month of July, a 12-hour evaporation measurement campaign was conducted simultaneously at nine of the sites. These included the upper and lower valley profiles as well as the lake sites.

The results of the summer of 1995 show that the snowmelt season induces the highest evaporation rates whilst the ongoing summer season has fluctuating but generally lower rates. After intensive rainfall, evaporation is particularly high, but rates drop exponentially thereafter. There is a very good correlation between the lysimeter and evaporation pan results ( $r^2$  of 0.96). Some of the preliminary evaporation pan results are illustrated in Fig. 2. It is apparent that the northerly site of the lower profile correlates well with the valley floor site at the same altitude at the end of the valley. The very windy site on the southeast-facing slope of the lower profile also correlates very closely with the windy but northwest-facing site of the upper profile. There is little direct correlation between evaporation and temperature for these sites. Fig. 3 illustrates the pattern of air and soil temperature, as well as percentage humidity from mid June to mid July for the southeast-facing site of the lower profile. The highest evaporation rates were obtained for the snowmelt period, particularly between the 25th of June and 3rd of July. This coincides with a period of low humidity and warm temperatures, as well as rapid vegetation growth.

The NE-facing sites parallel to each other, whilst the SW-facing slopes also show parallel patterns. The highest evaporation rates are found on the valley

floor in the windiest regions. Evaporation is not only dependant on exposition and radiation but also on windiness and temperature, and these patterns are not directly correlatable with altitude. Neither does evaporation react directly with the meteorological variables, rather depending on topography and vegetation. Due to these facts, the regionalisation of evapotranspiration needs a succinct geomorphological foundation and cannot be obtained successfully from smart extrapolations of Bowen ratios or similar point measurements alone.

The idea of regionalisation, an approach moving away from conventional point measurements, seeks for new techniques of interpretation carried out by means of two digital terrain models on different scales, the geographic information system ARC/INFO, coupled with an interpretation of LANDSAT TM taken the year before during the same season as the actual evaporation measurements. The digital terrain models serve for various functions, amongst others to calculate the daily potential radiation, whereby the first DTM is based on a grid mesh of 25 by 25m, and the second, on a grid mesh of 10 by 10m for resolution comparison reasons. In addition, the DTM serves to calculate the topographical roughness, which is calculated 3-dimensionally between adjacent grid cells. Of utmost importance is the notion that a detailed geomorphological map forms the basis of the parameterisation of hydrological response units each with their own layers of topographical, soil, vegetation, and meteorological characteristics. The hydrological units form the basis of the regional extrapolation of results, together with the remote sensing techniques used. The results are modelled by means of the Modular Modelling System.

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Figure 1



Figure 2  
*cumulative*

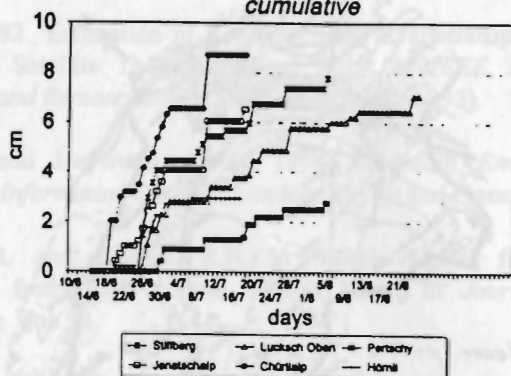


Figure 3a

LUKSCH (2366 m)

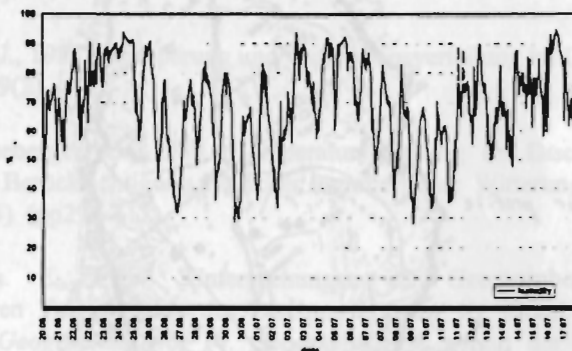
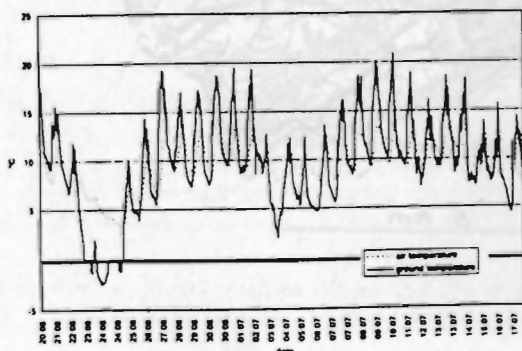


Figure 3b

LUKSCH (2360 m)





# DIATOMS COMMUNITIES IN HIMALAYAN HILLSTREAMS

**L. JÜTTNER, H. ROTHFRITZ, AND S.J. ORMEROD**

Catchment Research Group, PABIO, UWCC, Cardiff CF1 3TL, UK

Diatoms are siliceous algae and an abundant component of all aquatic ecosystems. Throughout the world, they are recognised as important indicators of ecological conditions and quality in surface waters. They are important primary producers in aquatic ecosystems and make a large contribution to their biodiversity. So far, however, there are few data on the occurrence and community composition of diatoms in Himalayan rivers. This is unfortunate in view of the opportunities for fundamental study, and in view of the growing interest in the development of biological indicators of environmental change in this sensitive region.

As part of a larger and ongoing hydrobiological study (Ormerod et al. 1994, this volume) we have now investigated riverine diatom communities across a wide ecological gradient in Nepal. Six geographical regions have been visited in the far west (Simikot-Jumla, Dunai), Central Nepal (Langtang, Likkhu *Khola*, Kathmandu Valley) and the east (Arun valley). Study sites incorporate catchments under terraced agriculture at lower altitudes, in streams through forest, alpine scrub, and tundra at higher altitudes.

Working within the general aims of establishing baseline conditions for Nepalese streams while developing biological indicators of change, the specific aims of this study have been:

- i) to assess the richness, diversity, and composition of diatom communities in relation to altitude, stream chemistry, geomorphological character, land use, and pollution; and
- ii) to assess the community composition of diatoms in different stream habitats, so permitting the development of sound sampling strategies;

We review some of the key results to date. Diatom communities changed markedly between sites: high altitude streams were characterised by species

from the genera *Fragilaria*, *Achnanthes*, and *Diatoma*, which are tolerant to turbulent flow; lower altitude streams contained more motile *Navicula* and *Nitzschia* species. Polluted streams in Kathmandu Valley were characterised by species which occur typically where there is organic enrichment (e.g. *Gomphonema parvulum*, *Navicula atomus*, *N. minima*, *N. cryptocephala*, *Nitzschia palea*).

From the regions analysed so far, species richness, diversity, and evenness were highest in tributaries of the Likhu Khola in the middle hills, but lower at high altitude. These effects might reflect flow conditions, habitat structure, and chemistry, for which we will provide correlative evidence. Diversity was also markedly reduced at polluted sites in the Kathmandu Valley.

Since diatoms are usually collected during monitoring only from riffles, we examined whether this strategy effectively recorded biodiversity, and faithfully revealed effects of pollution. Species richness, evenness and diversity did not differ between pools, riffles, and vegetation in the Likhu Khola, but pools in the Kathmandu Valley tended to have the highest values of all these measures ( $P < 0.1$ ). In addition, there were significant variations between habitats in the percentage of the total number of species recorded at each site; riffles on an average held the fewest (55.7%) and pools, the most (76%). The relative abundances of species also varied between habitats, but effects by organic enrichment were nevertheless apparent in all habitats sampled.

These results provide an important new insight into the biology and biodiversity of Himalayan rivers, and into the role of diatoms as ecological indicators.

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# ESTIMATION OF HYDROLOGICAL BALANCE COMPONENTS AT VARIABLE CONDITIONS OF THE MOUNTAINOUS CATCHMENT

**Z. KOSTKA AND L. HOLKO**

Institute of Hydrology SAS, Ondrasovecka 16, 03105 Liptovsky Mikulas,  
Slovak Republic

## INTRODUCTION

The importance of detailed, accurate, and theoretically-based quantification of water balance components is growing due to the demand for water resources. The water balance study was performed in the Jalovecky creek basin with an area of  $23.1\text{km}^2$  and a mean elevation of 1,500 mamsl. The basin is typical for many mountainous basins in Slovakia. Water balance was studied based on precipitation and runoff data measured in the basin and evapotranspiration calculated by the SOIL model, calibrated against field measurements for the period of six hydrological years from 1989 to 1994. This paper concentrates on the calculation of the evapotranspiration component and sensitivity of the model on different soils, vegetation, and micrometeorological parameters. The experience with estimates of areal precipitation in topographically complex terrain is briefly mentioned, and, finally, the results of water balance are analysed at the end of the paper.

## DETERMINATION OF THE MAIN WATER BALANCE COMPONENTS

The main problems of water balance computation in mountains are connected with the measurements of basic components of the water balance equation in harsh climatic and topographical conditions and estimation of their representative areal values. Since runoff measured at the basin outlet represents areal value, the main attention was devoted to the choice of method to be used for estimation of basin mean monthly precipitation. The method of elevation zones was chosen for calculation. Estimation of the

third main component of the water balance equation, evapotranspiration, is the most ambiguous. Our lack of knowledge of evaporation is due to scarcity of instruments that can measure evaporation accurately under all weather conditions. For this reason, the modelling of evaporation receives special emphasis. In this study, the SOIL water and heat model was used to simulate daily values of water content in each soil layer, soil temperature in the upper layer, and water loss due to evaporation and transpiration in the mountainous basin forested mainly by spruce.

As the SOIL model is a one-dimensional soil-vegetation-atmosphere model, its use for the calculation of water balance components related to the whole basin required the subdivision of the whole basin into six areas affiliated to particular storage gauges. These elementary areas are considered to be quasi-homogeneous regarding soil, vegetation, and climatic parameters. Sensitivity analysis was made as well as adopted from other studies to find the most important parameters included in calculation.

Simulated daily values of water content in each soil layer and soil temperature in the upper layer from the SOIL model were compared to measured values from the study basin (fig. 1). Calculated and measured transpiration of a spruce tree from a limited period were also used for the calibration of model parameters (fig. 2).

## **ANALYSIS OF WATER BALANCE CALCULATION**

Average precipitation during the studied period was 1,435mm. Approximately 59% of this amount was runoff and 40% evaporated. The remaining 1% represents errors in water balance calculations. As indicated in fig. 3, storages of water in the basin increase until the end of March. Approximately 40% of water entering the basin as precipitation from November to May leaves it as runoff in April and May. High evapotranspiration during summer months, together with runoff, continues to decrease the water storages so that basin inputs and outputs are balanced at the end of the hydrological year.

## **CONCLUSIONS**

The results of water balance calculations indicate that evapotranspiration in the basin is higher than reported for this region in the available literature on hydrology. The concept of partial areas in evapotranspiration and other water balance components' calculation is the basis of understanding

catchment processes. Due to the spatial variability of catchment characteristics (soil, cover, topography), different areas play various roles in the total basin behavior. As the basic laws of water movement and mass and energy conservation are the same in mountainous as well as in all other areas, the crucial problem seems to be the reliable determination and generalisation of meteorological input variables and parameters and parameters characterising soils and vegetation at highly-variable conditions of mountain basins.

Physically deterministic models, using the laws of energy and mass conservation, may be used in water balance calculation in mountain basins with reasonable results. Since such models generally contain nonmeasurable parameters besides parameters whose values are well established, they must be determined on more subjective grounds or taken from established knowledge. Many variables are also spatial and/or temporal averages, and are consequently difficult to measure over a complete basin.

The need for vegetation characteristics arises. The use of remote sensing techniques in leaf area index, surface temperature, and the determination of other parameters is in progress. The use of satellite images at parameterisation and arealisation in lowlands and agricultural areas is well established but some more work should be done in forested mountain areas.

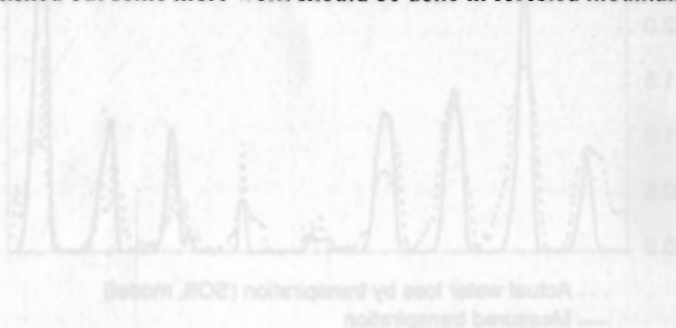


Figure 2. Comparison of water loss by transpiration calculated by the SOIL model and measured transpiration (period: August 18 to August 26, 1993).

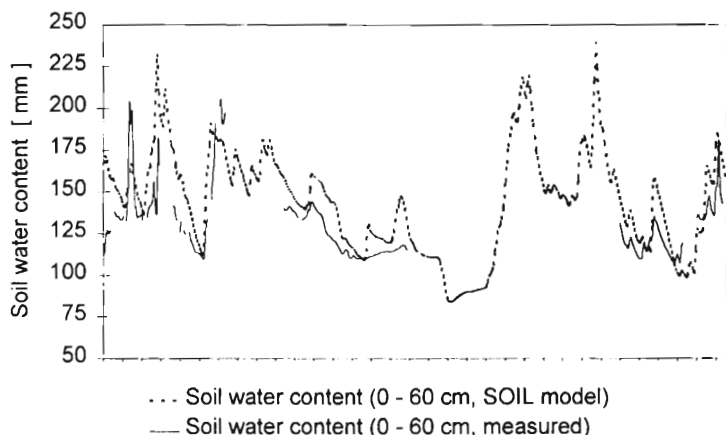


Figure 1. Comparison of measured soil water content in the 0-60cm layer and soil water content calculated by the SOIL model (period: June 10, 1993 to September 1, 1994)

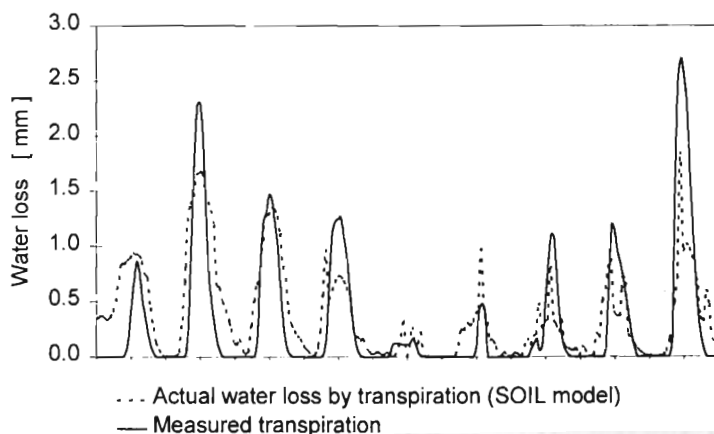


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## CONCLUSIONS

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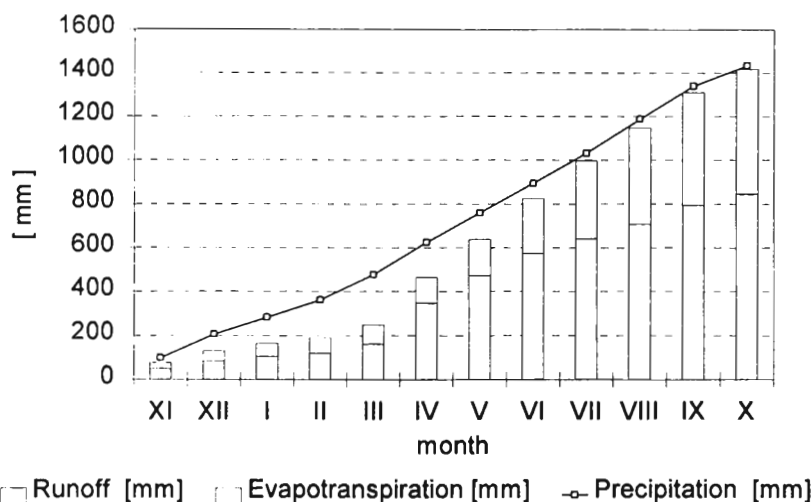


Figure 3. Measured runoff and total evapotranspiration calculated by the SOIL model compared to measured precipitation; average cumulative monthly values from the period 1989 - 1994

changes should take on transient phases, only the equilibrium state is considered. It is further assumed that most of the environmental factors (e.g. vegetation, soil, and landform) remain little changed so that the manner of hydrological response to climatic forcing will be similar to that of the present. Furthermore, the study is limited to the regional level and local variability has been considered. That altitude and latitude were the major elements of concern. Analysis was restricted to nonglaciated areas, using examples from China to provide empirical information. For the high mountain zones of northwestern China, Lei and Yeh (1991) have

# WATER BALANCE OF THE MOUNTAINOUS REGIONS OF CHINA

**CHANGMING LIU**

United Research Centre for Water Problems, Chinese Academy of Sciences,  
Beijing 100101, China

As a geographical region, mountains are complex in topography, microclimate, vegetation, and hydrological behaviour. For convenience, we define mountains as land where the relief exceeds 1,000m within an area of 100km<sup>2</sup>. Significant vertical and horizontal zonation exist within a mountain region (Barry 1981). Compared with their adjacent lowlands, mountain have lower summer heat and higher total precipitation. Seasonal frost or permafrost, together with varying durations of snow and ice cover, may occur at high elevations. Vertical variation in the climate is also reflected in vegetation which, in turn, has important feedback on the climate through interception and evapotranspiration (Fig. 1). Given the current state of our knowledge, the study of climatic change impacts on mountain hydrology is feasible only on a regional scale.

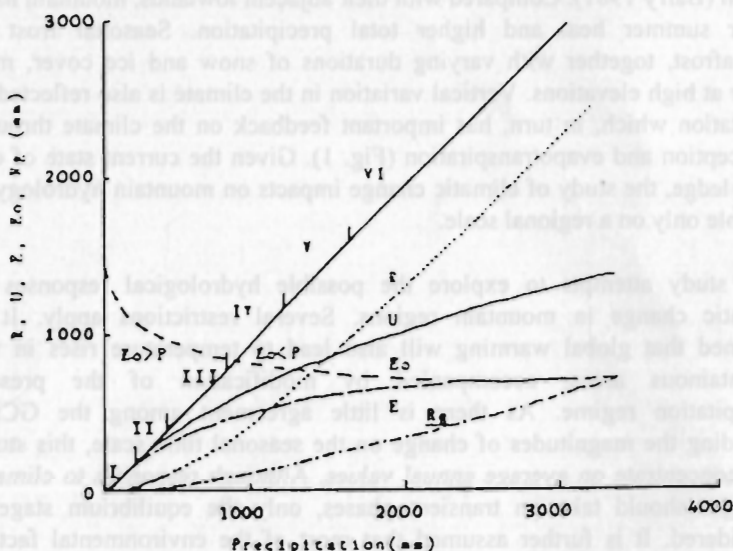
This study attempts to explore the possible hydrological responses to climatic change in mountain regions. Several restrictions apply. It is assumed that global warming will also lead to temperature rises in the mountainous areas, accompanied by modification of the present precipitation regime. As there is little agreement among the GCMs regarding the magnitudes of change on the seasonal time scale, this study will concentrate on average annual values. Although responses to climatic changes should take on transient phases, only the equilibrium stage is considered. It is further assumed that most of the environmental factors (e.g., vegetation, soil, and landform) remain little changed so that the manner of hydrological response to climatic forcing will be similar to that of the present. Furthermore, the study is limited to the regional level and local variability has been considered. Thus, altitude and latitude were the major elements of concern. Analysis was restricted to nonglacierised areas, using examples from China to provide empirical information. For the high mountain zones of northwestern China, Lai and Yeh (1991) have



investigated the effects of global warming on runoff from glacierised and permafrost zones.

In view of the scarcity of data and the uncertainties regarding the climatic change impacts, only qualitative interpretation of the results is warranted. One purpose of this work is to stimulate future research so that empiricism can be supplemented by physical understanding, and quantification can be improved to enable better prediction of hydrological responses to climatic change in mountain regions.

Figure 1. Precipitation, Runoff, Soil Water, Evaporation and Groundwater in China. P=Precipitation, R=Runoff, U=Soil Water, Eo=Potential Evaporation, E=Total Evaporation, and Rg= Groundwater



# ESTIMATION OF MEAN ANNUAL WATER BALANCE COMPONENTS IN A MOUNTAINOUS CATCHMENT

## OTO MENDEL

Institute of Hydrology and Meteorology, TU Dresden,  
Mommssenstrasse 13, 01069 Dresden, Germany

The aim of the paper is to calculate the mean annual water balance components in a mountainous highland catchment using a simple methodological approach. The study catchment, Lodomirka, is located in the Ondava highland region, situated in east Slovakia. The area of the catchment is  $1,85.8\text{km}^2$  and the altitude ranges from 270 to 550masl. For a particular catchment, over a long period, the relationship between the basic components for annual water balance is usually expressed in the following form.

$$P - R - E = 0 \quad (1)$$

where

P = mean catchment precipitation,

R = runoff, and

E = mean actual evapotranspiration.

The component of soil moisture storage S is equal to zero.

In the study of water balance components in a catchment, a basic question arises as to how the mean value can be calculated from point measurement components. In this case, the methodological approach is based on the dissimulation of the study catchment into square areas ( $4\text{km} * 4\text{km}$ ). Altogether 12 network nodes were established, and for each network node the annual precipitation and the evapotranspiration can be calculated from basic measured hydrometeorological and physico-geographical data. The corrections of the mean annual precipitation by Mendel and Pekarova (1983) were estimated for each network node according to the following equation.

$$P_{\text{cor}(\%)} = 22.03 - 0.01839.H_i + 0.0000094.H_i^2 \quad (2)$$

where

$P_{\text{cor}}$  = annual correction in percentage of annual measured precipitation in each network point and

$H_i$  = elevation in masl.

On the basis of equation (2), network point annual precipitation was calculated. The corrected precipitation was obtained by using the following formula.

$$P_{\text{cor,an}} = P_{\text{np}} \cdot (1 + P_{\text{cor}(\%)} / 100) \quad (3)$$

where

$P_{\text{cor,an}}$  = corrected annual precipitation,

$P_{\text{np}}$  = network point annual precipitation, and

$P_{\text{cor,an}}$  = percentage of annual precipitation correction.

It is known that evapotranspiration depends on the meteorological conditions in the study catchment, such as, net radiation, air temperature, and relative humidity, sunshine, wind speed, vapour pressure, and saturation deficit. Mendel and Golf (1990) calculated the dependence between mean air temperature and altitude for the territory of Slovakia using data from 36 meteorological stations, and the relation is given by the following formula.

$$T_i = 10.1 - 0.0052.H_i \quad (4)$$

where  $T_i$  = mean annual air temperature calculated for each study point of the catchment.

If we have estimated the mean annual air temperature for each point, we can also calculate the mean potential evapotranspiration for all points by the following formula (Novak 1994).

$$PET_i = 210.0 + 50.0.T_i \quad (5)$$

where  $PET_i$  = calculated potential evapotranspiration.

If we substitute equation (4) by equation (5), the potential evapotranspiration can be calculated in the following form.

$$PET_i = 715.0 - 0.26.H_i \quad (6)$$

According to Miklanek (1994) and Lang (1981), the present knowledge on mean annual evapotranspiration in mountainous catchments is based on conventional water balance estimates and it suffers from inaccuracies in the determination of precipitation. The vertical gradients of evapotranspiration, given by different authors and from different regions, range from 71 to 356mm decreases for each 1,000m increase in altitude. For the territory of Slovakia, the vertical gradient of potential evapotranspiration is a 260mm decrease for 1,000m increase in altitude. The vertical gradient of precipitation is a 90mm increase for 1,000m and the air temperature decreases by 0.5°C for a 100m increase in altitude. The potential evapotranspiration was calculated by equation (5) for each point on the catchment. By using the Mezenicev formula published by Vuglinskij (1982), we can calculate the actual evapotranspiration by using the following relationship.

$$AET_i/PET_i = (1 + (P_i/PET_i)^{-n})^{-1/n} \quad (7)$$

where

$AET_i$  = actual evapotranspiration for each network nodes and

$n$  = an exponent calculated for the study catchment, equal to 2.5085.

For all network nodes on the catchment, the mean annual precipitation (uncorrected and corrected) and the actual evapotranspiration were calculated, and then, from this, the mean catchment water balance components were calculated. Using the basic formula, equation (1), we can calculate the mean annual catchment component of runoff, expressed in the following forms.

$$R_1 = P - AET \quad (8)$$

$$R_2 = P_{cor,an} - AET \quad (9)$$

The results obtained show that the measured mean annual catchment precipitations were 789.5mm and the corrected 916.6mm, with mean annual corrections of 16.1%. The calculated mean annual potential evapotranspiration was 505.3mm by using usual uncorrected annual precipitation and 529.1mm using corrected annual precipitation. The calculated annual runoff by equation (8) was 284.2mm and by equation (9), 387.5mm. The measured runoff in the profile of Svidník was 410.0mm. The results show that the discrepancies between the calculated runoff and measured runoff by uncorrected precipitation is 30.6% and by corrected precipitation, only 5.5%. This shows that by using corrected mean annual precipitation and the simple equations (1-

9), good information on water balance components of the study catchment can be obtained.

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# ESTIMATION OF MEAN EVAPORATION PATTERNS WITH RESPECT TO ELEVATION

**PAVOL MIKLANEK**

Institute of Hydrology SAS, Racianska 75,  
83008 Bratislava 38, Slovak Republic

Evaporation data are essential for many hydrological studies. The measurements of evaporation are also included in some of the meteorological network stations, but, typically, these data are observed only in few stations and only during vegetative seasons. Direct measurements of evapotranspiration are carried out only on experimental and research stations (Molnar and Meszaros 1990). Therefore, the availability of evaporation and/or evapotranspiration data is very low and other approaches have to be used.

In some case studies, the distribution, i.e. the mean monthly values of evaporation, are needed in places where these data are not available (Mendel and Pekarovak 1995). As the mean annual values are relatively easier to obtain (to calculate or determine from maps), a simple method for the approximation of annual patterns is needed on the basis of some easy available differentiating criteria. This study represents an attempt to find such distribution with parameters dependent on the elevation above sea level.

The study is based on calculated monthly totals of potential evapotranspiration in 10 stations of Slovakia for a 25-year period from 1956 to 1980. Ten stations were selected in different elevations to cover the whole vertical range of Slovakia. The lowest station, Hurbanovo, is at 115masl and the highest one, Lomnický, is situated at 2,635masl.

The monthly values of potential evapotranspiration were calculated using the Penman equation (Novak 1989). Mean courses of evapotranspiration in absolute terms were transformed to relative annual courses expressed in percentage of the annual sum. This transformation allows the comparison of annual distribution in individual stations despite the great variation in absolute values.

For the approximation of the relative annual courses of potential evapotranspiration, the equation formally the same as that of normal (Gauss-Laplace) distribution, has been chosen in the following form.

$$\text{EKPR}(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\left(\frac{-(x-x_m)^2}{2\sigma^2}\right)} \quad (1)$$

where

EKPR = relative potential evapotranspiration (%)

$x$  = number of the month ( $x=1,2, \dots, 12$ ),

$x_m$  = time of maximum EKPR expressed in months (decimals allowed), and

$\delta$  = parameter controlling the shape of the curve (excess).

The best fit values of  $x_m$  and  $\delta$  have been found on all ten stations. Plotted in a graph, they showed elevation to be dependent. This is shown on fig. 1 (a and b) for both parameters. The dependence of these parameters on elevation is linear and can be described exactly enough by linear regression equations. The formulas found are as follow.

$$x_m = 0.324H + 6.336 \quad (2)$$

$$\delta = 0.298H + 2.288 \quad (3)$$

where  $H$  = elevation above sea level in thousands of meters.

Knowing the elevation of the station and using formulas (2) and (3), the seasonal variations of evaporation in relative terms can be obtained using equation (1). The absolute values of evaporation in individual months can be obtained if the annual total or its estimate is known. In such a case, the following equation can be used.

$$\text{EKPM}(x) = \text{EKPR}(x)\text{EP} \quad (4)$$

where

EKPM = modelled monthly evaporation [ $\text{mm month}^{-1}$ ] and

EP = annual total of evaporation [ $\text{mm year}^{-1}$ ].

The presented method was developed as a simple tool for modelling or approximation of the long-term average monthly potential evapotranspiration in different elevations. The only input data are the elevation of the station and

the estimate of the annual total of potential evapotranspiration or evaporation for the station.

Comparison of the computed monthly evaporation and the modelled one using equations (1) to (4) confirmed the applicability of the method on data used for the study. The comparison with data published by other authors allows us to conclude that the method is suitable for approximation of the mean monthly potential evapotranspiration or evaporation from the water surface in various altitudes in Slovakia, in relative terms as well as in absolute terms, with assumption that the annual total is determined independently.

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Figure 1. Altitudinal dependence of the parameter  $x_m$  for ten stations

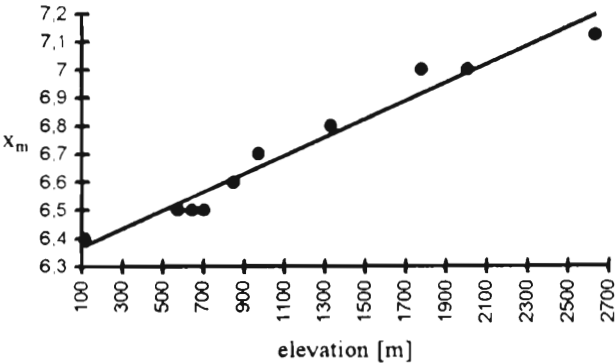
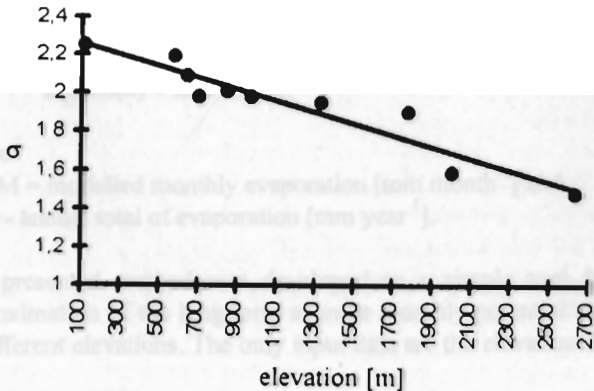


Figure 2. Altitudinal dependence of the parameter  $\sigma$  for ten stations



# BIODIVERSITY, CHEMISTRY AND STRUCTURE IN STREAMS OF THE NEPALESE HIMALAYA

**S. J. ORMEROD, S. T. BUCKTON AND P. A. BREWIN**

Catchment Research Group, School of Pure and Applied Biology,  
University of Wales, Cardiff CF1 3TU, UK

**A. JENKINS AND R. C. JOHNSON**

Institute of Hydrology, Crowmarsh Gifford, Wallingford, Oxfordshire,

**UKI. JUTTNER**

GSF - Forschungszentrum für Umwelt und Gesundheit, Institut für  
Ökologische Chemie, Neuherberg, 85758 Oberschleissheim, Germany

**A. SUREN**

NIWA, Kyle Street, Riccarton, Christchurch, New Zealand

Despite the perception that Himalayan rivers are sensitive to many environmental changes, there are almost no data on their biodiversity, or on the biological effects of catchment disturbance and pollution. Thus, in 1991, we began investigations of diatoms, bryophytes, microcrustaceans, macroinvertebrates, fish, river birds, and habitat structure in Nepal. It has now involved almost 150 rivers across a wide altitudinal and geographical range, from Simikot in the west to the Arun in the east. The general aims have been :

- i) to assess how different river organisms contribute to biodiversity;
- ii) to examine how stream biota and habitat structure might indicate river and catchment quality;
- iii) to provide a baseline against which future changes can be assessed;
- iv) to better understand river structure and function in Nepal; and
- v) to provide an impetus to further research and relevant training in the important but neglected field of river ecology and monitoring.

Here, we present some key results to date. They include:

1. pronounced changes in the taxon richness (e.g., Fig 1), community composition (e.g., Table 1), chemistry (Table 2), habitat structure, and functional attributes of rivers down the Himalayan profile;
2. variations in the chemistry and biology of streams between different regions (e.g., Table 2);
3. variations in the biology of streams in different land uses, particularly among diatoms, fish, and river birds; and
4. variations in biological communities in different stream habitats linked with differences between streams of contrasting habitat structure.

We hope that our studies will contribute to the development of a physico-chemical and biological typology of Nepal's rivers, but further work is required to understand how natural and anthropogenic factors interact to influence stream ecosystems.

Table 1. Stream chemistry in contrasting regions of the Nepal Himalaya

|                               | Siniot<br>(Oct 94) | Dunai<br>(Oct 94) | Anapurna<br>(Mar 92) | Langtang<br>(Mar 92) | Langtang<br>(Dec 94) | Everest<br>(Mar 92) | Makalu<br>(Oct 94) |
|-------------------------------|--------------------|-------------------|----------------------|----------------------|----------------------|---------------------|--------------------|
| n of streams                  | 24                 | 22                | 22                   | 14                   | 25                   | 22                  | 31                 |
| Mean values :                 |                    |                   |                      |                      |                      |                     |                    |
| pH                            | 7.7                | 8.0               | 7.8                  | 7.3                  | 7.9                  | 7.3                 | 7.4                |
| Calcium                       | 15.7               | 18.7              | 19.7                 | 3.8                  | 6.5                  | 6.3                 | 6.5                |
| Magnesium                     | 7.3                | 2.0               | 6.1                  | 1.4                  | 1.8                  | 1.5                 | 0.7                |
| Sodium                        | 2.3                | 2.8               | 1.4                  | 1.6                  | 1.7                  | 2.2                 | 2.4                |
| Silica                        | 3.4                | 5.3               | 2.9                  | 4.0                  | 3.5                  | 4.6                 | 4.5                |
| Nitrate                       | 0.19               | 0.15              | 0.19                 | 0.17                 | 0.09                 | 0.06                | 0.28               |
| Conductivity $\mu S\ cm^{-1}$ | 139                | 126               | 163                  | 37                   | 58                   | 89                  | 40                 |
| Chloride                      | 1.4                | 0.6               |                      |                      | 0.2                  |                     | 0.4                |
| Phosphate                     | 0.04               | 0.03              |                      |                      | 0.02                 |                     | 0.02               |
| Sulphate                      | 7.5                | 11.2              |                      |                      | 6.1                  |                     | 2.2                |
| Fluoride                      | 0.10               | 0.13              |                      |                      | 0.06                 |                     | 0.28               |
| Potassium                     | 2.1                | 2.2               |                      |                      | 1.2                  |                     | 0.8                |
| Strontium                     | 0.02               | 0.05              |                      |                      | 0.02                 |                     | 0.01               |
| Barium                        | 0.03               | 0.01              |                      |                      | 0.004                |                     | 0.002              |
| Manganese                     | 0.003              | 0.003             |                      |                      | 0.001                |                     | 0.001              |
| Iron                          | 0.02               | 0.04              |                      |                      | 0.03                 |                     | 0.02               |
| Aluminium                     | 0.05               | 0.05              |                      |                      | 0.05                 |                     | 0.05               |

All values in  $mg/l$  except pH and conductivity.

All values below detection given nominal value = 1/2 DL.

SDs available on request.

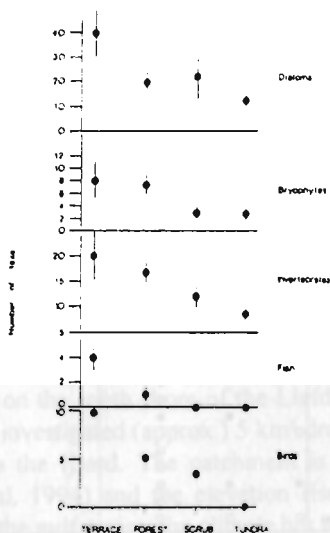


Figure 1. Changes in the numbers of species or families of various groups in catchments of decreasing altitude from tundra-alpine scrub forest and agricultural terracing in the Langtang and Lukla-Khola valleys in Nepal. (winter data from Oberrieder et al. 1994)

Table 2.

Relative abundances of aquatic macroinvertebrate families from 3 regions of Nepal during November 1994  
 Abundance categories: ○ = <0.1% ● = 0.1-1% ●● = 1-5% ●●● = 5-10% ●●●● = 10-15% ●●●●● = 15-20%  
 ●●●●●● = >20% of the total number of animals sampled in each region

|                      | Simikot | Dunai  | Makalu |                   | Simikot | Dunai | Makalu |
|----------------------|---------|--------|--------|-------------------|---------|-------|--------|
| <b>EPHEMEROPTERA</b> |         |        |        | <b>ODONATA</b>    |         |       |        |
| Baetidae             | ●●●●●   | ●●●●   | ●●●●   | Anisoptera        | ●●      | ●     | ●●     |
| Ephemerellidae       | ●●●     | ●      | ●●     | Zygoptera         |         | ○     | ●●     |
| Heptageniidae        | ●●●     | ●●     | ●●●●   | <b>HEMIPTERA</b>  |         |       |        |
| Ephemeridae          | ( )     | ○      | ●      | Mesoveliidae      |         |       | ●      |
| Siphonuridae         |         |        | ●●     | Aphelocheilidae   |         | ○     | ●      |
| Caenidae             | ●       | ●      | ●      | Corixidae         |         | ○     | ○      |
| Prosoptoma           |         |        | ( )    | Noronidae         |         |       | ○      |
| Leptophlebiidae      | ○       | ○      | ●●     | Gerridae          | ○       |       | ●      |
| <b>PLECOPTERA</b>    |         |        |        | Notonectidae      |         |       | ○      |
| Perlidae             | ●●      | ●      | ●●     | Nepidae           |         |       | ○      |
| Nemouridae           | ●●●     | ●●●●   | ●●     | <b>DIPTERA</b>    |         |       |        |
| Chloroperlidae       | ●       | ●      | ○      | Simuliidae        | ●●      | ●●    | ●●     |
| Pelloterlidae        | ○       | ●●     | ●      | Chironomidae      | ●●●     | ●●●   | ●●●●   |
| Leuctidae            | ○       | ○      | ●      | Tipulidae         | ●●      | ●●●   | ●●     |
| Perlodidae           | ●●●     | ●●     | ○      | Tabanidae         | ●       | ○     | ●      |
| Capniidae            | ( )     | ○      | ●      | Blepharocentidae  | ●       | ○     | ○      |
| Taeniopterygidae     | ( )     | ○      | ●      | Athericidae       | ●       | ●     | ●      |
| <b>TRICHOPTERA</b>   |         |        |        | Psychodidae       | ○       | ●●    | ●      |
| Hydropsychidae       | ●●●     | ●●     | ●●●●●  | Doiidae           | ○       | ○     | ○      |
| Rhyacophilidae       | ●●      | ●●     | ●●     | Ceratopogonidae   | ○       | ○     | ○      |
| Stenopsychidae       | ●       | ●●     | ●●     | Deuterophlebiidae | ○       | ○     | ○      |
| Philopotamidae       | ●●      | ●●●    | ●      | Stratiomyidae     |         |       | ○      |
| Psychomyiidae        | ●       |        | ○      | Amphizoridae      |         |       | ○      |
| Polycentropodidae    | ●       | ●      | ●      | Empididae         | ●       |       | ○      |
| Glossosomatidae      | ●       | ●      | ○      | Epithididae       |         | ○     | ○      |
| Odontoceridae        |         | ○      | ○      | Rhagionidae       |         | ○     | ○      |
| Leptoceridae         | ●       |        | ●      | Syrphidae         |         |       | ○      |
| Limnephilidae        | ●●      | ●●     | ●      | Osmyiidae         | ○       | ○     | ○      |
| Uenidae              | ●●      | ●●     | ●      | Pyralidae         | ○       |       | ○      |
| Brachycentridae      | ●●●     | ●●     | ●      | Tortricidae       |         |       | ○      |
| Hydroptilidae        | ○       | ○      | ●      | Corydalidae       |         | ○     | ○      |
| Lepidostomatidae     | ○       | ●●     | ●●     | Oligochaeta       | ●       | ●     | ○      |
| Goenidae             | ○       | ○      | ○      | Planariidae       |         | ●     | ●      |
| Hydrobiosidae        | ○       | ●      | ●      | Collembola        |         | ○     | ○      |
| Sarcostomatidae      |         |        | ○      | Ostracoda         | ○       | ●     | ○      |
| Ecnomidae            |         |        | ○      | Freshwater Crab   |         |       | ○      |
| Helicopsychidae      |         |        | ●      | Hydracanna        | ○       | ○     | ○      |
| Phryganeidae         | ○       | ○      | ○      | Hydrineae         |         | ○     | ○      |
| Calamoceratidae      | ●       | ○      | ●      | Pisidia           | ●       | ●     | ○      |
| <b>COLEOPTERA</b>    |         |        |        | Lymnaeidae        | ○       | ○     | ○      |
| Psephenidae          |         |        | ●●     | Zonitidae         | ○       | ○     | ○      |
| Elmidae              | ●●●●    | ●●●●●● | ●●     |                   |         |       |        |
| Dytiscidae           | ●       | ○      | ●      |                   |         |       |        |
| Hydrophilidae        | ●       | ●      | ●●     |                   |         |       |        |
| Gyrinidae            |         |        | ●      |                   |         |       |        |
| Sphaeriidae          |         |        | ○      |                   |         |       |        |
| Hydraenidae          |         | ●      | ●      |                   |         |       |        |
| Helodidae            | ○       |        |        |                   |         |       |        |
| Notendae             |         |        | ○      |                   |         |       |        |
| Lampyridae           |         |        | ○      |                   |         |       |        |
| Scirtidae            | ●       | ●      | ○      |                   |         |       |        |
| Phoridae             |         |        | ○      |                   |         |       |        |
| Coleoptera (Larvae)  | ○       | ○      | ○      |                   |         |       |        |

# ECOLOGICAL SEASONS IN THE HIGH ARCTIC (NW-SPITSBERGEN) DETERMINED BY TEMPORAL VARIATION OF STREAMWATER CHEMISTRY AND ITS SOURCES WITHIN THE CATCHMENT\*

**MARION B. POTSCHIN AND HARTMUT LESER**

Department of Geography, Division of Polar and Landscape Ecology,  
University of Basel, Spalenring 145, CH-4055 Basel, Switzerland

## INTRODUCTION

The University of Basel took part in all the three field campaigns of the Geoscientific Spitsbergen Expedition to Liefdefjorden during 1990-1992. This multi- and interdisciplinary project was connected to the larger programme PONAM of the European Science Foundation (ESF) and was titled "Land to Sea Sediment Transports and Material Fluxes in Polar Geosystems". Seventeen geo- and bioscientific institutes from Germany, Norway, and Switzerland were involved in this programme. Some results from the working groups were published in Blümel (ed 1992, 1994). Combined results of all research teams will be published in a synthesis-like study. For the Basel approach of research, compare Leser (1991, 1993).

## THE STUDY AREA

The base camp was located on the south shore of the Liefdefjorden at almost 80°N (13°E) and within the investigated (approx.) 5 km<sup>2</sup> drainage basin of the Kvikkåa, which drains into the fjord. The catchment is partly glacierised (approx. 35 %, Barsch et al. 1994) and the elevation rises up to 840masl. Because of the influence of the gulfstream, the climate has to be characterised, despite the high latitude, as mild.

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\* This project was funded by the Swiss Science National Foundation (SNF)

## THE FIELD WORK

The Basel research group for landscape ecology (led by Prof. H. Leser) started the fieldwork in mid May, to be there in time for the slush (initial snowmelt), and stayed until the end of August, the end of the ecologically relevant season. The field work was carried out during the years from 1990 to 1992.

Discharge was measured by means of flow meters and tracer dilution from the research group of Heidelberg. Data for discharge and detailed description of methods are published in Barsch et al. (1993) and are briefly outlined below.

ISCO 2700 sampler for stream water sampling (chemistry), sample interval 210 min

Suction cups (ceramic, Soil moisture Corp. CA) for soil water extraction, sample interval 48 hours

Temperature corrected conductivity and pH (K<sub>25</sub>; WTW LAT1) and NO<sub>3</sub><sup>-</sup>, NH<sub>4</sub><sup>+</sup> and PO<sub>4</sub><sup>3-</sup> (photometer) were measured directly in the field laboratory. All samples were stabilised by adding 1 Vol % HNO<sub>3</sub> sp. and stored until analysis in prewashed polyethylene bottles and at c. 2 °C in the dark. Cations and anions were run at the University of Basel, Department of Geography. For detailed information on the analytical methodology and precision for ions, see Potschin (1995) or Potschin and Leser (1994).

## RESULTS

Field studies were conducted to examine the environmental factors which influence or control ion composition and amount. Specially, these studies focussed on variations in solute chemistry during the high arctic seasons. In all three years, a significant seasonal pattern in the discharge and solutes can be recognised and divided into five distinct phases. The highest values of electrical conductivity (>100mS/cm) and concentrations of various ions are measured in the first part of phase I (first snow ablation phase = slush), while the lowest (30-50 mS/cm) appear in phase IV, the so-called "ice-melting (ablation) phase".

The hydrograph of the Kvikkåa responds directly to changes in melting energy input to the catchment (Scherer 1994) and therefore peaks can be related to the melting of snow, ice, and permafrost. The following figure demonstrates a typical seasonal trend for the discharge and conductivity of the Kvikkåa runoff, which represents all the three years (compare Fig.1). The electrical

conductivity here is acting as one example of the streamwater chemistry and should not been seen as the sum of all analysed ions as most of the time its values are below 100 [mS/cm].

The presentation will concentrate on the results of the ecological seasons. The single phases and sources of water and its chemistry throughout the catchment will be discussed on the basis of detailed data.

## FURTHER PREDICTIONS

This investigation at 80°N was carried out to study the ecological parameter in detail, to finally develop a model for material flux in a so-called "black box" (quasi-closed system). The study area was selected as an example of a landscape not influenced by human beings. The results of this study, therefore, set a zero-variant for further studies. The consequences climate warming will have on the introduced ecological seasons will be discussed. Comparison of this study with similar studies in the Swiss Alps are under investigation (compare Döbeli, C., this volume).

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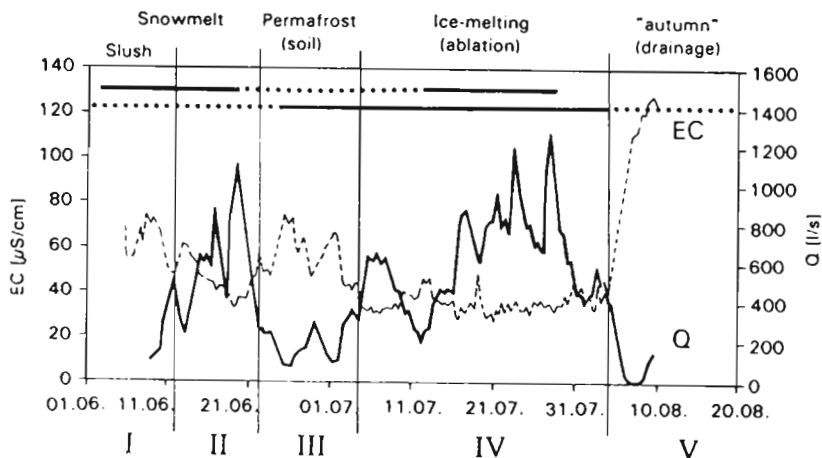
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Figure 1. Seasonal distribution of discharge [ $\text{l/s}$ ] and electrical conductivity [ $\text{mS/cm}$ ] for the Kvikkåa runoff. "I" to "V" represents distinct phases determined by the Spearman regression



types of fruits, and 10 types of wild edible fruits have been recorded in the watershed, which indicates high biodiversity in such a small area.

A hydrological study was carried out in the watershed. The type drainage of the watershed is dendritic and the texture is fine on the higher elevation, gradually becoming coarser in the valley. The study was divided into estimation and experimentation on: (i) drainage, discharge, and sediment concentration; (ii) precipitation, overland flow, and soil loss; and (iii) precipitation-partitioning pathways. The drainage density of the watershed is very high, its total number of channels consisting of 20 of the first order.

# HYDROECOLOGICAL ANALYSIS OF AN AGRAIAN WATERSHED OF THE SIKKIM HIMALAYA

**S.C. RAI AND E. SHARMA**

G.B. Pant Institute of Himalayan Environment and Development,  
P.O. Tadong, Sikkim-737 102, India

The hydrological cycle is the most important ecological process determining the structural and functional dynamics in a watershed system. Sustainability and higher productivity of various land uses/land covers in watersheds are also dependent on the hydrological cycle. Information on the hydrological cycle in the Himalayan region is very important for considering management strategies at the watershed level. Different land uses are interdependent through hydrological linkages. The present investigation was undertaken to find out the different ecological processes linked with hydrology in a hilly watershed.

The Mamlay watershed is located in southern part of the Sikkim Himalaya. It has an elevation range from 300 to 2,650masl, with a total area of 3,014ha, covering 34 villages. The watershed has 45% of its area under agriculture, 26% under forest cover, and 29% is wasteland. The watershed area is typified by a folded structure and varied lithology, with older rocks occupying the upper structural levels. It bears the evidence of two persistent thrusts, namely the Sikkip and Tendong. A total of 113 tree species, 6 types of food grains, 8 types of pulses, 39 types of vegetables, 4 types of spices, 7 types of fruits, and 10 types of wild edible fruits have been recorded in the watershed, which indicates high biodiversity in such a small area.

A hydrological study was carried out in the watershed. The type drainage of the watershed is dendritic and the texture is fine on the higher elevation, gradually becoming coarse in the valley. The study was divided into estimation and experimentation on: (i) drainage, discharge, and sediment concentration; (ii) precipitation, overland flow, and soil loss; and (iii) precipitation-partitioning pathways. The drainage density of the watershed is very high, its total number of channels consisting of 80 of the first order,

18 of the second order, and 7 of the third order. The discharge in the rainy season was highest and the lowest was recorded in the summer. It ranged between 363 to 2,840 l/sec at the outlet of the watershed. In the first order streams, the sediment load ranged from 0.4-5 mg/l in summer, 57-84 mg/l in winter, and 128-387 mg/l during the rainy seasons.

The precipitation was recorded at six locations with all slope aspects of the watershed, covering lower, mid, and high, hills for the period of four years from 1991 to 1994. The average annual precipitation was 2,016 mm in the high hills, 1,737 mm in the mid hills, and 1,460 mm in the lower hills. Overland flow was estimated to be highest (9.6%) in the cropped area and lowest in large cardamom-based agroforestry area (2.2%). Soil loss was highest (477 kg/ha) in the cropped area and lowest in the dense, mixed natural forest. Nutrient loss in the eroded soil was also estimated in comparison to the parent soil.

Comparison of the soil loss in the total watershed area basin's natural forest, plantation forest, cardamom agroforestry area, mandarin agroforestry area, and cropped area showed that the loss was highest in the cropped area and the lowest in the mandarin agroforestry system. The total nitrogen loss from the watershed through soil erosion was 3,035 kg/year; organic carbon, 15,438 kg/year; and total phosphorus, 848 kg/year.

Partitioning of the incident precipitation into various pathways in natural forest, plantation, and cardamom agroforestry areas in the temperate zone, and natural forest and mandarin agroforestry areas in the subtropical zone of the watershed was estimated. Floor interception was highest in the temperate natural forest while the lowest was recorded in the plantation forest. The biomass incorporation of precipitation was higher in forests than in agroforestry systems.

The comparison of overland flow, soil and nutrient loss, and precipitation-partitioning in various pathways in different land uses of the Mamlay watershed suggests that natural broad-leaved forests and agroforestry systems promote conservation of soil, water, and nutrients. Therefore, land use planning and development programmes should focus on these land uses in the hills.

# A STUDY OF WATER BALANCE PARAMETERS WITH REFERENCE TO ENVIRONMENTAL PROBLEMS IN KATHMANDU

**B. UPADHYAY**

Central Department of Meteorology, Tribhuvan University, Kathmandu,  
Nepal

**B. R. UPADHYAY**

Institute of Engineering, Tribhuvan University, Kathmandu, Nepal

The components of the hydrological cycle, namely precipitation, surface water, groundwater, and evaporation, have a profound influence on the environment. Precipitation is seen as a natural scavenger of pollution and precipitation intensity as the cause of soil erosion. The amounts of conventional pollutants and soil washed out by precipitation were estimated for Kathmandu. Inadequate precipitation often causes partial failure of crop, leading to periodic scarcity in Kathmandu. The characteristics of such dry spells, such as their frequency, variations, and so on, have been fully examined and discussed.

For drinking water supply, especially during the dry season, Kathmandu has to depend mostly on groundwater resources which are preserved for longer periods of time and should be properly utilised. It is reported that the present trend of excessive extraction of ground water may deplete the water to dangerous levels and hazards like soil subsidence, reduction of dry weather flow in rivers and springs, and deterioration of water quality will occur in the future. Keeping this in mind, hydrological aspects of groundwater are analysed and discussed. The role of evaporation in introducing particulate matter into the atmosphere has also been briefly examined.

# PECULIARITIES OF RADIATION BALANCE ON SLOPES AND THE IMPORTANCE OF THESE PECULIARITIES FOR THE COMPUTATION OF EVAPORATION FROM MOUNTAIN BASINS

V. VUGLINSKY

State Hydrological Institute, 23, 2nd line, St.-Petersburg, 199053, Russia

Determination of the radiation balance of some areas as a factor of energy resources is the objective of many climatic and hydrologic computations. The methods available make it possible to compute the radiation balance on a flat terrain quite accurately. In mountains, however, it is necessary to compute the radiation balance on slopes that differ in steepness and exposure. To solve this problem, a theoretical scheme has been developed to compute the mean long-term radiation balance of slopes; and appropriate computations have been made at six sites in the Trans-Baikal mountains and on the adjacent terrain.

Data of actinometric and meteorologic standard observations were used for the computations. Monthly radiation balances of slopes of different exposures and steepness were computed from the following equation.

$$R_{sl} = (Q_{sl} + q_{sl}) (1 - \alpha) - I_{sl} \quad (1)$$

where

$Q_{sl}$  and  $q_{sl}$  = mean monthly values of direct and dispersed solar radiation on the slope on account of cloudiness,

$\alpha$  = mean monthly reflective capacity of the slope (albedo) and

$I_{sl}$  = effective radiation of the slope.

The greatest difficulty was encountered in the computation of mean monthly total solar radiation ( $Q_{sl} + q_{sl}$ ) on the slope. Therefore, a special theoretical formula has been developed.

Computations of mean long-term monthly radiation balances of mountain slopes show a need to account for the variation in  $R_{s1}$  depending on the exposure and steepness from May to September only. During the other months these variations are negligible..

It has also been established that changes in the radiation balance on gentle slopes, depending on their exposure, are also small in summer. The radiation balance tends to increase with the increase in slope steepness; at a steepness of  $25^\circ$ , the radiation balance on the northern slope may be 25 - 30% less than that on a flat terrain, and the radiation balance on the southern slope is 10-20% less than that on a flat terrain.

The results obtained from this study were taken into account for the computation of evapotranspiration from the mountain basins in the Vitim River basin in the Trans-Baikal region. An improved equation of M.I.Budyko was used for the assessment of evapotranspiration.

These results demonstrate quite convincingly the necessity to account for changes in the radiation balance on slopes (depending on the slope steepness and exposure) in the assessment of evapotranspiration from mountain basins. For example, errors in the normal annual evaporation from mountain basins, without taking account of the above factor, attain +37% on the northern slope (steepness  $20^\circ$ ) and -11% for the basin on the southern slope (steepness  $25^\circ$ ). Some case studies are given in the paper.

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# CORRELATION BETWEEN WATER QUALITY AND PLANKTON COMPOSITION IN AN URBAN LAKE IN SRI LANKA

**PADMINI DE ALWIS AND HEMANTHA DASSANAYAKE**

National Aquatic Resources Agency, Crow Island, Colombo 15,  
Sri Lanka

The Beira Lake is one of the manmade urban lakes situated in the city of Colombo and has been in existence for about five centuries. The lake area was gradually reduced to 175 acres due to the vast developmental activities in its immediate surroundings. Although in the past it was reported to have been an attractive and fine piece of wetland with crystal clear water, the accelerated eutrophication process has resulted in the present deterioration of the water quality.

A detailed study was conducted immediately after the appearance of blue-green algal bloom. Physico-chemical and biological aspects were studied to ascertain the environmental conditions for the purpose of developing a management strategy to improve the lake's environment. This study revealed that the amounts of phosphorous and nitrogen compounds have greatly increased in the recent past. The lake receives nutrients from a number of point sources and inlets which serve as diffused sources from non-sewered populated areas. These inorganic compounds together with alkaline pH have increased the algal productivity destroying the delicate balance of the lake. Major changes have occurred in the composition and abundance of aquatic life. The composition of phytoplankton showed an increased number of blue-green algae but a decrease in green algal species and diatoms. *Microsystis* species became dominant among the phytoplankton population. The occurrence of a few zooplankton species were also observed. Among them, *Paramoecium* and *Verticella* were found to have increased in the Beira Lake waters. The study indicated that changes in the composition of plankton is directly related to the concentration of nutrients and other pollutants in the lake waters.



An environmentally-sound and economically-viable solution should be adopted to prevent further deterioration of the lake water and provide a healthy environment for the aquatic life. Some short-term and long-term measures to reverse eutrophication effects are also discussed.

# CONTRIBUTION TO THE KNOWLEDGE OF GENUS HIMALOPSYCHE (TRICHOPTERA : RHYACOPHILIDAE) FROM NEPAL

## **WOLFRAM GRAF**

Department of Hydrobiology; Fisheries and Aquaculture, University of  
Agriculture, Forestry and Renewable Natural Resources (BOKU)

Max-Emanuel Str.17, A-1180, Vienna, Austria

## **SUBODH SHARMA**

Aquatic Ecology Centre (AEC), Department of Biology, School of Science,  
Kathmandu University, Dhulikhel, Nepal

A checklist of the species of *Trichoptera* known to be found in Nepal is given together with references and localities. In addition, species of the genus *Himalopsyche*, collected occasionally from November 1993 to April 1994 from Nepal's Western Inner Himalayan and Eastern Fore Himalayan regions, are reported. Habitat preferences of the genus are described.

# A CHECKLIST OF WATER BEETLES OF NEPAL WITH DISTRIBUTION PATTERNS IN RELATION TO ALTITUDE

**MANFRED A. JÄCH**

Natural History Museum, Burgring 7, A-1014, Vienna, Austria.

**SUBODH SHARMA**

Aquatic Ecology Centre (AEC), Department of Biology School of Science  
Kathmandu University, Dhulikhel, Nepal

A checklist of the species of aquatic beetles belonging to nine different families so far reported from Nepal are listed together with synonyms and taxonomic references. References are provided for the first records obtained from Nepal together with the localities where altitude (m) at which the species were found. In addition, the collections by the Department of Hydrobiology (University of Agriculture, Vienna) on different occasions, from November 1993 to April 1995, were identified; and the species not yet reported from Nepal are listed with locality records. Remarks are made on the findings of the families *Limnichidae* and *Scirtidae*. Taxonomic difficulties on the identification of some Nepalese specimens of the families *Elmidae* and *Psephenidae* are discussed. Variations in the species' composition of the fauna in relation to altitude are illustrated.

# **WATER USES IN NEPAL - IMPACTS AND EFFECTS ON THE AQUATIC ENVIRONMENT**

**OTTO MOOG**

Department of Hydrobiology, Fisheries and Aquaculture, University of Agriculture, Forestry and Natural Renewable Resources (BOKU)  
Max-Emanuel Str. 17, A-1180 Vienna, Austria

**SUBODH SHARMA**

Aquatic Ecology Centre (AEC), Department of Biology, School of Science  
Kathmandu University, Dhulikhel, Nepal

Water is a very important gift to mankind by Nature. Its proper use in any form is very important not only for the purpose of drinking but also to raise the economic standard of the country. This is the right time when Nepal, with rich water resources in the form of rivers, should think of preserving its water quality. The construction of majestic temples, for instance, along the banks of the river is clear evidence of the early Nepalese spiritual relationship with rivers. Remarkable religious importance is given to rivers. Every year thousands of pilgrims visit the Bagmati River with the hope of gaining purity by sprinkling its holy water over themselves. Almost all cremation grounds in Kathmandu lie along the bank of this river. Nepalese have always believed in the spiritual nature of the rivers in past and will continue to do so in future irrespective of the quality of the water, thereby giving rise to the danger of contracting serious diseases. Owing to rapid urbanisation and industrialisation in Kathmandu Valley, the Bagmati River is used to drain away the city's wastes. The increasing use of this river for hydropower, irrigation, water mills, drinking water, cattle, car and wool washing, and the removal of tonnes of sand and gravel to be used as building materials, has added to the seriousness of the problem. All these activities are carried but regardless of their impact on the aquatic environment. All these human impacts and the problems faced by the aquatic environment are briefly discussed. In addition, the need for proper authorities to stop such activities is also expressed.

# DISTRIBUTION AND SPECIES' COMPOSITION OF LEECHES (ANNELIDA:HIRUDINEA) IN THE AQUATIC HABITATS OF NEPAL

**HASKO NESEMANN**

Department of Hydrobiology, University of Agriculture, Forestry and  
Renewable Resources (BOKU), Max-Emanuel Str. 17, A-1180, Vienna,  
Austria

**SUBODH SHARMA**

Aquatic Ecology Centre (AEC), Department of Biology, School of Science  
Kathmandu University, Dhulikhel, Nepal

Out of a total of 178 sites sampled on different occasions from November 1993 to December 1995, from an altitude of 80m to 3,802masl, aquatic leech fauna of Nepal were found on 26 sites only. The distribution was restricted mostly to Midland valleys and Dun valleys such as, Kathmandu, Pokhara, and Bharatpur. Occasional findings reported from the Middle Hills and Dang valleys are also presented. The fauna were very poorly distributed in the *Terai* belt and were missing in the higher mountain regions of the country such as the Inner Himalayan and the Fore Himalayan zones. Leeches belonging to three families with nine different species are listed. *Alboglossiphonia weberi*, *Alboglossiphonia annandalei* *Batrachobdelloides reticulatus*, *Hemiclepsis marginata*, *Helobdella stagnalis*, and *Placobdelloides fulvus* of the family *Glossiphoniidae* and only one representative of the family *Salifidae* i.e. *Barbronia weberi*, are reported with illustrations. Furthermore, two species of the terrestrial family *Haemadipsidae* collected along the banks of the streams are identified as *Haemadipsa sylvestris* and *Haemadipsa zeylanica*.

# CHARACTERISTICS OF PRECIPITATION AND DISCHARGE OF A MOUNTAINOUS BEECH FOREST AREA IN NORTHEASTERN JAPAN

**KIYOTAKA SAKAIDA**

Tohoku University, Aoba, Sendai, Miyagi Pref., Japan

**HAJIME MAKITA**

Hirosaki University, Bunkyo-cho, Hirosaki, Aomori Pref., Japan

**YUKIO TORIKAKA**

Sapporo District Meteorological Observatory, Sapporo, Hokkaido, Japan

The Shirakami Mountains located in the northernmost part of Honshu, a Japanese main island, is one of world's first natural heritages in Japan (Fig.1). They are famous for the original Siebold's beech (*Fagus crenata*) forest which covered almost all cool temperate zones in Japan until the early 1960s. Since then, everywhere in Japan beech forests have been cut down and changed into artificial forests of temperate conifers such as *Cryptomeria*, *Chamaecyparis*, *Pinus*, *Larix*, etc. Today, a forest of about 450sq. km. in these mountains is the largest original stand of beech as a continuous mass.

The beech forests on these mountains, together with other arboreal and herbaceous plant communities, offer habitats for many kinds of animals. Some of those animals, such as the Japanese black bear and Japanese serrow, as well as edible and medicinal plants and fungi, have long been natural resources for the people living around the mountains. Also, rivers originating in these mountains are irrigating vast paddy fields till today.

The hydrological characteristics of these mountains, however, have not yet been studied because of the absence of meteorological survey points and inaccessibility (there are few trails here). First, we tried to estimate the precipitation and discharge using the data of discharge for three catchment areas. The results are summarised as follows.

1. Both heavy rainfall and heavy snowfall are inclined to occur during the passage of the Japan Sea Low which blows a southwestern wind at the surface of 900 hPa.

2. Annual areal precipitation estimated by the water budget method ranged from 3,500 to 4,000mm, which is 1.2 to 1.5 times (in summer) or 1.8 to 2.5 times (in winter) as large as the annual precipitation of dam-site stations at the mouths of catchments

(Fig. 2, Table 1). The glaring discrepancy between two annual precipitation is caused by both the increasing precipitation in higher altitude and lowering of the capturing ratio of rain gauges at dam-site stations.

3. Daily discharge in spring is remarkably related to temperature, and, alternately, with precipitation since May. The characteristics of discharge in spring depend upon the distribution of altitude and slope direction for the three catchments.

4. Two Landsat data scenes during the period of lingering snow clarify why more snow accumulation is observed on the north or east sides of slopes than on the south or west sides. The melting snow volume estimated from the two Landsat data is equivalent to the discharge within the period measured at dam-site stations.

**Fig. 1. The Shirakami mountains and the World Heritage Area**

A solid line surrounds the heritage area of ca. 170km<sup>2</sup>. A : The buffer area of the "Forest ecosystem reserve (Park area)", B : The buffer area of the "Forest ecosystem reserve" and the ordinal zone of the "Natural environment reserve", C : The core area of the "Forest ecosystem reserve (Park area)", D : The core area of the "Forest ecosystem reserve" and the special zone of the natural environment reserve". The dam-site stations are MY (Nishi-meya), SB (Subari) and HG (Hayaguchi)

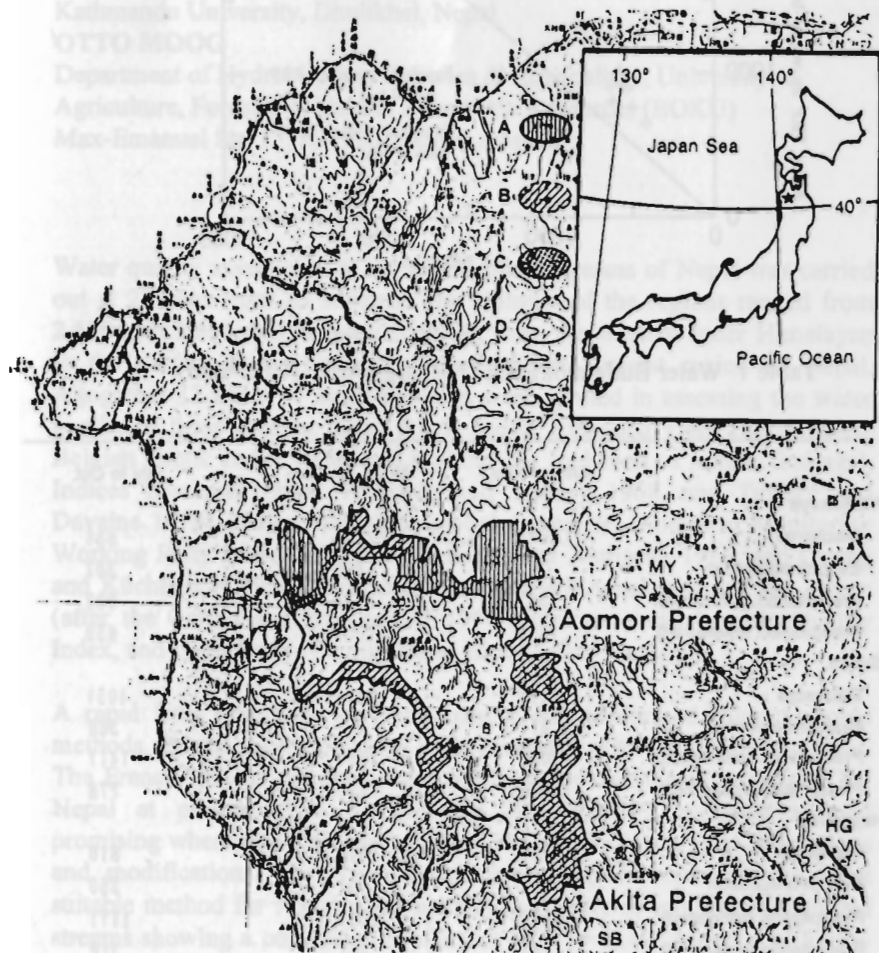




Fig. 2 Comparison between the dam-site precipitation and estimated precipitation

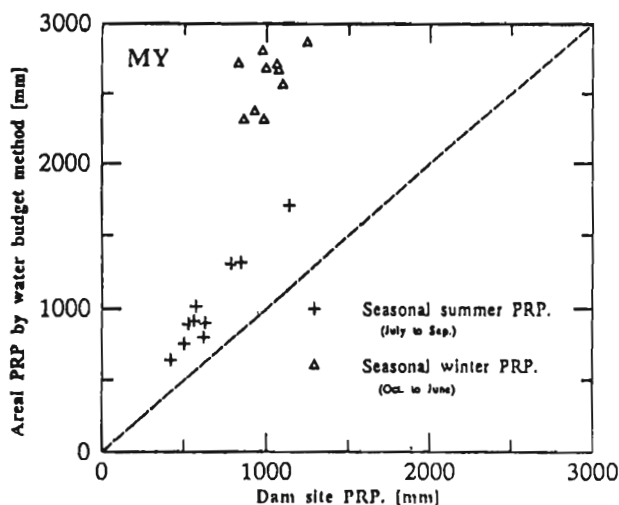


Table 1 Water Budget of Each Discharge Area (Unit=mm)

|                           | Annual total | Nov. to June | July to Oct. |
|---------------------------|--------------|--------------|--------------|
| <b>Nishimeya</b>          |              |              |              |
| Discharge                 | 2844         | 2158         | 686          |
| Evapotranspiration        | 723          | 416          | 307          |
| Precipitation (estimated) | 3567         | 2574         | 993          |
| Precipitation (measured)  | 1662         | 1003         | 659          |
| <b>Subari</b>             |              |              |              |
| Discharge                 | 3191         | 2143         | 1051         |
| Evapotranspiration        | 811          | 451          | 360          |
| Precipitation (estimated) | 4005         | 2594         | 1411         |
| Precipitation (measured)  | 1978         | 1200         | 778          |
| <b>Hayaguchi</b>          |              |              |              |
| Discharge                 | 2709         | 1900         | 810          |
| Evapotranspiration        | 811          | 451          | 360          |
| Precipitation (estimated) | 3520         | 2351         | 1171         |
| Precipitation (measured)  | 1142         | 967          | 310          |

# USING SEVERAL INDICES IN WATER QUALITY ASSESSMENT OF HIGHER MOUNTAIN STREAMS OF NEPAL

**SUBODH SHARMA**

Aquatic Ecology Centre (AEC), Department of Biology, School of Science  
Kathmandu University, Dhulikhel, Nepal

**OTTO MOOG**

Department of Hydrobiology, Fisheries & Aquaculture, University of  
Agriculture, Forestry & Natural Renewable Resources (BOKU)  
Max-Emanuel Str. 17, A-1180 Vienna, Austria

Water quality assessment in higher mountain streams of Nepal was carried out at 27 sites from 23 streams. The altitudes of the regions ranged from 2,530m to 3,802masl, thereby covering from the western Inner Himalayan to the eastern Fore Himalayan zones of the Everest region of Nepal. Altogether 12 kinds of index methods were applied in assessing the water quality of these regions: Trent Biotic Index, Extended Trent Biotic Index, Belgian Biotic Index (with and without the inclusion of single findings), Indices Biotiques (after Verneaux and Tuffery 1968, and Tuffery and Davaine 1970), Indice biologique global normalisé, Biological Monitoring Working Party Score (after the Anglian Water Authority 1986, and Coring and Küchenhoff 1994 transformations), BMWP/Average Score Per Taxon (after the Coring and Küchenhoff 1994 transformation), Lincoln Quality Index, and Hilsenhoff's Family-based Biotic Index Method.

A rapid field estimation of water quality was performed using saprobic methods and the results obtained were compared with the different indices. The French Indices and the related methods are considered unsuitable for Nepal at present. The BMWP and BMWP/ASPT methods seemed promising when used after the inclusion of local taxa with local adaptations and modifications. The Trent Biotic Index proved relatively the most suitable method for Nepal when applied to slightly or moderately polluted streams showing a correlation coefficient of ( $r^2$ ) = 0.42. Absence of highly sensitive local taxa from the score list and underscoring or overscoring of the intolerant or tolerant families of macroinvertebrates are regarded as the

chief limitations of such indices when used in a country other than the country of their origin.

# THE ROLE OF SNOW DEPOSITS IN RAINFALL-RUNOFF SIMULATIONS FOR SMALL HIMALAYAN BASINS, NEPAL

**J. BUCHTELE**

Institute of Hydrodynamics, Czech Academy of Sciences,  
Podbabská 13, 166 12 Prague, Czech Republic

**A. HERRMANN**

Institute for Geography and Geoecology, Technical University,  
Langer Kamp 19c, 38106 Braunschweig, Germany

**O.R. BAJRACHARYA**

Department of Hydrology and Meteorology, Babar Mahal,  
Kathmandu, Nepal

The sparse availability of data for the evaluation of water storage in snow covers and glaciers makes conceptual models reasonable tools for an inverse task, i.e. the improved estimation of inputs in the rainfall-runoff process in those cases where precipitation and discharge are known. This problem is obvious and urgent in mountainous areas.

The daily time series of precipitation and discharge and air temperature over six years, from 1988 to 1993 have been used for runoff simulation in the following Himalayan basins: Imja *Khola* of Khumbu region (4,375-8,501masl, 135km<sup>2</sup>, 27% glaciated), Langtang *Khola* (3,800-7,232m, 340km<sup>2</sup>, 38%) and Modi *Khola* of Annapurna area (3,160-8,091m, 148 km<sup>2</sup>, 33%). The modelling tools used were the *Sacramento Soil Moisture Accounting Model* in connection with Anderson's Snow Model.

Due to some uncertainties concerning the representativeness of individual data series, some analyses and comparisons of alternative outputs have been carried out which provide an idea about some aspects of topography (vertical gradients of air temperature and precipitation, their seasonality, etc).

For the estimation of runoff changes caused by land-use changes, simulation in which inputs and parameters have been altered may be used; sensitivity

analysis using incremental scenarios also provides some idea of the possible effects of climatic warming.

Fig. 1 Observed and simulated discharge, Langtang Khola

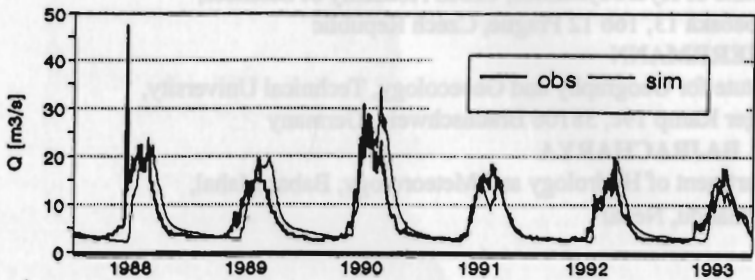
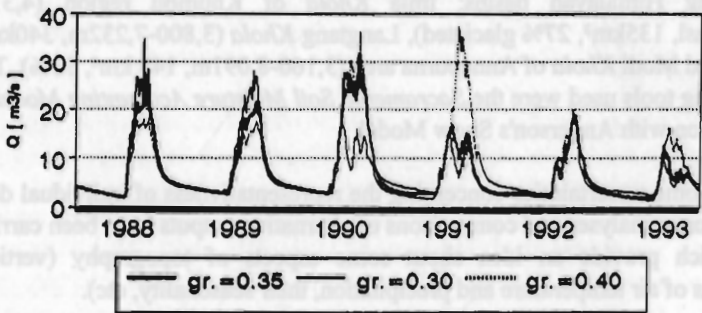
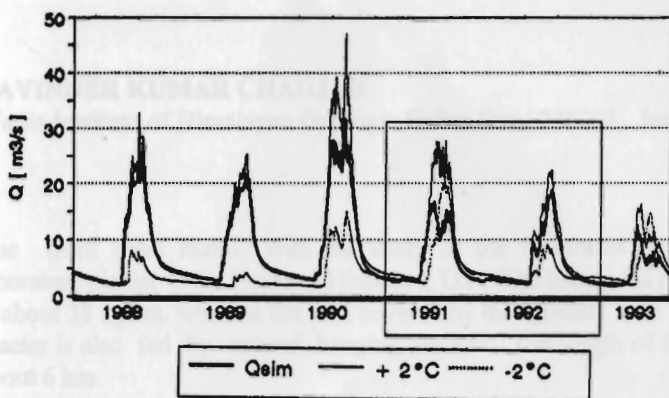


Fig. 2 Influence of air temperature gradient on simulated discharge, Langtang Khola



**Fig. 3** Effects of air temperature change on simulated discharge, Langtang Khola



Sawar: There are two arms of the glacier, one in the left margin of the glacier and the other in the right margin. Both are at about the same height (i.e., 1.500m a.s.l.). The origin point of the Mandakini is mainly from the right snow of the glacier. Melt-out water from the left snow also feeds the water of the Mandakini, and runs the main channel about 100 m northwest of the Kedarnath temple. It appears that this was a part of a single glacier, which has been divided into two parts separated by its medial moraine before receding (Figure-1). Originally, there was only one glacier when it was in its advancing stage. Extensive melting has thinned the glacier to such an extent that it could not divide its two medial moraines and has been divided into two parts, thus forming two Chorabari snouts.

# GLACIAL GEOMORPHOLOGY OF THE CHORABARI GLACIER, GARHWAL HIMALAYA

**RAVINDER KUMAR CHAUJAR**

Wadia Institute of Himalayan Geology, Dehra Dun -248001, India

The work deals mainly with the study of the landforms made by the Chorabari glacier in the Garhwal Himalaya, U.P. The basin area of the glacier is about 38 sq.km. whereas the area covered by the glacier is 15 sq.km. The glacier is also fed by several hanging glaciers. The length of the glacier is about 6 km.

**Snout:** There are two snouts of the glacier, one in the left margin of the glacier and the other in the right margin. Both are at almost the same height i.e., 3,800masl. The origin point of the Mandakini is mainly from the right snout of the glacier. Melt-out water from the left snout also feeds the water of the Mandakini and meets the main channel about 100 m northwest of the Kedarnath temple. It appears that this was a part of a single glacier, which has been divided into two parts separated by its medial moraine before receding (Figure-1). Originally, there was only one glacier when it was in its advancing stage. Excessive receding has thinned the glacier to such an extent that it could not disturb its own medial moraine and has been divided into two parts, thus forming two Chorabari snouts.

**Moraines:** Some of the observations and interpretations of moraines in the active zone of the glacier are as follow.

- a) The main medial moraine is now playing an active role in the glacier activities. It is acting as the left lateral moraine of the main glacier and right lateral moraine of the tributary glacier, though the tributary glacier has a common accumulation zone with the main glacier. This suggests that the glacier has undergone a vast amount of receding due to which its own medial moraine has divided the main glacier into two parts. As a result, two separate snouts of the same glacier have developed.

- b) The left snout has retreated about 200m more than the right snout, suggesting that the left glacier is thinning faster than the right one.
- c) There was a readvance of the glacier before the final stage of retreat, which was indicated by the presence of new lateral moraine (present) near the snout, within the earlier lateral moraine. This advance was smaller in size as compared to the earlier glacier before retreat.

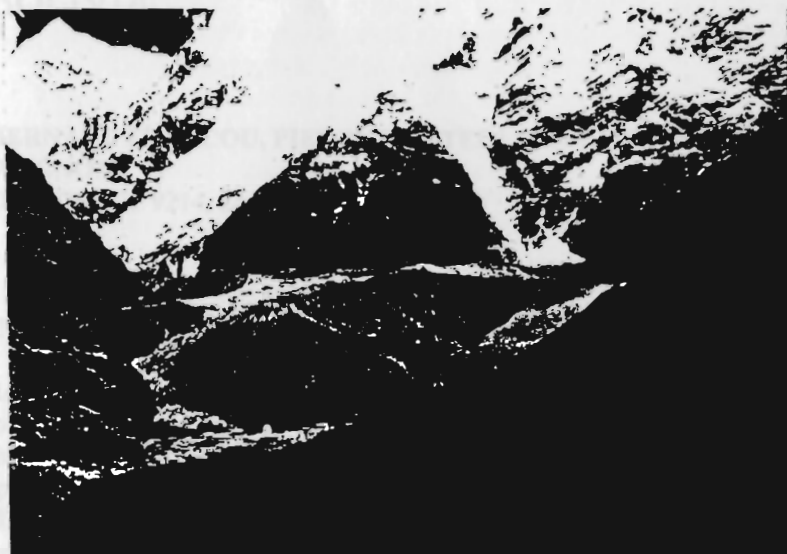
Cycles of advance and retreat: In order to study different cycles of advance and retreat of the Chorabari glacier, different loops of lateral and terminal moraines have been studied in its inactive zone (i.e. the zone which is no longer in contact with the glacier).

A series of five well-defined lateral and terminal morainic loops are noticed in the inactive zone of the Chorabari glacier. These morainic loops have been used as the basis for reconstructing the glacier history in defining the sequence of glacier episodes before its complete deglaciation from this zone.

The moving ice body, which formed the stage II landforms, did not have the energy to destroy the existing larger landforms of stage I, but it could only modify its lateral and ground moraines. This suggests that the glacier energy associated with the formation of smaller superimposed landforms of the later stage was of a lower order and insufficient to significantly alter the pre-existing landforms. These loops suggest that, after their development, no major movement of the glacier took place in the region.



Figure 1. Accumulation (partial) and Ablation zones of the Chora bari glacier in which the main medial (in foreground) has divided the glacier in two parts



region for which the period 1961-1993, a monitoring programme has been conducted on the Zongo Glacier, Bolivia, in order to study mass and hydrological balance. This research survey aims at understanding what the glacier response is to seasonal variability. In the Central Andes, the largest climatic variability are due to different phases of Southern Oscillation (ENSO events). The period from 1961 to 1993 was marked by a negative trend of the South Oscillation Index (SOI), particularly during the 1981-82 ENSO event. This paper presents a short synthesis of the principal results obtained during these four cycles from 1961 to 1993, with emphasis on the

# FOUR YEARS OF MONTHLY MASS BALANCE ON A TROPICAL GLACIER: THE ZONGO GLACIER, 16°S, CORDILLERA REAL, BOLIVIA

**BERNARD FRANCOU, PIERRE RIBSTEIN AND PATRICK  
WAGNON**

ORSTOM, CP 9214, La Paz, Bolivia

## INTRODUCTION

Recent studies have emphasised the extreme sensitivity of tropical glaciers to climatic changes (Hastenrath and Kruss 1992, Thompson 1992). It seems that the strong response of these glaciers to climatic forcing is partly due to specific seasonal patterns of accumulation and ablation (Franco et al. 1995). The main accumulation and ablation occur during summer and an important part of the glacier surface is submitted to a predominant ablation regime the whole year round. Since 1991, a monitoring programme has been conducted on the Zongo Glacier, Bolivia, in order to study mass and hydrological balance. This monthly survey aims at understanding what the glacier response is to seasonal variability. In the Central Andes, the largest climatic variabilities are due to extreme phases of southern oscillation (ENSO events). The period from 1991 to 1995 was marked by a negative trend of the South Oscillation Index (SOI), particularly during the 1991-92 ENSO event. This paper presents a short synthesis of the principal results obtained during these four cycles from 1991 to 1995, with emphasis on the ablation variabilities on a monthly scale.

Mass balance is estimated from a stake network which extends to the ablation and accumulation zones. Regular measurements of snow accumulation and density in pits have completed the survey system. Six rain-gauges between 4,700m and 5,200m, and a limnometric station near the glacier snout allow the estimation of hydrological balance.

## MASS AND HYDROLOGICAL BALANCES

The following table presents the different characteristics of the 4 measured cycles.

| Years   | Bn (1)   | P (2) | A (3) | Q (4) | ELA (5) |
|---------|--|-------|-------|-------|---------|
| 1991-92 | -1.38  | 0.92  | 2.30  | 2.25  | 5300    |
| 1992-93 | 0.02   | 1.06  | 1.04  | 1.18  | 5100    |
| 1993-94 | -0.73  | 0.85  | 1.58  | 1.56  | 5200    |
| 1994-95 | (row to be completed with the data of August 1995) |       |       |       |         |

- 1) *Specific net balance (m of water)*
- 2) *Precipitation near the glacier (4,880-5,200m) (m of water)*
- 3) *Specific ablation :  $A = P - Bn$  (m.of water)*
- 4) *Specific runoff for a 2.1 km<sup>2</sup> glacier area (m of water)*
- 5) *Equilibrium Line Altitude (in masl)*

Mass balance was negative, except during the 1992-93 cycle. This result is coherent with the trend of the last two decade as reconstructed from hydrological data by Ribstein et al. (1995). The 1991-92 cycle was marked by a significant loss in ice volume, which is generally recorded during ENSO cycles in the Central Andes.

From figures 1 and 2, it is possible to point out some general features. Ablation is always very strong early in summer (October-December), before the full precipitation season which extends normally from January to March. A second ablation peak is observed immediately after the humid months of April and May. The dry cold months (June-August) may be considered as a *steady state* period for the largest surface of the glacier. Nevertheless, other features may be observed.

- 1) The ENSO year 1991-92 was characterised by a clear shrinkage of the accumulation period near the ELA (< 2 months); this year, as the others in general, it was observed that a deficit in the precipitation during the wet months is always associated with strong ablation rates, even at high altitudes (5,300-5,500m). This was observed in January 1994 and February 1995.
- 2) During the last two years, it was also possible to measure notable ablation rates during the dry season, particularly in August 1994 and July (and August) 1995.

## CONCLUSIONS

1. The complexity of ablation and accumulation regimes in the tropics makes it necessary to survey glacier balance every month.
2. The intensity of ablation closely depends on the variability of precipitation distribution during summer; the high quantity of energy and humidity available between October and April explains the main peaks of runoff occurring during this period.
3. Ablation rates during the cold-dry season may be important, as shown by the last two cycles.

Energy balance measurements conducted on the glacier surface will make it possible to explain how climatic variability controls glacier behaviour, making these glaciers useful indicators of climatic change at low latitudes.

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Fig. 1 : Monthly mass balance at 5,200-5,100m (ELA position when mass balance is in equilibrium). Mean values of 7 representative stakes

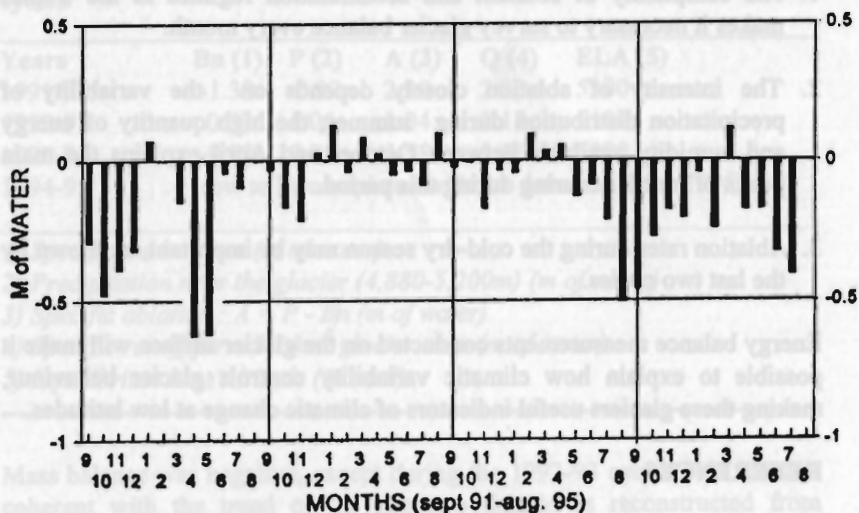
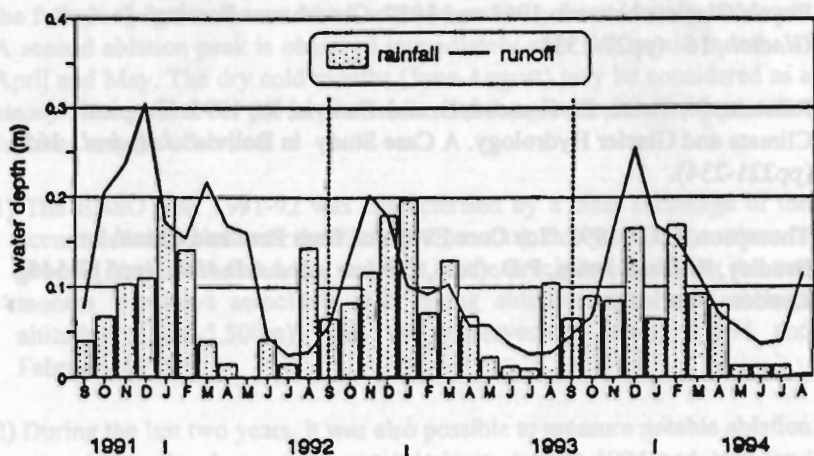


Fig. 2 : Month precipitation (average of 4 rain-gauges) and runoff during the 4 cycles 1991-95 (1994-95 to be added in the definitive version of the paper)



# SCANNING ELECTRON MICROSCOPIC STUDY OF QUARTZ GRAINS OF DOKRIANI BAMAK (GLACIER), GARHWAL HIMALAYA, INDIA

**J.T. GERGAN AND D.P. DOBHAL**

**Waida Institute of Himalayan Geology, Dehradun - 248001, India**

Dokriani Bamak (glacier) is located in the Garhwal Himalaya, west of Gangotri Glacier, between 31°49' to 35°20' north longitude and 78°74' to 78°51' east longitude. This glacier is one of the glaciers on the southern slopes of the Gangotri group. It is a valley glacier. The meltwater of Dokriani Bamak forms the Din Gad, a tributary of Bhagirathi river, which joins the Bhagirathi river near Bhukhi village 52 km from Uttarkashi on the way to Gangotri temple.

The glacier originates from two cirques in the vicinity of Janoli (6,633m) and Draupadi ka Danda (5,716m). The ice flowing from the two cirques join at a height of 4,800m and form a fall. This ice-fall cascades down in a NNW direction from a height of 4,800 to 4,300m, then takes a turn in the westerly direction. At the base of ice-fall, ogives are developed. On the convex side of the turning zone of the glacier from NNW to W, a zone of stagnation on the margin of the glacier has developed. The glacier is free of large crevasses till it comes down to a height of 4,200m. It then moves through a 100 to 150m-wide crevassed zone, and finally terminates at a height of 3900 m. The total height of the glacier is 5.5 km.

At present, the Dokriani Bamak flows between the lateral moraines of the last glacial period, which stand nearly 100 to 150 m above the present day level of ice surface. In the lower half of the ablation zone, the debris content is very high. This is reflected by the large cover of supraglacial debris towards the snout and formation of supraglacial moraines and latero-frontal dump moraines. The supraglacial debris consists largely of angular blocks and fragments of gneisses and schists. Dumping of latero-frontal-dump moraines has been active for past few years with the recession of the snout,

at a rate of nearly  $10 \text{ m yr}^{-1}$ . Latero-frontal dumping was observed from 1991 to 1994.

The right margin has its source in the headwall on the western slopes of Janoli ridge. Freeze and thaw processes, supported by strong solar radiation and large diurnal temperature changes at an altitude of over 4,500m accelerate the erosion of the headwall of cirque. This is leading to oversteeping and enlarging of cirques by shedding coarse debris into the glacier, most of which fall into the crevasses at the margin of the cirques. The debris of the left lateral marginal moraine deposits are generated in the headwall north of Draupati Ka Danda cirque. A large part of the debris falls in the open crevasses in ice-fall between an elevation of 4600 to 4800 m . Some of this debris gets engulfed into the ice to form englacial sediments and some of it falls down into crevasses to form subglacial sediments. The left marginal moraines emerge out of the surface of the glacier at a height of nearly 4,800m . On the other hand, the right lateral moraines are formed at a height of 4,350m . The difference in formation between left and right lateral moraines is largely due to sharp turns in the flow direction of the glacier from NNW to W in the height zone of 4,350 to 4,200m. The two marginal moraines move down almost parallel to each other to a height of 4,000m. From there on they merge into each other to form a continuous supraglacial debris cover. Sizeable portions of the supraglacial debris of the two lateral moraines fall into crevasses to form sub-space and englacial debris in second crevassed zone at a height of 4,200-4,100m. The fraction of supraglacial debris is also transported by supraglacial streams.

The major source of glacial debris in the Dokriani Bamak glacier comes from the cirque walls and the smaller fraction from the reworking of the old moraines. Grain size analysis was carried out to separate fine and very fine fractions (63-250  $\mu\text{m}$ ) from glacial debris samples. An optical microscope was used to identify quartz grains and these were picked up for Scanning Electron Microscopic (SEM) studies. The surface textures of quartz grains through SEM have shown that quartz grains from supraglacial samples are mostly angular in shape. On the other hand, quartz grains from proglacial samples are largely subangular. Grains from old lateral moraines are angular to subangular. In the present study, it was observed that mechanical weathering is the predominant process. The evidence of chemical weathering has also been noticed.

# SNOW AND GLACIER HYDROLOGY IN NEPAL: PROJECT RESULTS FOR THE PROVISION OF DATA AND INFORMATION FOR WATER RESOURCES' DEVELOPMENT

## **W. GRABS**

Global Runoff Data Centre, Kaisein-Augusta-Anlagen 15-17,  
56068 Koblentz, Germany

## **O. BAJRACHARYA**

Department of Hydrology, Babar Mahal, Kathmandu, Nepal

## **C. HOTELETT**

Wissenschaftlicher Mitarbeiter, Kommission für Glaziologie der Bayerischen,  
Akademie der Wissenschaften, Marstallplatz 8,

D - 80538 München, Germany

## **R. KAYASTHA**

Department of Hydrology, Babar Mahal, Kathmandu, Nepal

Water is the primary renewable resource of Nepal and the main source of energy production in the country. To increase the efficiency of water resources' management in Nepal, information about the seasonal and regional distribution of river discharge originating from the snow and glacier fields of the high Himalaya, is necessary. In 1987 the Government of Nepal and the Government of Germany agreed to a technical cooperation project, between the Department of Hydrology and Meteorology (DHM) and the German Technical Agency (GTZ), to establish a measuring service for snow and glacier hydrology in Nepal.

Under difficult institutional and environmental conditions, six Hydrometeorological stations have been established in the high Himalayas for acquiring the meteorological and hydrological parameters. Modern technologies have been introduced with regard to station instrumentation, discharge measurements, data processing, and modelling. A monitoring system has been introduced to enable staff to control instrument functions, shorten repair times, check data plausibility, and analyse causes for data losses. On an average, about 70-75% of the data can be retrieved from the



station network. Since 1987, the data have been archived in an electronic database management system to facilitate queries, retrieval and the compilation of data products. Yearbooks, with mean daily data, have been prepared and published, including the 1993 data.

From the beginning, the elaboration of data products as input for water resources' planning and development was envisaged as an important objective. A conceptual mathematical snow and glaciermelt model has been selected and adapted to Himalayan conditions which show significant differences compared to conditions in the European Alps. The model has been calibrated for three of the six high mountain glacierized drainage basins, namely the Langtang, Imja, and Modi *Khola* basins. The model is applied by the trained staff of the Snow and Glacier Hydrology Unit within the DHM. The results show that, despite data gaps, it is possible to make good estimates of the snow and glaciermelt runoff from these basins. The model operates on a daily basis with precipitation and temperature as the main inputs. The results demonstrate that, together with daily radio contacts with all stations, it is possible to use the model operationally in a near real-time mode. The last step in the operationalisation of the system would be to establish telemetric capacity in stations that are of economic importance for harnessing water resources, e.g. in planned and implemented hydropower projects.

To assess water resources' potentials in the Himalayas, it is necessary to develop regionalisation models for basins without snow and glacier hydrology stations. Ground-based methods had to be preferred before remote-sensing techniques because of financial and technical constraints in the current project. First results obtained from the regionalisation effort indicate that simple regression models can give reasonable indications of snow and glaciermelt runoff potentials for ungaged basins in Nepal.

# EFFECT OF SNOW AND ICE ON THE GARHWAL HIMALAYA ECOSYSTEM

**SYED HASNAIN, RENOJJ THAYYEN AND  
DEVENDRA S. CHAUHAN**

Himalayan Glacier Project, School of Environment Sciences,  
Jawaharlal Nehru University, New Delhi - 110067, India

The Ganga River basin between 29° 45' - 31° 30' north latitudes and 78° 2' - 80° 7' east latitudes and having an area of 30,000 km<sup>2</sup>, is called the Garhwal Himalaya. The Garhwal Himalaya contains more than 1020 large and small glaciers (Vohra 1981). The ecosystem has extreme variability in relief, precipitation, and radiant energy input. This is reflected in the diurnal, monthly, and seasonal variations in climate and hydrological responses. The basin has permanent ice cover, and also receives abundant winter snowfall from westerlies. The pattern and the quantity of runoff above Devaprayag both in the Bhagirathi and Alaknanda Rivers depend, therefore, on the extent of winter snowpack, incidence and form of precipitation, and thermal regime which determines the pattern of melting in spring and summer time.

Much of the water in the Himalayan region during the summer season is supplied by the melting of snow and ice. Snowmelt in the Himalayas is important. In the western Himalayas, 70 per cent of the annual discharge of the Indus and its tributaries are comprised of snowmelt (Tarrar 1982). This contribution of snowmelt to the annual discharge of streams and rivers in the Himalaya declines from west to east. However, meltwater from glaciers and winter snowpacks plays an important role in the conditioning of the hydrological response of rivers and streams which rise from high Himalyan catchments. Though studies of the snowcover and hydrology of glaciers in the Himalayan region date back to more than a century earlier, there has been remarkably little work done on the parameters mentioned above, in this region. As a consequence very little is known about this component of the hydrologic cycle compared to other processes in this environment which are even less understood.

The high degree of uncertainty about natural processes in the Himalayan environment has made the situation in these regions even more vulnerable. Since the past four decades, the Himalayan region has seen transformations at an unprecedented rate. Developmental activity in the face of inexorable population increase has brought about changes in this fragile ecosystem despite a poor understanding of the biogeographical processes. Development has opened up the accessibility of these formerly remote areas, and has led to ever increasing demands on the natural resources of this region. The economy of this region, which has individually been subsistence-based, is now being oriented towards a market economy.

Data on discharge and sediment transfer, collected on main glacierised basins in the Ganga headwaters in the Garhwal Himalaya since 1992, is presented.

# RECENT CHANGES OF GLACIAL PHENOMENA IN THE KHUMBU REGION, NEPAL

**FUSHIMI HIROJI**

School of Environmental Science, University of Shiga Prefecture,  
2500 Hassakacho, Hikone, 522 Japan

**YABUKI HIRONORI AND SEKO KATSUMOTO**

Institute of Hydrospheric-Atmospheric Sciences, Nagoya University,  
Furocho, Nagoya 460-01, Japan

**YAMADA YUZURU**

Nagaoka Institute of Snow and Ice Studies, NIED, STA, Suyoshicho,  
Nagaoka 940, Japan

The fluctuation of 15 glacier termini were measured in the Khumbu region, East Nepal, in the 1970s and the glaciers are classified into 4 groups, retreating (8 glaciers), stationary (3 glaciers), advancing (3 glaciers), and irregular (1 glacier), according to their fluctuation rates.

Since the 1970s, almost all glaciers have shrunk greatly, although a possible advance was recorded for some glaciers during the first half of the 1980s. The rate of retreating of some glaciers has accelerated during the 1980s as compared to the 1970s.

According to the geometric image analysis using the Spot data of 1987 and 1993, the retreating trend of glaciers has been continuing in the Khumbu region where we are going to survey the changes of the glacial phenomena in the fall of 1995 in order to report the recent fluctuations of the glacier termini and glacier lakes and the related influence on the ecohydrology of the high mountain areas in the Nepal Himalaya.

# THE EFFECT OF SNOW AVALANCHES ON THE HYDROLOGIC REGIME OF KUNHAR BASIN IN THE PUNJAB HIMALAYA, PAKISTAN

**M. INAMULLAH KHAN AND ATHANASIOS LOUKAS**

Water and Power Development Authority,  
285/A Shadman Colony, Lahore, Pakistan

**MICHAEL C. QUICK**

Department of Civil Engineering, University of British Columbia,  
Vancouver, British Columbia, V6T 1Z4, Canada

This study sets out to investigate the effect of snow avalanches on the hydrology and runoff generation in the Kunhar basin in Northern Pakistan. The Kunhar River is a major tributary of the Jhelum river in the Punjab Himalaya of the North West Frontier Province, Pakistan. The basin area is about 2,500km<sup>2</sup> and its elevation ranges from 800 to 5,300m. The vegetation consists primarily of coniferous forest, extensively cleared pasture, and alpine tundra. The watershed has a seasonal snow cover which develops from early November onwards, reaching a maximum depth in March or April. Also, the snowpack increases greatly at the upper elevations. Snowmelt begins in early April and lasts until July or August when it overlaps with the Indian monsoon period. Temperatures are generally high during the snowmelt period, averaging about 14°C between May and August at the Battakundi station.

The Kunhar basin experiences intense avalanche activity above an elevation of 1,850m, which redistributes the snowpack for more than 2,000m of elevation (De Scally 1992). Recent attempts to simulate and forecast the flow from the Kunhar basin failed mainly because of the inability to forecast the redistribution of flow due to snow avalanches.

The objectives of this study are to analyse the snowmelt and snow avalanche effects using the U.B.C. watershed model and to produce a flow forecasting system which takes into account the snow avalanche effects.

The U.B.C. watershed model is used by the Water and Power Development Authority of Pakistan, to forecast flows from the Himalayan and Karakoram ranges. The structure of the model is based on hydrological behavior as a function of elevation in the watershed. Also, the model can be used to simulate the redistribution of snowpack caused by avalanching. Daily values of maximum and minimum temperature, and precipitation are the necessary meteorological input data. Temperature and precipitation data from the Battakundi station (2,660m), and temperature data from the Astore station (2,630m) were used in this study.

The U.B.C. watershed model was first calibrated to nine years of flow record (1979-1988) at the mouth of the basin without the influence of avalanches. The results of the original calibration for the nine years showed that the simulated flow deviates significantly from the observed hydrograph. For this original calibration, the total volume deviated by about 4% of the observed volume and the Nash-Sutcliffe coefficient efficiency was about 63%.

The above deviation from the observed data was mainly because of the non-representativeness of the precipitation measured at Battakundi station. For this reason, the representative precipitation factor in the U.B.C. model, POSREP, was adjusted for each year and a significant improvement in the results was achieved. For this second stage, the volume deviation was reduced to -1.9% and the coefficient of efficiency increased to about 78% for the years 1979-1989.

De SALLY (1992) documented and studied the avalanche activity in the Kunhar basin and it is believed that the distribution of snowmelt runoff will be considerably affected by the snow avalanches. For this reason, the U.B.C watershed model was used to estimate the effect of avalanches in the basin. To simulate the avalanche activity, each elevation band was separated in two sub-bands, the avalanche affected area, and the unaffected area. The U.B.C. model was calibrated again using precipitation adjustment factors, POADJ, for each avalanche-affected area of each band. The volume of snow subtracted by avalanches from the upper bands was made equal to the volume of snow avalanched to the low and mid-elevation bands.

By using the above procedure, the deviation of the flow volume was decreased to about 1.6% and the coefficient of efficiency increased to 84% for the nine years. The results of this analysis showed that the avalanche-

starting zone is located at band 6 which has a mean elevation of about 4,000m. The snow then cascades downslope and the runout and track zone are located at bands 3 and 4 with mean elevations of about 2,450m and 2,800m respectively. The percentage of the affected area by avalanches in the Kunhar basin is estimated to range from 12% to 21%. These results are in agreement with the results of the previous study (De Scally 1992). De Scally studied only a small area (288km<sup>2</sup>) in the upper valley of the Kunhar basin and extrapolated the results for the upper elevations. Furthermore, this study shows that about 16% of the snowpack at band 6 (mid-elevation 4,000m) is, on an average, subject to avalanching. The deposition of this snow occurs at bands 3 and 4.

These snow avalanches have a direct effect on the snowmelt. Firstly, the snowmelt in the runout areas starts about seven days later and lasts 20 to 30 days more than in the areas not affected by avalanches. As a result of the larger snow accumulation in the runout areas, the snowmelt volume increases by about 200 to 300%. Also, the maximum snowmelt from the avalanche runout areas is about 100% higher than the maximum snowmelt at the non-affected areas. The timing of the maximum snowmelt is delayed by about 15 days in the runout zones. These results show that snow avalanches increase both the volume and period of the snowmelt, also changing the distribution of the snowmelt.

The above results of flow simulation by using redistribution of snow were then used to produce a forecasting system for avalanche activity. This system was then used to forecast the flow from the Kunhar basin. Analysis of the results showed that the total avalanche volume and snow water equivalent due to avalanching, for each affected band (bands 3, 4, and 6), is highly correlated to the maximum snow accumulation of snowpack at band 6. Linear regression analysis was performed and the relationships for each band were estimated. The coefficients of determination of these equations were always above 90% with a maximum of 99%. This high correlation shows that there is a very strong relationship between avalanche activity and snowpack at band 6. So, if the snowpack at band 6 is measured, then the maximum snow accumulation, which occurs in late March or early April, can be estimated. From the developed equations, the total avalanche volume, the avalanched snow, and the affected area can be estimated and used in the U.B.C watershed model to forecast the flow for the coming season. The application of this procedure showed that the proposed forecasting system gives a reliable estimation of flow volume and distribution.





# MELTING AND EVAPORATION OF GLACIER SYSTEMS OF THE HINDU KUSH-HIMALAYAN REGION AND LIKELY CHANGES IN THE SYSTEMS AS A RESULT OF GLOBAL WARMING

**V.M. KOTLYAKOV AND I.M. LEBEDEVA**

Institute of Geography, Russia Accademy of Science, Stazomoretny St 29  
Moscow

The Atlas of the World Snow and Ice Resources has been recently compiled in Russia. The snow cover and glaciers of the Central Asian Region are given considerable attention in the Atlas. Maps illustrate the climatic conditions, snow cover, avalanches, glaciers, and melt water runoff in the region of the Hindu Kush and the Himalayas.

This report demonstrates that the existence of glaciers in the region is largely dependent upon the high mountains and a steep-slope relief, due to which the concentration of snow in the nourishment areas is several times the annual amount of solid precipitation. The amount of precipitation decreases by 50% as we go from the northern Hindu Kush macro-slope, subjected to the Mediterranean cyclones, to the eastern part of the Himalayas, which comes under the severe effect of the Indian monsoon in view of the annual maximum of precipitation being shifted from winter to summer. A diagram of atmospheric circulation is given, along with the zoning of the region based on the value of the vertical gradient of annual precipitation; there is also a map indicating the annual precipitation at the height of the equilibrium line, specifying the ratio of summer precipitation and the prevalent type of precipitation.

The studies on glacier melting and evaporation processes, carried out on the basis of an enormous volume of in-situ observations and secondary sources, have revealed that the main factor influencing melting in the entire region is total solar radiation. During the summer months, at equal altitudes from the Hindu Kush to the eastern tip of the Himalayas, it declines by one third as a consequence of greater cloudiness and pressure of the water vapour in the

air produced by the growing effect of the Indian monsoon. Frequent snowfall and abrupt rises of albedo serve to weaken the radiation factor of melting still further. At the same time, the length of the melting period from the northwestern to the southeastern part of the region increases from three summer months to a year, owing to greater influx of solar radiation during the autumn-winter-spring period. This increase in length of melting period is encouraged by the maximum of cloudiness and precipitation during the winter season in the Hindu Kush and their minimum in winter in the Himalayas. The ultimate annual value of ablation at equal heights of the equilibrium line is the same both in the Hindu Kush and in the Himalayas, even though the Himalayas are situated much more to the south.

Maximum evaporation from the glaciers (the first hundreds of millimeters per year) has been observed in the Hindu Kush, due to dry and clear weather during the melting period. Here, in the inner areas, the ratio of melting accounts for one fifth of the annual value of ablation. As we proceed to the eastern tip of the Himalayas, summer evaporation gives way to condensation, due to the saturating humidity of the monsoon air masses, and evaporation prevails for the rest of the year. The ratio of evaporation in the annual value of ablation amounts to the first few per cent.

The entire region under consideration is punctuated by local fields of penitents that are formed in the process of melting under conditions of a powerful influx of direct solar radiation, negative air temperatures and low pressure of water vapour. These conditions exist in summer in the Hindu Kush and in spring in the Himalayas. A map is given showing the value of annual ablation of glaciers at the height of their equilibrium line, the ratio of evaporation in it, and the areals of penitent growth. In the inset, one can see the annual ablation-to-mean summer air temperature curves for the Hindu Kush, and Western, Central, High, and Eastern Himalayas. The values of annual ablation are found from the annual march of radiation and heat balance components in each of the aforesaid mountain countries. The balance components are calculated in accordance with a special procedure developed on the basis of field observations.

To elucidate the impact of global warming, several options for air temperature change were adopted: temperature rise by one degree in winter, with the earlier regime of precipitation; the same for summer, similar changes of air temperature, with a 15% increase in annual precipitation. A map showing the current air temperature in summer and annual amplitude of air temperature at the height of the equilibrium line is also given. The

areas of annual value of ablation decrease and increase, depending on the height of the equilibrium line subject to appropriate changes of climatic indicators, are shown.

# SNOWMELT RUNOFF ESTIMATION FROM A HIMALAYAN CATCHMENT USING THE SRM MODEL

**B.P. PARIDA**

Department of Civil Engineering,  
Indian Institute of Technology, New Delhi - 110016, India

Knowledge of runoff from mountainous watersheds is useful for planning eco-friendly micro- and mini-hydropower schemes. Such power plants not only augment the power supply but also help in employment generation in remote hill areas. In such an attempt, the Central Electricity Authority, India, has identified, besides other mountainous areas, the middle Himalayan region for the implementation of new hydropower projects. But, the general feature of the middle Himalayan region is that the major portion of the catchments located in this region are above 4,200masl and under permanent snow cover, and other parts of these catchments, below 4,200m, experience seasonal variations of snow cover. As a result of this, during periods of hot weather and rainfall, large quantities of additional flow take place in the mountainous streams. Therefore, proper planning and design of hydraulic structures across such streams would need a reliable estimation of snowmelt runoff.

From amongst several models available in literature, an attempt has been made to use a simple concept so that reliable flow estimation together with easy implementation of the model can be achieved. The SRM model of NASA, USA is one such model and is primarily based on the use of the degree-day concept. Besides, this model does not require elaborate data as do many other models, and hence is easily implementable.

The model has been used for snowmelt runoff estimation from a middle Himalayan catchment, namely the Goriganga catchment, which originates from the Milam glacier at an elevation of 3,600masl. The snow depletion rate estimation needed by the model has been carried out using actual snow cover data and LANDSAT-1 imagery. This, along with other hydro-meteorological data such as stream flow, rainfall, and maximum and minimum air temperature data for the same year, has been used to calibrate the model's

parameters, which in turn have been used to estimate snowmelt runoff values for the year 1988.

A comparison of observed and simulated flows, in general, showed a good agreement and the Nash-Sutcliffe Goodness-of-Fit Index was found to be 0.76. Based on the results, the model can be implemented for other snow-bound catchments, too, for reliable snowmelt runoff estimation. However, as the SRM model is very sensitive to lapse rates and degree-day factors, these should be determined very carefully. Even the snow cover depletion curves used in the model are established based on the number of satellite images for improvement in estimation.

# THE DISTRIBUTION OF GLACIERS AND SNOW COVER IN THE YARLUNG ZANGBO-BRAHMAPUTRA RIVER BASINS

**Z. QUNZHU, Y. ZEHNIANG, AND M. DESHENG**

Lanzhou Institute of Glaciology and Geocryology,  
Chines Academy of Science, 174 Donggang West Rd., Lanzhou, Gansu  
730000, China

The Yarlung Zangbo River flows from west to east, originating in the glaciers on the northern slope of the Mariyangzong Kangri mountains ( $30^{\circ}00'N$ ,  $82^{\circ}01'E$ ) in Tibet, China, with its main stream valley along the east-west fault zone. The Himalayan mountains are located in the southern part of the basin, while the Gangdise, Nyaingentanglha, and Baxoila mountains surround the basin on the northern and the northeastern sides. There are some main tributaries in the basin, such as the Nyang, Lhasa, Parlung Zangbo, etc.

The Yarlung Zangbo river turns sharply to the south around the Nangagbarwa Peak ( $7,782\text{masl}$ ,  $29^{\circ}30'N$ ,  $95^{\circ}10'E$ ), passing through the Himalayas and then turning southwest after flowing across the border nearby the Paxikar of China where it meets other tributaries, such as the Xibaxa, Kamen, Sankosh, Tista, etc, that originate in the south slope of the Himalayas. It takes the name of Brahmaputra in India. The total length of the Yarlung Zangbo-Brahmaputra-Jamuna is  $2,806.0\text{km}$  of which  $1,940\text{km}$  is within China, and the basin area is about  $5,19,570.0\text{ km}^2$  of which the  $3,37,230.0\text{km}^2$  is within China, accounting for 64.9% of the total basin area (Fig. 1).

The Yarlung Zangbo-Brahmaputra is located in an the area of low latitudes, with big changes in the elevation of the basin and an extremely remarkable difference of natural zone from the tropical zone and the aiphyllum of subtropical zone to the alpine frigrideserta. The warm and humid southwestern monsoon air in the Bay of Bengal travels along the river valley, along the terrain of the Himalayas, and results in abundant precipitation, reaching maximum values of  $4,000\text{mm}$  per year. According to

statistical data, precipitation in the basin decreases from the southeast to the northwest, by 4,496mm/year in Parikar, 1,000mm/year around Tangmai, and 634mm/year in Nyingchi.

In the middle and upper reaches of the river valley, the precipitation decreases sharply, leaving the area with less annual precipitation; for example, 434mm/year in Xigaze because the southwestern monsoon is affected by the protective screen of the Himalayas.

The glaciers and snow cover are widely distributed in the alpine area of this basin. The primary investigation shows that the glacial area in the whole basin is 16593.6km<sup>2</sup>, which is about 82.5%, of which 13682.6km<sup>2</sup> is on China's side. The annual runoff volume of glacial meltwater can only reach up to 173.19x10<sup>8</sup>m<sup>3</sup> in China, equalling 14.8% of the annual runoff volume at the border where the Yarlung Zangbo flows to India. The snow-covered area in the whole basin is about 57477.0km<sup>2</sup>, drawn from NOAA/AVHRR image of March 25, 1988. The distribution condition of glaciers and snow in each mountain system, and main branching streams in the basin, have been analysed (Table 1 and 2). Due to the impact of the global change, the temperature has risen and precipitation has decreased in the Yarlung Zangbo River basin. Hence the glacial annual mass balance is negative, about 300-700mm/year, and most of the glaciers in this basin have retreated recently.

**Table 1. The Statistics of Glaciers and Snow Cover in the Basin of Yarlung Zangbo-Brahmaputra River**

| Name of Mountain                    | Glacial Area (km <sup>2</sup> ) | Percentage of Glacial Area in Total Basin area | Elevation of Glacial Snow Line (m) | Snow Area (km <sup>2</sup> ) | Percentage of Snow Area in Total Area Basin |
|-------------------------------------|---------------------------------|--|------------------------------------|------------------------------|---|
| North slope of Himalaya Mts.        | 7407.8                          | 44.7   | 4500-6000                          | 15246.0                      | 26.5  |
| South slope of Himalaya Mts.        | 4274.2                          | 25.8   | 4400-5500                          | 26469.0                      | 46.1  |
| South slope of Nainyentangliha Mts. | 3797.6                          | 22.8   | 4400-5300                          | 9756.0                       | 17.0  |
| South slope of Gangdise Mts.        | 813.3                           | 4.9  | 5600-6000                          | 1965.0                       | 3.4   |
| South slope of Hengduan Mts.        | 300.7                           | 1.8  | 4500-5000                          | 4050.0                       | 7.3   |
| Total                               | 16593.6                         | 100.0  |                                    | 57477.0                      | 100.0                                       |

Note: The snow area in this basin is for reference only.

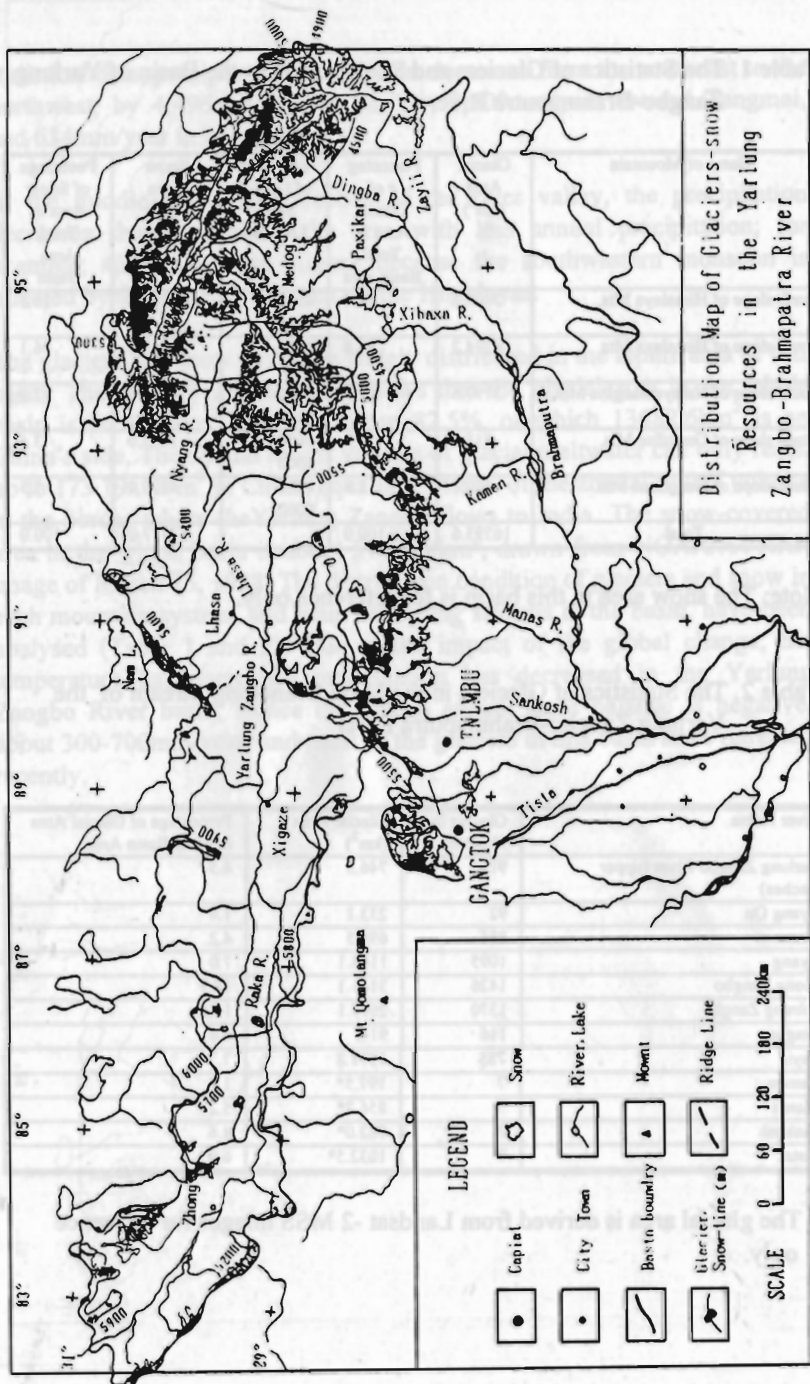
**Table 2. The Statistics of Glaciers in the Main Branching Stream of the Yarlung Zangbo-Brahmaputra River**

| River Name                           | Glaciers in Numbers | Glacial Area (km <sup>2</sup> ) | Percentage of Glacial Area in Total Basin Area |
|--------------------------------------|---------------------|---------------------------------|--|
| Yarlung Zangbo River (upper reaches) | 912                 | 746.3                           | 4.5  |
| Nyang Qu                             | 92                  | 233.1                           | 1.4  |
| Lhasa                                | 885                 | 690.5                           | 4.2  |
| Nyang                                | 1095                | 1164.1                          | 7.0  |
| Yiong Zangbo                         | 1426                | 3141.1                          | 18.9   |
| Palrung Zangbo                       | 1370                | 2699.1                          | 16.2   |
| Dingba                               | 116                 | 91.8                            | 0.6  |
| Zayii                                | 785                 | 1271.8                          | 7.7  |
| Kamen                                | ?                   | 197.5*                          | 1.2  |
| Manas                                | ?                   | 856.7*                          | 5.2  |
| Sankosh                              | ?                   | 762.0*                          | 4.6  |
| Tista                                | ?                   | 1032.5*                         | 6.2  |

\* The glacial area is derived from Landsat -2 MSS images for reference only.



Figure 1.



# GLACIER ABLATION UNDER DEBRIS COVER, FIELD OBSERVATION ON LIRUNG GLACIER, NEPAL HIMALAYA

**BIRBAL RANA**

Institute for Hydrospheric Atmospheric Sciences,  
Nagoya University, Nagoya 464-01, Japan

**MASAYOSHI NAKAWO**

Institute for Hydrospheric Atmospheric Sciences,  
Nagoya University, Nagoya, Japan

**YUTAKA AGETA**

Institute for Hydrospheric Atmospheric Sciences,  
Nagoya University, Nagoya, Japan

**JUMPEI KUBOTA**

Tokyo University of Agriculture and Technology

**ATSHUHI KOJIMA**

Faculty of Agriculture, Iwate University

## INTRODUCTION

One of the most common characteristics of glaciers in the Nepal Himalaya is the presence of a debris-covered surface in the ablation area. This tremendously influences the ablation process of the glacier itself. Evaluation of ice-melt under debris-cover is important for runoff modeling of glacierised drainage basins. In order to evaluate this melt, field observations were made, between 18th to 21st June 1995, near the active terminus of Lirung Glacier.

## OBSERVATION SITE AND DATA COLLECTION

Lirung Glacier is located in Langtang Valley, 60km north of Kathmandu, Nepal. Langtang Valley has been under constant hydrometeorological and glaciological observation from 1981. Heat budget observations, including temperature, relative humidity, wind speed and ground heat flux, were recorded at 5-minute intervals on three different debris sites of Lirung Glacier from 17th to 21st June. Ablation was measured twice a day on 30 points having different debris thickness from clean ice to 13cm thick ice. The site

was artificially prepared after clearing away the big boulders from the plots. A string to the surface was measured twice a day and the difference was taken as the ablation under debris.

## METEOROLOGICAL CONDITIONS

The mean air temperature during the ablation experiment period was  $6.1^{\circ}\text{C}$ ; relative humidity, 97%; incoming short wave radiation,  $121\text{W/m}^2$ ; wind speed,  $1.1\text{m/s}$ ; and total precipitation,  $11.5\text{mm}$ .

## RESULT AND DISCUSSION

Figure 1 shows the observed ablation rate with the debris thickness for day-time and night time. It was found that the maximum ablation,  $10\text{cm/day}$ , occurred under a debris thickness of  $2.5\text{cm}$ . At lower thicknesses, the reflectivity of the surface is high, and thus less energy can be used for ice melting. The critical thickness is approximately  $8\text{cm}$ . At higher thicknesses, the energy is stored and used for increasing the surface temperature and later released during night time, rather than conducting heat to lower surfaces for melting. Although, the order of the ablation is similar to observations made in the Punjab Himalaya (Mattson et al. 1993). The maximum ablation occurred at higher thicknesses. Figure 2 shows the comparison of the calculated ablation rate to the observed ablation rate using the energy balance equations (Nakowa and Young 1981). It can be seen that, during daytime, the calculated ablation rate, using the energy balance equation, overestimates nearly twice the observed ablation and during night time underestimates by half. This may be because the plots were in a lower valley than the energy budget observation site, and thus, less incoming energy is actually available for melting than is used.

Fig. 1. Relation between debris thickness and daily mean observed ablation, Lirung Glacier

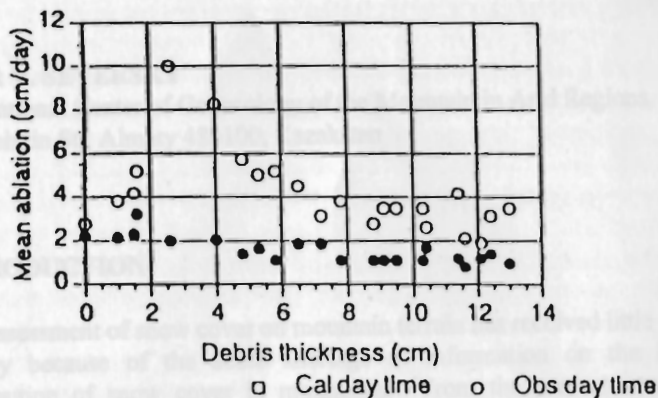
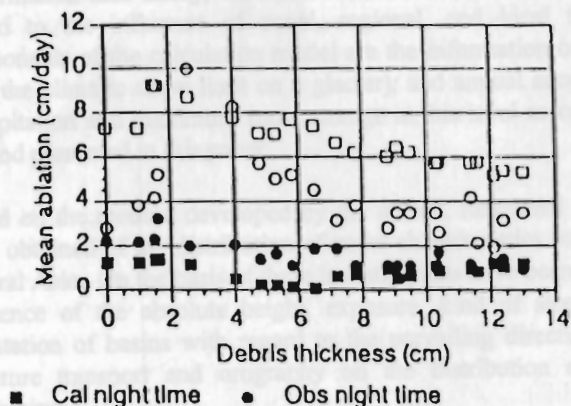


Fig. 2. Comparison of daily mean calculated to observed ablation during day time and night time



# DISTRIBUTION OF SNOW COVER IN THE MOUNTAINS OF CENTRAL ASIA

**IGOR V. SEVERSKY**

International Center of Geoeecology of the Mountain in Arid Regions,  
99 Pushkin St., Almaty 480100, Kazakstan

## INTRODUCTION

The assessment of snow cover on mountain terrain has received little attention, mainly because of the acute shortage of information on the kind and distribution of snow cover in mountains. From the present conventional surveys, it is impossible to determine the snow conditions on most of the mountain terrain by earlier methods. The author has developed a method that remedies the situation and allows one to evaluate the snow conditions in mountain territory, including for regions that have not been studied. The method is based on known regional relationships of snow conditions (periods of formation and decay, thickness and wetness of snow cover), with due regard to the influence of zonal, regional, and local factors. Important components of the calculation model are the information on the inferred firm line (the climatic snow limit on a glacier), and annual accumulation of solid precipitation and maximum snow storage at this level as calculated from the method presented in this paper.

Based on the method developed by the author, functional relationships have been obtained of the distribution of snow characteristics on the mountains of Central Asia. On the basis of these investigations have been undertaken on the influence of the absolute height, exposure, kind of sloping surfaces, and orientation of basins with regard to the prevailing direction of atmospheric moisture transport and orography on the distribution of snow cover in mountains.

## BASIC DATA

Methodical evaluations have been based mainly on the data of the standard snow surveys in the Pamir, Tian Shan, Gissaro-Alai, Altai, Caucasus,

Djungarskiy Alatau, and Alps. The information mainly used was contained in a catalogue of glaciers and scientific publications in hydroclimatology and glaciology for the Hindukush-Karakoram, Tibet plateau, and Kuen-Lun.

The method of assessing of the influence of local factors on the distribution of snow cover is based on the data of many year-round measurements at a special snow-measuring network (northern Tian Shan), including 35-60 (depending on the year), snow measuring platforms, which differed in absolute height, exposure, and kind of sloping surface.

The method of calculating the elevation of the climatic snow line is based on the empirical dependence of the mean elevation of the firm line on the glacier area. In the mountain regions of the world (Eurasia, North America) this dependence has an asymptotic character, and similar parameters that have made it possible to generalise the results of the definitions into a unified universal relationship (Fig. 1). It has been found that the glacial range in mountains decreases sharply as the glacier area increases to a certain limit and does not depend on morphological type of glacier and increasing area (Fig. 1). The paper presents empirical models for calculating the lower limit of a firm line.

Calculation of the height distribution of snow characteristics is based on typification presented by the author; for the conditions in the Pamir, Tian Shan, Djungarskiy Alatau, and Altai, eight types of vertical distribution of snow storage and three types of stable snow cover periods were found (Seversky and Blagoveshensky 1983, Seversky and Pimakina 1980).

## RESULTS

The analysis results of all accessible information about the snow cover in various regions of Eurasia, from the Alps in the West to the Altai-Sayon mountain system in the East, and from Kibin in the Scandinavian mountains in the north to the Pamir and Karakorum in the south, provide the opportunity to confirm that the snow-cover distribution in mountains of the interior continental regions depends on the following important relationships.

Similar conditions of relief and the position of the region, with respect to the periphery of mountainous countries, correspond to uniform character (type) in the spatial distribution of snow conditions. These show a close relation to absolute height and geographical location of a certain point. It should be

noted that the distribution of snow cover periods is more stable than the height distribution of snow storage.

Hence, the period of stable snow cover in the mountains of Central Asia are grouped into three types of vertical distribution. The first type, with the strongest vertical gradients of the considered conditions, is typical for orographically-open basins on the western periphery of mountainous countries. The second is for peripheral basins unfavourably-oriented with respect to the prevailing directions of moisture-bearing airstreams. The third, with the smallest vertical gradients, is for orographically-closed interior continental regions.

All three types are the same according to the character of the vertical distribution of the period of formation of stable snow cover. The greatest differences are found in the periods of decay of snow cover. The formation of snow cover is influenced by both the precipitation regime and temperature conditions which vary more or less smoothly over the territory. However, differences in periods of decay of snow cover depend mainly on the values of total snow storage.

The vertical distribution of maximum snow storage varies considerably: for the same territory, eight types of snow storage distribution with absolute elevation have been found.

1. The first type of this distribution, other factors being equal, is determined by the orientation of the macroslopes of mountain ridges towards prevailing directions of the moisture-bearing air streams (Fig. 3).

2. The vertical gradient of snow storage in the major snow basins decreases from west to east, the largest values of the gradients characterise the west slope of the Scandinavian mountains. These values are reduced by one half in the West Caucasus and even more at the western periphery of the Tian Shan and Altai. Within separate regions, changes of snow storage in the direction from west to east are not substantial in comparison to the change in function of absolute elevation in geographic latitude.

3. The influence of the effects of mountain massifs and orographic barriers is clearly indicated in the snow cover distribution in mountains. The first is apparent in a monotonic decrease of snow storage from the periphery to the interior of the mountainous country. The second is indicated in the sharp contrasts of the snow conditions on the windward and leeward slopes of

ranges, which present obstacles to the moisture barrier air streams. A clear example of the second effect is the distribution of snow storage on the slopes of the Katun Range in the Altai (Fig 4). In the Uba river basin, approaching the Katun range, snow storage increases drastically to a maximum at the ridge zone with a drastic decrease beyond the ridge; at a distance of 40-50km values decrease to those typical for the vast interior mountain region of the Altai.

4. The maximum snow storage continuously increases to the climatic snow line elevation in the mountains of the interior continental regions of Eurasia. From available information one can confirm that, above the snow line, the snow storage increases with elevation, at least to elevation contours to 200-400m below the ridges surrounding the mountain glacier basin (excluding separate peaks); above this level and approaching the catchment divides, the snow storage decreases in accordance with the redistribution of snow due to wind and avalanche action.

5. In most mountain regions, substantial redistribution by wind is found only above the upper forest limits; it is especially great in the ridge regions of the glacier-neve zone. Relatively large snow storage at the upper forest limit is a result of the redistribution of snow by wind. A second maximum of snow storage is found in many basins in the lower third part of the slopes of closed river valleys and at a distance of 200-400m below the ridges.

Characteristics due to local factors are superimposed on the general spatial pattern of snow conditions in mountains. Regarding the level factors, orientation of slope, character of vegetation, and wind conditions influence the distribution of snow cover. In some cases, the horizontal contrasts are larger than the vertical contrasts because of the importance of these factors. So, according to the influence on periods of snow cover in the Zailiskiy Alatau, a change of orientation from north to southwest corresponds to a change in absolute elevation by more than 1000m (Seversky and Seversky 1990, Seversky 1989 and Sosedov 1967). With the vertical gradients of maximum snow storage characteristic of the Zailiskiy Alatau, a change of orientation from north to east (west) corresponds to a decrease of absolute elevation by almost 1,000m. However, a decrease of snow storage from meadow slopes to coniferous forest is double the change corresponding to a decrease in absolute elevation from 2,500 to 1,500m.

The influence of slope orientation and vegetation character in the temperate snow region is greater than the influence of absolute elevation. In snowier regions, contrasts in exposure diminish. In the snowiest regions at the western



periphery of mountainous country these differences are small and determined by differences of exposure and losses by snow evaporation.

The characteristics of the distribution of snow cover in the mountains considered here are found in all interior continental regions of Eurasia. A comparative appraisal leads to the conclusion that the horizontal distribution of snow conditions, due to macroorientation of slopes, location of the regions with respect to the periphery of mountainous countries, and the influence of local factors, are greater than interregional and vertical differences.

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Figure 1. The dependence of firm line altitude on the area of glacier 1 - The Altai, Sayani; 2 - The Djungarskiy- Alatau; 3 - the Tien Shan; 4 - the Pamir - Alai; 5 - the Bolshoi Caucasus; 6 - the Alps; 7 - full field of points; 8 - zone where the glacier area is shown outside the scale ( $F 20\text{km}^2$ )

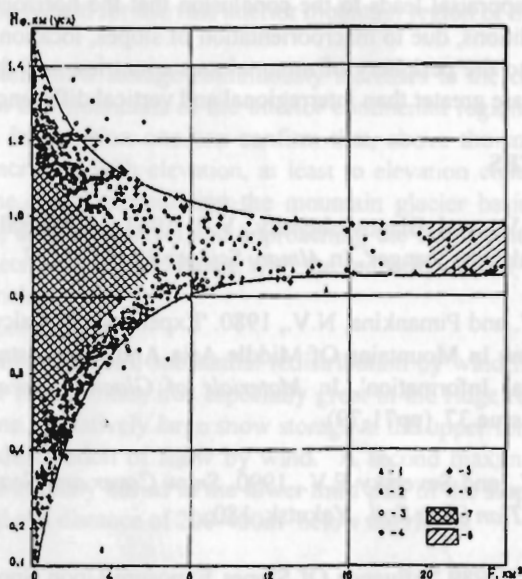


Figure 2. The altitude relations of the firm referred and upper forest limits and subalpine bushes. Mountain regions: 1 - the Altai, Sayani; 2 - the Djungarskiy Alatau; 3 - Tien Shan; 4 - the Pamir, Gissaro-Alai; 5 - the Caucasus; 6 - the Urals; 7 - Kamchatka; 8 - Himalayas, the Karakorum, Tibet, Alashan

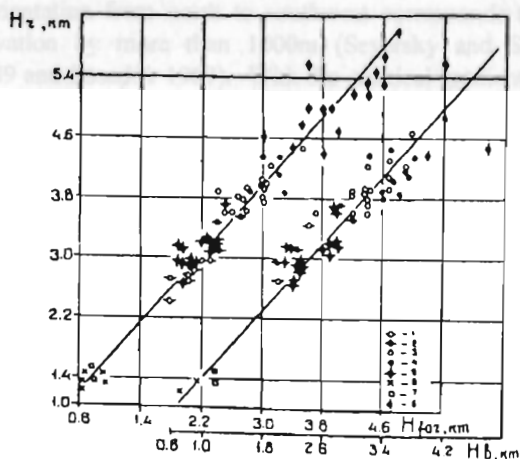


Figure 3. The standard dependences of the water maximum stock norms in snow cover  $W$  or the absolute  $H$  and the orientation in peripheral regions of the Tien Shan, the Pamir, and the Gissao Alai. Figures at the regress line mean an azimuth of the main river valleys dip

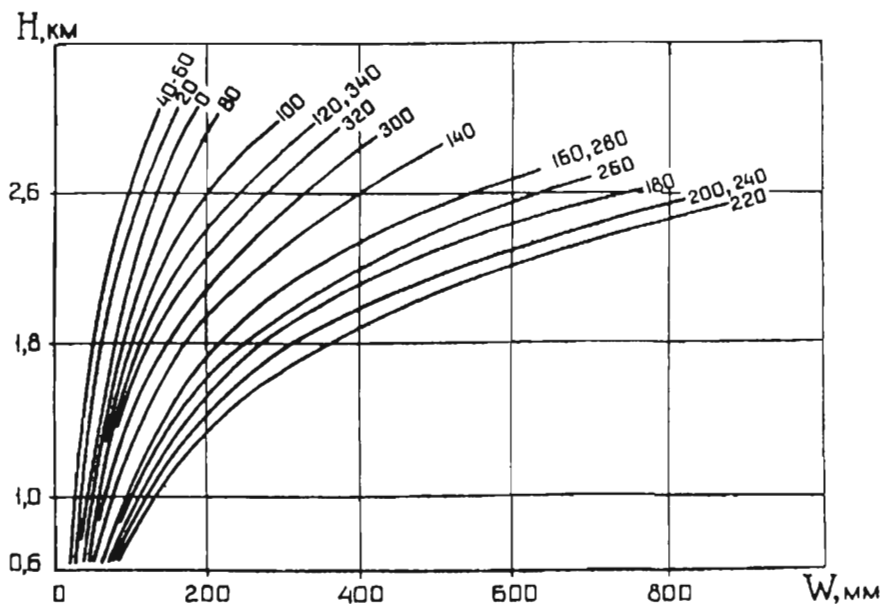
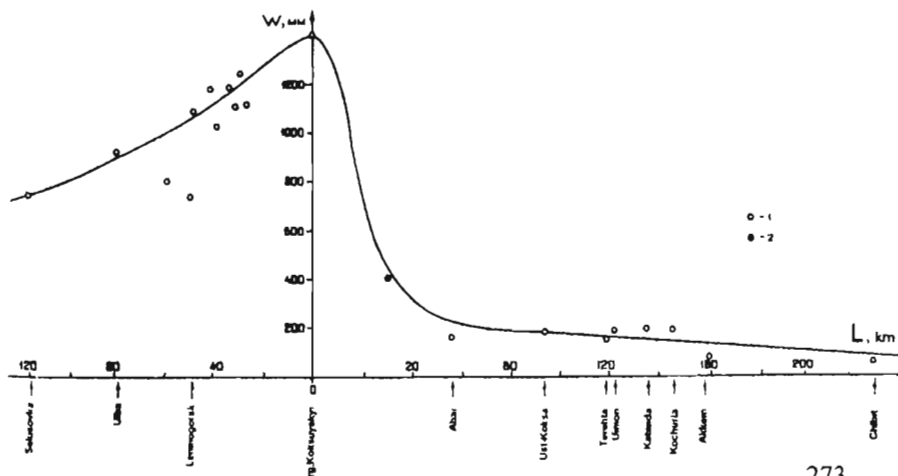


Figure 4. Distribution of average maximum snow stocks (put at a 2,000m height) on the Altai depending on a distance of orographic barrier (the Koksui ridge). 1 - by data of routine snow survey, 2 - by data of total precipitation measurements



# THE CONTRIBUTION OF GLACIER MELT TO RIVER DISCHARGE IN AN ARID REGION

**YASUYUKI UJIHASHI**

Department of Architecture and Civil Engineering,  
Fukui University of Technology, 3-6-1, Gakuen, Fukui, 910, Japan

**JINGSHI LIU**

Lanzhou Institute of Glaciology and Geocryology,  
Academia Sinica, 73000, Lanzhou, P.R. China

**MASAYOSHI NAKAWO**

Institute for Hydrospheric-Atmospheric Sciences, Nagoya University,  
Furo-cho, Chikusa-ku, Nagoya, 464-01, Japan

## INTRODUCTION

Cities in oases surrounding the southern Taklamakan Desert derive their water supply from rivers which originate in the West Kunlun Mountains, where there are many glaciers in alpine regions. Recently, it is feared that the desert area might extend with the retreat of glaciers due to global warming and the consequent decrease of river flow caused by it. This study deals with the contribution of glaciermelt to river discharge in two rivers originating in the West Kunlun Mountains, based on the water budget in the basins.

## STUDY BASINS AND DATA

### *Study Basins*

The study basins are the Yurungkax river basin ( $14,575\text{km}^2$ ) and the Keriya river basin ( $7,358\text{km}^2$ ). The Yurungkax river basin has an average height of 4,750m, and has elevations ranging from 1,650 to 7,000m. Similarly, for the Keriya river basin, the height ranges from 1,880 to 6,500m, the average being 4,878m. There are many glaciers in the alpine regions, above 5,000m, of the both basins. The glacier areas of the Yurungkax river basin and the Keriya river basin are 20% and 9.26% of the basin areas respectively. Maps of the basins are shown in Figs. 1 and 2.

## Data

No systematic data have been collected in the alpine regions of both the basins. Records of 34 or 35 years, of the hydrological and meteorological variables observed at the outlet of the basins and discharge, precipitation, air temperature and evaporation, and few meteorological elements from the stations surrounding the basins were available.

## METHOD

Taking into account glacier melt runoff and neglecting the mass balance of glaciers, the water budget equation of the basins can be written as (Ujihashi et al. 1995) follows.

$$Ps + Gm - Es - Q = f\phi S \quad (1)$$

where  $Ps$ ,  $Gm$ ,  $Es$ ,  $Q$  and  $f\phi S$  are the precipitation on soil surface (non-glacier area), the glacier melt runoff, the evaporation from the soil surface, the outflow from basin outlet, and the increment of storage respectively.  $Gm$  can be determined as the rest term in (1), when the other terms are estimated or observed. Dividing the entire basins into 10 or 11 zones, with elevations of 500m intervals and the spatial distribution of evaporation and precipitation were determined using the following simple relationships, (Ujihashi et al. 1995).

$$Pz = 0.09(Z - 1300) + 28 \quad (2)$$

$$Pz_{ij} = r_1(1+r_2)P_{0j}, \quad r_1 = Pz/P_{0m}, \quad r_2 = Cr(P_{0i}/P_{0m} - 1) \quad (3)$$

Where  $Pz_{ij}$  is the precipitation in the zone at an elevation of  $z_n$  in the  $j$ -th month and  $i$ -th year;  $Pz$  is the precipitation in the zone at an elevation of  $z_m$ ;  $P_{0m}$  is the mean annual precipitation at a standard station;  $P_{0i}$  is the precipitation at the station in the  $i$ -th year; and  $z$  is the elevation.

$$Ez = C\forall Ep, \quad C = 1 - \exp(-a\forall Pr) \quad (4)$$

$$Ep = 8.70Tz + 31.4 \quad (\text{Yurungkax river}), \quad Ep = 8.70Tz + 31.4 \quad (\text{Keriya river}) \quad (5)$$

Where  $Ez$  is the evaporation in the zone at an elevation of  $z_m$ ;  $Ep$  is the evaporation from a pan;  $a$  is a constant value ( $=0.0061$ );  $Tz$  is the monthly

mean air temperature at an elevation of  $z_m$ ; and  $P_r$  is the monthly precipitation in the zone.  $f_{zs}$  is neglected because it is small.

## RESULTS

The glaciermelt runoff estimated as the rest term in (1), the outflow from basin outlet, and the ratio of the glaciermelt to the total discharge are shown in Fig. 3 for Yurungkax river and Fig.4 for Keriya river. In the case of the Yurungkax river basin, the ratio ranges from 30% to 80% with an average of about 50%, with a few extraordinary values. In Keriya river, the ratio shows a wide range with the average value of about 43%. These results show that the role of glaciermelt is very important in hydrological processes in arid regions.

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Ujihashi, Y. et al. 1995 'Hydrological Study on the Contribution of Glaciermelt to River Discharges in the Taklamakan Desert, China' (In Japanese). In Nakawo (ed), *Study on the History of Desert Formations Using Ice Cores Analysis* (pp156-166). Nagoya: Institute for Hydrospheric - Atomospheric Sciences, Nagoya University.

Figure 1. Map of the Yurungkax river basin

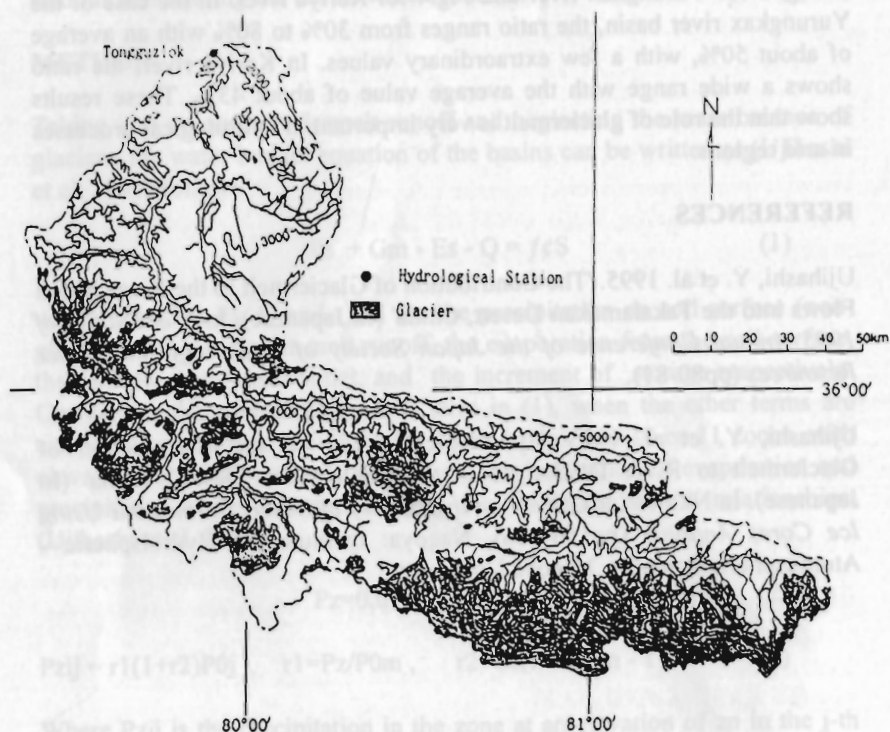


Figure 2. Map of the Keriya river basin

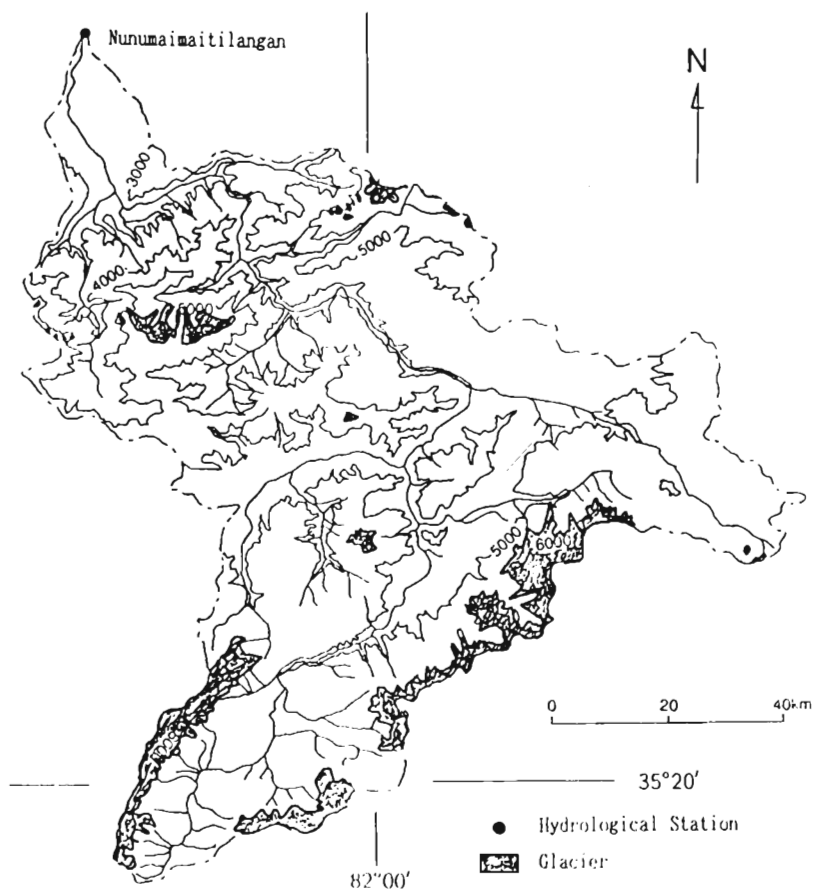




Figure 3. The time variation of glacier melt, river discharge and the ratio of glacier melt to river discharge in Yurungkax river basin

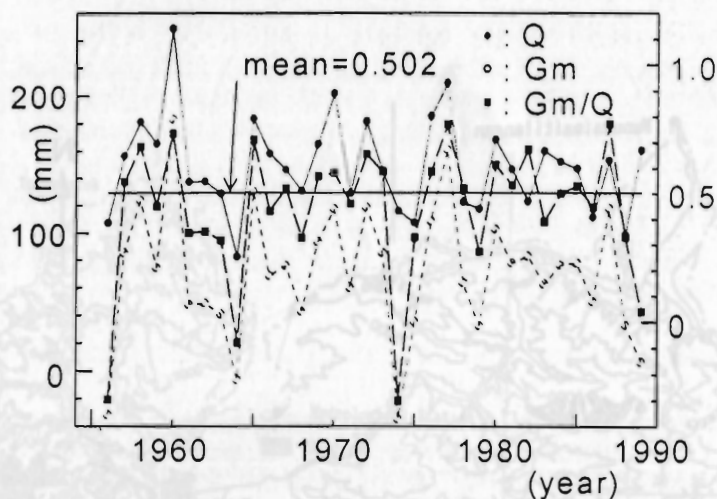
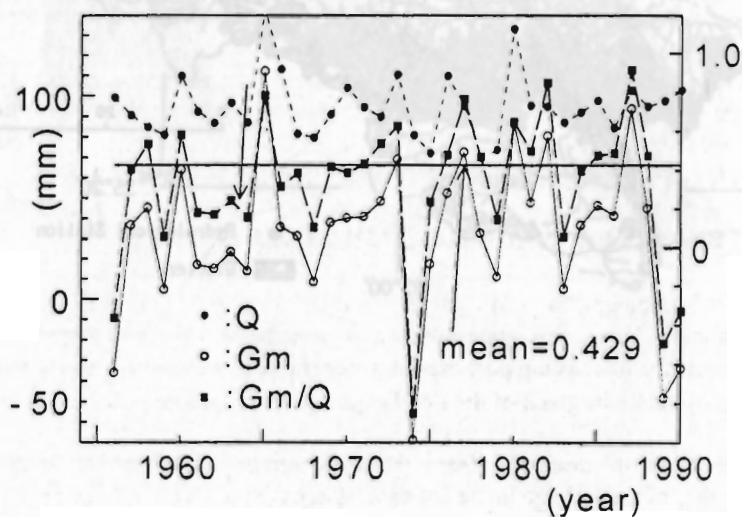


Figure 4. The time variation of glacier melt, river discharge and the ratio of glacier melt to river discharge in the Keriya river basin



# MATHEMATICAL MODELLING OF FLOOD AND DEBRIS FLOWS CAUSED BY OUTBURSTS FROM HIGH MOUNTAIN LAKES

**YURI B. VINOGRADOV**

State Hydrological Institute,  
23, 2nd Line, St. Petersburg, Russia

## INTRODUCTION

This paper discusses three models related to catastrophic hydrological occurrences in the mountains. The first model calculates and predicts a hydrograph of ice-dammed lake outbursts; the second model calculates the occurrence probability distribution of the volumes and maximum discharge of water from moraine lakes; and the third one computes the volume and discharge of flood water from the hydrograph as well as the volume and maximum discharge of debris flow. The three models are developed for high elevation mountains where occurrences of glacial outbursts are quite common.

Glacial outburst flood are quite rare on a particular site, but, in general, they are quite common in mountains of high elevations. This paper presents the principles of modelling of two dangerous hydrologic occurrences: outbursts from the ice-dammed lakes, and of moraine lakes.

## OUTBURSTS FROM ICE-DAMMED LAKES

Satellite photographs and glacial monitoring should provide sufficient information about the appearance and conditions of ice-dammed lakes. However, for forecasting purposes, it is beneficial to also have a mathematical model of the hydrograph of the flood expected from such an outburst flood.

The process of discharge from the ice-dammed lake, starting from the beginning of the leakage in the ice-dam, is considered. The leakage process is defined by two main sources: the increasing cross-sectional area of the tunnel

and the decline in the hydrostatic pressure due to a decreasing water volume in the lake. The assumption is that the potential energy of the water in the lake will be completely spent on the tunnel melt.

The modelling equation for the relationship between rate of expansion of the tunnel and decline of water volume in the lake is discussed.

The model computing outburst hydrographs with their characteristically strong negative asymmetry was validated for the following lakes: Lake George in the Chugach Mountains, Lake Alaska (1951), Lake Talsequa on the Coastal Ridge on the border of British Columbia and Alaska (1958), glacier lakes Medvezhii, in the western Pamir Mountains (1973), and Grenalown (1935, 1939) and Grimsvetn (1922, 1934, 1945) both in Iceland. Sufficient correspondence of the model was obtained with somewhat vague data for the lake Vatnsdalur (1898) in Iceland and the Pleistocene Missoula Lake in the Columbia River Basin.

In cases when the tunnel diameter is approaching dimensions corresponding to the size of the ice-dam, the model should be applied with great care.

## **MORaine LAKE OUTBURST**

Moraine lakes are very common in conditions of high elevation mountains. They appear, evolve, and disappear. Sometimes they burst out catastrophically. Forecasting such outbursts is best accomplished by using graphs showing temporal increases in water volumes in the lakes. If the graph curve has a parabolic shape, and the annual increment in water volume increases consistently, the outburst probability is very high.

For purposes of ecological planning in mountainous terrains with moraine lakes, the probability distribution curves of lake volumes and maximum discharge rates are required. Methods of calculation of such curves are not available. Nevertheless, there are some possibilities to obtain such distribution curves by mathematical modelling under some reasonable assumptions. The technique for such modelling, mainly stochastic but with some elements of deterministic approach, is discussed.

The methodology of the modelling can be applied to any high elevation mountain terrain, e.g. the Himalayas, Hindu Kush, Karakoram, Tibet, Andes, etc.

## DEBRIS FLOWS

In many cases, the proposed algorithms can be combined with the model of the transport-dislocation debris flows process. As a result, characteristics of a given probability for debris flows can be obtained. This process can occur only on the slopes that exceed the critical value.

Some of the problems stated in this paper are considered in more detail by Vinogradov (1977 and 1980).

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# FLOW SEPARATION ON ZONGO GLACIER

**PATRICK WAGNON, PIERRE RIBSTEIN AND  
BERNARD FRANCOU**

ORSTOM, CP 9214, La Paz, Bolivia

## INTRODUCTION

Measuring the electrical conductivity of meltwater runoff is a way to separate flow into two pathways through the glacial hydrological system (Collins 1979); englacial flow passes through ice-walled conduits or in surface channels where minimum chemical enrichment occurs whereas subglacial flow moves in contact with bedrock or sediments, thus becoming heavily solute-loaded (Lecce 1993). Field observations have been processed on Zongo Glacier not only during summer (which corresponds to a period of accumulation and strong ablation in this intertropical zone) but also during winter (which presents a limited ablation). This tropical glacier ( $2.1\text{km}^2$ ) is located in the Cordillera Real, Bolivia ( $16^\circ 15'S$ ,  $68^\circ 10'W$ ) and covers 77% of a southeast facing basin consisting of Triassic granodiorite (Ribstein et al. 1995). Two main proglacial streams, located on the right and left banks of the glacier, escape from the glacier tongue and feed a frontal lake drained by a unique stream. This discharge is permanently recorded by a limnimetric station. The objectives of this study are to examine diurnal variations of electrical conductivity as a function of discharge and to separate englacial and subglacial components.

## METHOD

Continuity of flow brings the equation :

$$Q_t = Q_e + Q_s \quad (1)$$

where  $Q$  is discharge ( $\text{l s}^{-1}$ ) and the subscripts,  $t$ ,  $s$ , and  $e$  represent total, subglacial, and englacial respectively. Moreover, if  $C$  is solute concentration

approximated by electrical conductivity ( $\mu\text{S cm}^{-1}$ ), the following equation gives an estimation of the subglacial flow  $Q_s$ .

$$Q_s = [(C_t - C_e)/(C_s - C_e)]Q_t \quad (2)$$

On the field site, the total discharge  $Q_t$  is measured at the limnimetric station and a portable WTW LF 96 conductivity meter, which automatically standardises conductivity values to a temperature of  $25^\circ\text{C}$ , was used to get  $C_t$ .  $C_e$  and  $C_s$  had to be estimated in order to evaluate  $Q_s$  from the equation (2). The conductivity of the meltwater, flowing at the glacier surface, gives an accurate estimation of  $C_e$  and the maximum conductivity value of the meltwater exiting from the glacier is the inferior limit of the  $C_s$  estimation.

## RESULTS-DISCUSSION

During selected survey days, maximum discharge occurred between 1300h and 1600h and coincided with a decreasing of conductivity values (Figure 1). This is coherent with the fact that, during warm hours of the days, solute free surface meltwater contributes to a large part of the total discharge and lowers the conductivity (Lecce 1993).

Unlike Lecce's observations (1993) of the Conness Glacier, California, USA ( $Q_s = 5\text{-}25\%Q_t$ ), the amount of water routed through the subglacial system contributes most of the water to the proglacial stream ( $Q_s = 60\text{-}98\% Q_t$ , except during exceptionally high discharge when  $Q_s$  lowered to 33% of  $Q_t$  : Figure 2). Since Lecce (1993) found a much smaller contribution for the subglacial flow, even though the bedrock is similar, the Zongo subglacial system may be more developed than the Conness one, due to size difference (Zongo :  $2.1\text{km}^2$ , Conness :  $< 0.5 \text{ km}^2$ ). These results are sensitive to the estimates used for  $C_e$  and  $C_s$ , which are fairly good because of the direct conductivity measurements of clean meltwater at the glacier surface for  $C_e$  ( $C_e = 1 \mu\text{S cm}^{-1}$ ) and various field surveys at different locations on the glacier for  $C_s$  ( $C_s = 40 \mu\text{S cm}^{-1}$ ).

Results from the two streams escaping from the glacier tongue are different. The right bank stream shows the same behaviour as the main stream below the frontal lake, although the left bank stream is mostly supplied by the englacial flow ( $Q_s = 19\text{-}43\% Q_t$ ). This suggests that the bedrock is bent from the left to the right bank. Therefore, most of the subglacial flow is driven from the left to the right bank of the glacier, which is why the right bank stream is larger and more heavily solute- loaded.

The discharge peak is 2 to 4 hours in advance of the conductivity minimum (Figure 1). Also, Figure 2 shows that the subglacial discharge peaks two or three hours before the englacial discharge peak. This out-of-phase response suggests that englacial and subglacial conduits are widely interconnected (Collins 1979). During the day, assuming that the daily discharge peak is mainly due to surface melting and, therefore, due to an increasing of englacial water volume, if these two systems were not interconnected, the daily discharge peak would coincide with the daily minimum of conductivity. The fact that the discharge maximum and conductivity minimum are delayed in time proves that englacial conduits are connected to subglacial ones.

During the dry cold winter, when conditions are different from the wet warm summer, total discharge variations are low and the contributions of englacial and subglacial flows remain constant during the day ( $Q_s = 55\% Q_t$  at the limnometric station). This proves that the two drainage systems are not to be interconnected and are to flow independently.

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Figure 1. Total discharge and conductivity on March 3, 1995

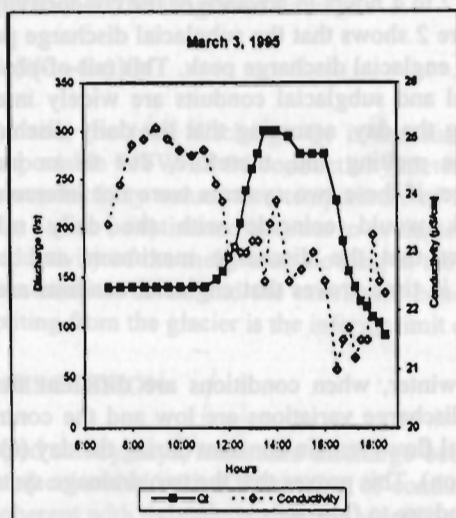
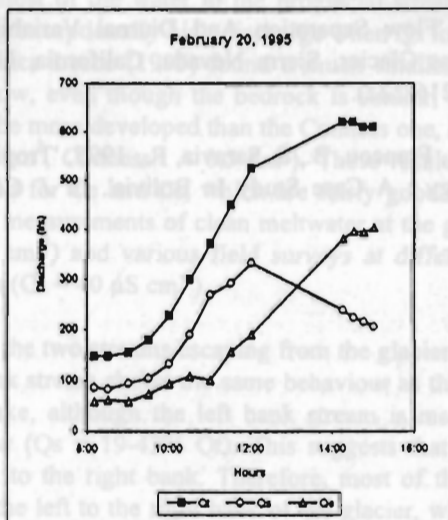


Figure 2. Flow separation on February 20, 1995





# RESPONSE OF CRYOSPHERE TO CLIMATIC WARMING SINCE THE 1980s OVER THE NORTHERN HEMISPHERE

**DING YONG-JIAN**

Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, Lanzhou 730000, China

The paper is mainly concerned with changes in glaciers, permafrost, and snow cover since the 1980s, over the northern hemisphere.

## VARIATION OF GLACIERS

Table 1 shows the glacier mass balance (B) average for 10 years, and relative variance of air temperature ( $\Delta T$ ) estimated by the linear relationship between mass balance and equilibrium line altitude (ELA) and difference between average ELA and ELAo as  $B=O$  (Ding 1995). It is found that, except for glaciers in Scandinavia, glacier mass balance is obviously decreasing in the 1980s compared to the 1960s and 1970s. Loss of mass balance is obviously decreasing in the 1980s, corresponding to the rise of 1.0-1.5°C in air temperature compared to the temperature of 10-20 years before. However, there is an increase of mass balance in Scandinavia even with a rise of about 0.7-1.0°C in air temperature. In the hemispherical range, loss of mass balance during the 1980s increased sharply by 1.3 times compared to the 1960s and 1970s, with a resultant rise of 0.38°C in air temperature.

Based on the sensitivity of change of small glaciers to climatic warming (Ding and Haeberli 1995), variations of front position of glaciers for lengths shorter than 2km are compared between the 1980s and the 1970s in the main glacier areas of the hemisphere (Table 2). It may be found that small retreating glaciers increased by 15-20% in the 1980s compared to the 1970s.

## CHANGE OF PERMAFROST

The change in permafrost since the 1980s is also remarkable. The change in permafrost temperature in the Alps has been continuously measured during the past several years (Haeberli et al. 1993). The results show that permafrost temperature at 10m depth is rising by 0.5-1.0°C per ten years, which resulted in twice the increase in thaw of underground ice in the 1980s than in the 1970s. The descending rate of surface height of the Gruben rockglacier in the Swiss Alps in the 1980s is two to three times more than in the 1970s. Surface depression of the rockglacier is caused by melting of the buried ice in the frozen layer (Vonder Muhll and Schmid 1993).

In the north of China, comparison of the 1970s with the beginning of the 1990s demonstrates that seasonal thaw depth has increased at least 30cm in the Amur area of Mehe county (Gu et al. 1993), and permafrost temperature at 20cm depth rose by about 0.8°C. The southern limit of perennial permafrost has degenerated 500-3,000m along both sides of the Daling River in the Lingzhong and Fuke areas in the 1980s compared to the 1970s, so that the range of thaw area has expanded remarkably and the island thaw area has appeared in the perennial frozen region (Yuan 1989). In the upper reach of Hilongjiang River, Hilongjiang Province, investigations have shown that, compared to the 1950s, the southern limit of permafrost in the 1980s has extended up to 50-100km along the valley and permafrost temperature at a depth of 10m has risen by 0.6°C (Yu et al. 1993).

In the Tian shan Mountains, northwest China, there is an obvious change in permafrost (Table 3). Comparison of permafrost temperature, frozen thickness, and table between the 1970s and the 1980s, in two quite close positions, shows that these permafrost characteristics vary with climatic warming.

## CHANGE OF SNOW COVER

The average area of snow cover in spring and within a year has been reduced by 1.4 million km<sup>2</sup> (4.5%) and 1.0 million km<sup>2</sup> (4.0%) in the 1970s and 1980s respectively, in the northern hemisphere.

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Table 1. Change of Air Temperature Relative to Zero Balance in Various Regions.  $\Delta T$  is Estimated by Difference between ELA and ELA<sub>0</sub> with Lapse Rate of 0.65°C/100m

| Durations           |                 | Alps | Scandinavia | Rocky Mts | Tianshan Mts | Mean |
|---------------------|-----------------|------|-------------|-----------|--------------|------|
| 1961-1970           | B (mm/yr)       | -60  | -118        | -427      | -84          | -184 |
|                     | $\Delta T$ (°C) | 0.2  | 0.5         | 1.0       | 0.2          | 0.5  |
| 1971-1980           | B (mm/yr)       | -24  | -45         | -343      | -354         | -192 |
|                     | $\Delta T$ (°C) | 0.1  | 0.2         | 0.7       | 1.0          | 0.5  |
| 1981-1990           | B (mm/yr)       | -590 | 267         | -912      | -418         | -413 |
|                     | $\Delta T$ (°C) | 1.7  | -1.2        | 1.9       | 1.2          | 0.9  |
| Average (1961-1990) | B (mm/yr)       | -255 | 35          | -567      | -285         | -216 |
|                     | $\Delta T$ (°C) | 0.7  | -0.2        | 1.2       | 0.8          | 0.6  |

Table 2. Ratio of Advance and Retreat of Glaciers for Length Shorter than 2km between 1970s and 1980s

| Glacier areas | Durations | Ad. Glaciers % | St. Glaciers % | Re. Glaciers % | Mass balance (mm) |
|---------------|-----------|----------------|----------------|----------------|-------------------|
| Alps          | 1971-1980 | 48.0           | 12.4           | 39.6           | -24               |
|               | 1981-1990 | 33.6           | 3.9            | 62.5           | -590              |
| North America | 1971-1980 | 53.9           | 18.2           | 27.9           | -117              |
|               | 1981-1990 | 31.8           | 26.8           | 41.4           | -386              |
| High Asia     | 1971-1980 | 26.3           | 12.4           | 61.3           | -265              |
|               | 1981-1990 | 7.1            | 15.4           | 77.5           | -380              |
| Mean          | 1971-1980 | 42.8           | 14.3           | 42.9           | -142              |
|               | 1981-1990 | 24.4           | 15.3           | 60.5           | -315              |

Table 3. Comparison of Some Permafrost Parameters between the Kuixian Pass and Source of Urumuqi River in the Tian Shan Mountains, China

| Position                | Date      | Altitude (masl) | Active Layer Temperature | Frozen Table (m) | Depth of Permafrost | Source          |
|-------------------------|-----------|-----------------|--------------------------|------------------|---------------------|-----------------|
| Kuixian pass            | 1973-1975 | 3271            | -2.0                     | 2.0              | 100                 | Qiu et.al, 1983 |
| Source of Urumuqi river | 1991-1992 | 3300            | -0.7                     | 3.0              | 50                  | Jin et.al, 1993 |
|                         |           | 3450            | -1.0                     | 3.5              | 60                  |                 |
|                         |           | 3500            | -1.6                     | 2.0              | 95                  |                 |
|                         |           | 3540            | -1.8                     | 2.3              | 100                 |                 |

# THE NATURE OF ABLATION AND AGGREGATION ON THE DUSTED SNOW SURFACE

**SUNIL ADHIKARY, KATSUMOTO SEKO, MASAYOSHI NAKAWO, YUTAKA AGETA**

Institute for Hydrospheric-Atmospheric Sciences,  
Nagoya University, Nagoya 464-01, Japan

**NOBUO MIAZAKI**

Climate Engineering

## INTRODUCTION

Actual glacier surfaces in the Himalayas are contaminated by natural dust which control the ablation of glaciers. Hence, it is important to understand the role of dust in glacier mass balance. It has been experimented on by several researchers in the past and it has been proved that dark material on the snow/ice surface increases melting in dust amount and, again, retards the melting beyond that limit. The amount of dark material on the snow/ice which exhibits exactly the same ablation as that yielded by bare snow/ice surfaces is called "critical amount". A satisfactory quantitative estimate of ablation under different meteorological conditions has not been achieved. To obtain comprehensive knowledge, snow dusting experiments were performed on the snow surface at Saiho, Nigata Prefecture, Japan, in March 1995. The two main purposes of the experiments are: (i) to get a better understanding of the relationship between the rate of dusting, meteorological conditions, and ablation rate; and (ii) to observe the nature of the aggregation of dust and examine its relation to the meteorological condition.

## METHOD

Black soils having the same grain size range ( $0.35 \geq \phi > 0.15$  mm), dry albedo (0.08), and dry density ( $448 \text{ kg/m}^3$ ) were uniformly spread in different amounts on 25 square centimetre snow surfaces. After making the plots, non-flexible graduated strings were fixed above all the plots. The depression at the plots were measured at gradations on the strings every one to two hours. To

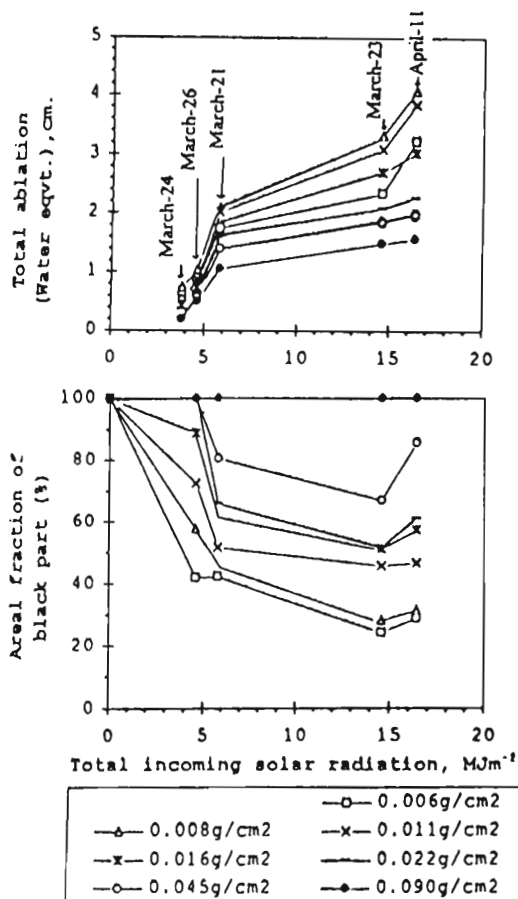
investigate the aggregation, photos of every plot together with a colour scale were taken at one to three hours intervals. Ten minutes averaged meteorological data such as air temperature, relative humidity, incoming solar radiation, and precipitation have been utilised for the analysis.

## RESULTS

Solar radiation is the most effective energy source which melts the snow/ice surface. Fig.1(a) illustrates total ablation under different solar radiation inputs. The ablation never shows a linear increase with increasing solar radiation. With more energy than  $5.8 \text{ MJm}^{-2}$ , the ablation is large but the increasing trend is gentle. The ablation was highest on the plot with  $0.008\text{g/cm}^2$  on each day it was checked. The critical amount for each experiment appeared to be different and showed a linear relation to the total incoming solar radiation, as Nakawo and Takashi (1982) have predicted from a modelling study.

The series of experiments show that particles of soil-dust change their location in a short time after melting starts. Due to the movement of particles on the melting crust, soil-dust had started to aggregate. In Fig.1(b), the areal fraction of the black part on each plot has been drawn against total incoming solar radiation. Areal fraction of black parts rapidly decreased for small inputs of energy of up to about  $5.8 \text{ MJm}^{-2}$ . At higher inputs of energy, where the melting rate is high, the aggregation becomes intense, causing an increase in albedo, and hence the increasing trend in ablation rate is suppressed. Therefore, it is considered that the aggregation of particles could be negative for melting. These results are quite encouraging and useful for studying the nature of ablation and aggregation of dust on glacier ice as well.

Fig. 1:(a) Relationship between total incoming solar radiation and total ablation with several dusting rates.  
(b) Dependency of the aggregation of the dust to the total incoming solar radiation



# THE ASSESSMENT OF SNOW ACCUMULATION, PRECIPITATION AND RUNOFF OVER THE KARAKORAM GLACIER SYSTEM FROM SATELLITE IMAGES

**KRENKE ALEXANDER AND NOSENKO GENNADY**

Institute of Geography, Russian Academy of Sciences,  
Staromonetny Lane 29, Moscow, 109017, Russia

The ablation over the glaciers could be calculated from the summer air temperature adjusted to the height of the snowline (Krenke 1982). By the definition of the snow line (more precisely - equilibrium line) the accumulation is equal to the ablation. The position of the snow line is possible to estimate from satellite images. The assessment of precipitation and runoff in the high alpine zone is carried out taking into account the accumulation on the glaciers, its relation to the solid precipitation, and runoff coefficient.

The glacier boundaries and their morphological types were estimated for the whole Karakoram on the satellite images made with cameras KFA-1,000 and KFA-200. The total surface of glaciers appears to be equal to 12,100 sq.km, their volume according to the typical thickness for each type is about 2,200 cubic kilometres, their water equivalent about 1,900 cubic kilometres. The altitude of the snow line on the glaciers was estimated using the analytical phototriangulation on overlapping images. The lowest (4,200masl) is the snow line on the glaciers on the southwestern slope of the Rakapochi massif, the highest (6,000masl) one is on the Central Rimo glacier. Along the western and southwestern slopes of the Karambar, Rakapochi, Kudjut, and Masnerbrom ranges, the snow line height decreases very rapidly to the southwest. The isokhyons are very close to each other. The snow line is relatively low along the valleys of Karambar, Hunza, Ind, and Shyok opened to the southwest. This permits us to conclude that the main amount of precipitation over Karakoram is generated by the Mediterraneanian cyclones coming from the west. The



influence of monsoon precipitation is reflected in isokhyon features in the western Karakoram only, but even there they play a secondary role.

The calculation of accumulation was carried out by the superimposition of the map of summer air temperature and the map of the snow line on the glaciers. The accumulation decreases from 3,500mm in the region of the Rakapochi massif to less than 500mm in the vicinity of the Tibetan border. The comparison with the measurements of the Chinese expedition on the Batura Muztagh glacier (Hunza River basin) shows the error to be as small as 10%. The typical features of the accumulation map are the isoline loops, reflecting the interaction of air streams with the complex mountainous topography. The existence of such streams is distinguished by the vegetation distribution on the images, too.

The precipitation is estimated as accumulation divided by the coefficient of concentration. For the assessment of this coefficient, the morphological type of the glacier and relation of its surface to the surface of surrounding slopes were taken into account. On the precipitation map, one can see its decrease to the northeast from 2,000mm on the southern slopes of Karambar range to 200 - 300mm in Tibet.

The glacier runoff in milimetres is assumed to be equal to the ablation at the snowline at first approximation. The total amount is about 17 cubic kilometres and the average period of mass turnover is about 120 years. The glacier runoff into the Ind River (14 cubic kilometres) is almost five times more compared to the glacier runoff in the Jarkand River.

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# RECENT CHANGES IN MID-LATITUDE MOUNTAIN CLIMATE AND SNOW COVER CONDITIONS

**ROGER G. BARRY**

National Snow and Ice Data Center/CIRES, University of Colorado,  
Boulder, Colorado 80309-0449 USA

## MOUNTAIN CLIMATE RECORDS

The value of climatic records collected at high mountain observatories over many years is being increasingly recognised. Valuable syntheses of climate records have recently been made for the Sonnblick Observatory in Austria (Auer et al. 1990) and the Pic du Midi Observatory (2,862m) in the Pyrenees (Bücher and Dessens 1991). At the Pic du Midi, there is a mean annual temperature increase of  $0.94^{\circ}\text{C}/100$  year (measured between 1882 and 1970) perhaps associated with an increase in cloudiness. The warming trend was most marked in spring and autumn and is shown to be greater at three mountain stations (Pic du Midi, Säntis, and Sonnblick) than at low elevation stations in western Europe. The mountain stations in the Alps (Säntis, Sonnblick, and Zugspitze) also show an increase of maximum and minimum temperatures whereas lowland stations in this area and also the Pic du Midi show that minimum temperatures increase much more than maximum values (Weber et al. 1994). This asymmetry in response merits further examination.

## SNOW COVER

Records of winter snowfall and snow cover in mid-latitude mountain areas have enormous economic importance for winter tourism as well as for water supply. Most records show significant short-term anomalies, in recent years and in the past, but there are few signs of any persistent long-term trends.

A 100-year series of snow depths on January 1 at Davos, an alpine valley station in Switzerland, indicates an interval with above-average depths around 1920 and lower depths in the late 1980s, but Föhn (1990) points out that the deficit in the latter period in January was offset by delayed springtime

ablation. Analysis of daily records from 1901 to 1992 at four Swiss stations (Davos 1,590m; Zurich 569m; Lugano 276m; and Säntis 2,500m) confirms the occurrence of below average snow depths in the late 1980s to early 1990s, but shows that values were still lower and snow cover duration shorter in the 1940s (Beniston et al. 1994 and personal communication 1994). Röhner et al. (1994) note the lack of a general trend and the wide interannual variability in maximum annual snow storage at 50 stations in the Swiss Alps, with records from the 1940s. In Austria, several different snow cover indices show no significant trends during the period from 1895 to 1990 in the Tyrol, despite a general warming (Fliri 1992). In contrast, Mohnl (1991) reports a decline in daily new snowfall amounts since the late 1970s at 40/51 alpine stations following an increase after 1930 in the northern Alps between 800 and 1,800m. Higher stations exposed to the westerlies show many snowy winters between about 1900 and 1925, when the circulation over Europe was more zonal in character. Station records and empirical estimates for the Snowy Mountains of Australia also suggest high and low snowfall regimes lasting 10 to 20 years, with no apparent overall trends (Duus 1992).

Eurasian snow-depth data up to 1984 for 284 stations across the former USSR have recently been processed at the National Snow and Ice Data Center, Boulder, Colorado, USA (NSIDC 1994). Twenty-five stations have snow-depth records beginning before 1921 and a further 85 begin during the period from 1921 to 1936. Time series of mean values of snow depth and associated daily temperature and precipitation amount have been analysed for the November to April cold season at 110 stations (Barry et al. 1995). Cold-season mean snow depths in different regions of the former USSR display considerable variation between locations although some broad patterns can be detected. In the southern regions of the former USSR, mean cold-season snow depths are lower and show less interannual variability. A decreasing trend is observed from the early 1950s at stations located in the middle elevations of central Asia and in the Caucasus region, except for increased depths during the period from 1965 to 1975, the decreases were associated with warmer conditions in the cold season.

Negative correlations between snow depth and temperature for the cold season range from 0.5 to 0.7 in the southern regions of this country; the highest values are located in the Caucasus region and central Asia at elevations between 600 and 2,000m.

## PROJECTED EFFECTS OF GLOBAL WARMING

Local and regional assessments have been made of changes in snow cover duration using GCM climate projections with simple indexing or changes in moisture balance and runoff via snowmelt runoff models. For the Victoria Alps, Australia, for example, Haylock et al. (1994) find snow cover duration to be highly sensitive to temperature. A 1°C warming could reduce snow cover duration by 50% or more at low to moderate elevations, with major impacts on the local skiing centers and related economy, whereas realistic precipitation changes will have a negligible effect. Corresponding studies have been published for Austria (Koch and Rüdel 1990). They calculate that snow cover duration will decrease by about 25 days per degree Celsius warming in winter. For the French Alps, Martin et al. (1994) simulate seasonal snow depth at 37 sites where observations are also available and evaluate snow cover sensitivity to a doubled CO<sub>2</sub> scenario. An air temperature increase of 1.8°C and modified radiation conditions are incorporated. They find that snow cover duration is reduced by 20% in the north (40% in the south), or 30-40 days at 1,500 m, but there is reduced sensitivity at higher elevations, contrary to the inference that climatic fluctuations on certain time scales may be more pronounced at higher elevations (Barry 1990).

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# APPROACHES TO REDUCING THE HAZARD OF AN OUTBURST FLOOD OF IMJA GLACIER LAKE, KHUMBU HIMAL

**RICHARD KATTELMANN**

Sierra Nevada Aquatic Research Lab, Star Route 1, Box 198,  
Mammoth Lakes, CA 93546, USA

**TEIJI WATANABE**

Graduate School of Environmental Earth Science,  
Hokkaido University, Sapporo 060, Japan

Glacial lakes are a common feature of the Himalaya in general and the Khumbu Himal region of eastern Nepal in particular (Ives 1986). Most of these lakes tend to be stable and pose little threat. However, some glacial lakes are naturally unstable because of the conditions that contain them. Many catastrophic floods have occurred in the Himalaya when a dam of moraine and/or ice failed suddenly and released massive amounts of water that had been stored in a glacial lake. In recent years, several glacial lake outburst floods in and near the Khumbu region have demonstrated the hazard (Yamada and Sharma 1993). An outburst from the Nare Glacier above Mingbo and Pangpoche in 1977 destroyed several houses along the Dudh Kosi River. In August 1985, the moraine dam of Dig Tsho in Langmoche Valley failed catastrophically, and the resulting flood destroyed the almost-completed hydroelectric plant near Thamo and disrupted trade and tourism throughout the region. About three million cubic metres of debris were transported dozens of kilometres downstream. In July 1991, the flood from Chubung lake in the Ripimo Shar glacier scoured the Rowaling valley and damaged structures near the river in Beding. Erosion was limited to tens of thousands of cubic metres of material in this small outburst. Field observations of changes in affected river channels caused by the latter two events were made in 1982, 1992, and 1994 in the Langmoche case and in 1983 and 1992 in the Rowaling case.

A lake continues to grow on the surface of the Imja Glacier east of Dingboche in the Khumbu region (Watanabe et al.1994). This glacial lake may be a serious natural hazard to villages immediately downstream and the

Dudh Kosi valley in general because of the possibility of a massive flood if its ice-cored moraine dam were to fail. Early indications suggest that a major hazard already exists but that failure of the moraine dam is not imminent. The lake is much larger than Dig Tsho and is located only a few kilometres above the villages of Dingboche, Pangpoche, and Phunkithangka, which are close to the river channel. Further downstream, villages such as Jorsale and Phakdingma and isolated homes and fields on river terraces could be severely damaged.

At the request of Khumbu residents, site investigations were made in 1994 to evaluate the feasibility of reducing the hazard of an outburst flood. The application of a siphoning technique (Grabs and Hanisch 1993) seems to be appropriate to the conditions. A siphon system is currently being tested at Tsho Rolpa in the Rowaling valley (Damen, personal communication). This test and its eventual expansion is an important development in engineering for reduction of the hazard of glacial lake outburst floods. Although the siphoning approach appears to be relatively effective, practical, inexpensive, and safe, there remains a substantial risk of seismic events, ice calving, mass failure of the lateral moraines, rapid incision of the outlet channel, and piping through the terminal moraine until the lake level is lowered. In the case of Imja Lake, there may be opportunities to harvest sections of the winter ice cover and move them over the moraine and to carefully excavate the long outlet channel in a sequential manner. Flood warning systems are a valuable intermediate step in reducing hazards to people (Kattelmann 1994). A warning system for the Imja and Dudh Kosi valleys, using observers and reliable radio communications is necessary until the risk of an outburst is reduced. Imja Glacier Lake presents a rare opportunity to actively reduce a natural hazard instead of just respond to the eventual damage.

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#### PUREV BAAT

Institute of Water Policy, Ulaanbaatar 211238, Mongolia

The Hentai mountains are situated near Ulaanbaatar in the northeastern part of Mongolia. They are situated near the southern boundary of permafrost of the northern hemisphere. In these mountains, uplands are characterized by discontinuous to continuous permafrost. The Hentai uplands experienced one to two periods of glaciation during the Pleistocene period. The high mountains of Hentai were subject to past glaciation as evidenced by the presence of cirques, troughs, and till sheets. The cryogenic processes and phenomena in these mountains are dominated by altitudinal zonality.

Based upon the intensity of cryogenic processes, these mountains are divided into three zones.

1. The gilet zone or tundra, above 2,300masl
2. Mountain Tundra zone, above 1,400masl
3. Forest-tundra zone, above 1,100masl
4. Mountain-slopes zone upto 1,100 masl

In the gilet zone, cryoplanation terraces are well-developed. The intensity



# PERIGLACIAL PROCESSES IN HENTEI - MOUNTAINS

**RADNA LOMBORINCHEN**

Institute of Geography, Mongolian Academy of Science,  
Institute of Water Policy, Ulaanbaatar 211238, Mongolia

**PUREV BAAST**

Institute of Water Policy, Ulaanbaatar 211238, Mongolia

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Based upon the intensity of cryogenic processes, these mountains are divided into three zones.

1. The golet zone or tundra, above 2,200masl
2. Mountain Taiga zone, above 1,400masl
3. Forest-steppe zone, above 1,100masl
4. Mountain-steppe zone upto 1,100 masl

In the golet zone, cryoplantation terraces are well-developed. The intensity of frost weathering, frost sorting, and solifluction is very high. In the Taiga zone, the intensity of these processes is moderate but icing is prominent. There is a vast difference in cryogenic processes in the northern and southern slopes in the forest-steppe zone. The northern mountain slopes are covered by the forests (larch, cedar) whereas the southern slopes are naked. The cryogenic processes and phenomena are confined to the northern slopes in this zone. The mountain steppe is different from others, with scanty cryogenic processes.

# STUDIES ON SNOW-COVER MONITORING ON THE TIBETAN PLATEAU BY REMOTE SENSING

**Z. QUNZHU, F. XUEZHI, W. GUANGYU, AND L. XING**

Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, Lanzhou, Gansu 730000, P.R.China

From the analysis of recent NOAA/AVHRR data and MSS images of Landsat-1 and 2, it has been found that the seasonal snow deposit on the Tibetan Plateau is mainly distributed in the following regions.

1. In the eastern and southeastern parts of the Tibetan Plateau, namely the eastern section of the Himalayan Mountains and other regions including the Nyainqentanglha Mountains, Hengduan Mountains, Anyemaqen Mountains, Bayan Har Mountains, and Qinghai Lake area, where the snow cover is about 50% of the total area.
2. In the western and northwestern parts of the Tibetan Plateau, namely the Ali region, Karakunlun Mountain, Western Kunlun Mountain, Pamir Plateau, etc.
3. In the mountainous areas around the Tibetan Plateau, such as the middle and western sections of the Himalaya Mountains, Kunlun Mountain, Qilian Mountain, etc.

On the vast Jiangtang upland, from south of the Yarlung Zangbo River to north of the Kunlun Mountains and the interior of the Hoh Xil region, the terrain is flat, the climate is dry with strong wind and less snowfall, and the snow deposits are distributed in patches. According to NOAA data statistics, the multiyear average snow cover area (1967-1983) of the Tibetan Plateau was about  $31.6 \times 10^4 \text{ km}^2$ .

In contrast to North America and Eurasia, the snow cover area on the Tibetan Plateau has a larger annual variation and exhibits a bimodal distribution, i.e. the first peak occurs from October to November in late

Autumn and early winter and the second peak occurs from April to May in the late winter and early spring. The snow cover area reaches a maximum of 16.3% in February in the whole region, followed by April and December. From late July to early September, the snow cover (including glaciers and permanent snow deposit) is least, amounting to only 5.3%. However, in the areas such as the upper reaches of the Yangtze River and the Yellow River in the eastern and northeastern parts of the plateau and the Qinghai Lake area, the snow cover area reaches a maximum in April.

In contrast to the northern hemisphere and Eurasia (Figures 1 and 2), the snow cover area on the Tibetan Plateau has a larger interannual variation due to greater precipitation variability in winter and spring. The variation coefficient ( $C_v$ ) of the snow cover area on the Tibetan Plateau is 0.536 ( $n=17$ ), while those of the northern hemisphere and Eurasia are 0.054 ( $n=20$ ) and 0.042 ( $n=20$ ) respectively. The study also showed that the period from the late 1970s to the early 1980s was the largest snow cover period of the plateau in the last 20 years.

Fig.1 Annual Variation of Snow Area in the  
North Hemisphere and Euro-Asia  
(From D.A.Robinson, 1993<sup>(1)</sup> )

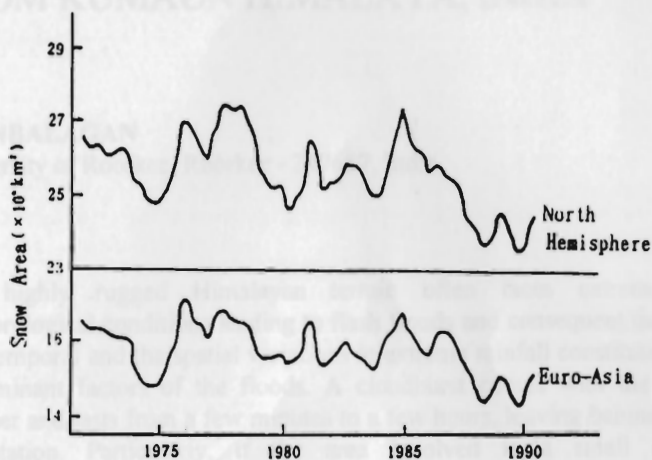
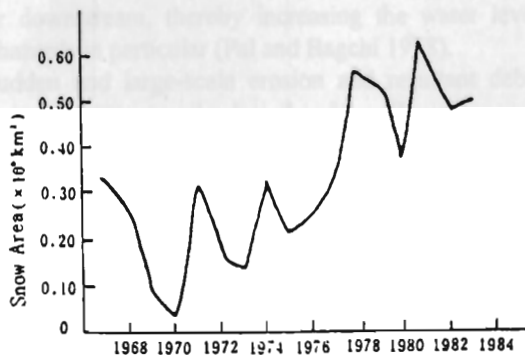


Fig.2 Annual Variation of Snow Area  
in the Tibete plature



# HAZARDS OF EROSION AND SEDIMENTATION DUE TO CLOUD BURST IN SMALL CATCHMENTS - A CASE STUDY FROM KUMAUN HIMALAYA, INDIA

**R. ANBALAGAN**

University of Roorkee, Roorkee - 247667, India

The highly rugged Himalayan terrain often faces extreme hydro-meteorological conditions leading to flash floods and consequent devastation. The temporal and the spatial variations in extreme rainfall constitute the chief determinant factors of the floods. A cloudburst comes with the speed of thunder and lasts from a few minutes to a few hours, leaving behind a trail of devastation. Particularly, if the area involved is a small catchment characterised by steep hill slopes and river bed gradients, the impact is more ravaging.

The most important adverse effect of cloud burst is the triggering of large-scale mass movement, which introduces enormous amounts of sediment to the drainage system (Carson et al. 1988). The consequences of large scale erosion due to cloudburst in small catchments is two fold .

- i) The excessive sediment load may cause aggradation of the river bed further downstream, thereby increasing the water level in general and flood hazards in particular (Pal and Bagchi 1978).
- ii) The sudden and large-scale erosion and resultant debris, including big boulders, may temporarily dam the river. The subsequent breaching may cause a devastating surge of water leading to excessive mass movements along its course.

In this connection, a case study related to a cloud burst in the Karmi area of the Kumaon Himalayas, India and the resultant flash floods leading to the washing away of many houses and loss of human lives and livestock, in addition to bank erosion along the Karmi stream, is presented.

# SOIL DEVELOPMENT ON GLACIAL AND GLACIOFLUVIAL DEPOSITS IN CENTRAL AND EASTERN NEPAL IN RELATION TO CLASSIFICATION AND LANDSCAPE HISTORY

**RUPERT BÄUMLER AND WOLFGANG ZECH**

Institute of Soil Science and Soil Geography, University of Bayreuth,  
D-95440 Bayreuth, Germany

Forty soils developed from glacial and glaciofluvial deposits between 2,700 and 5,000masl in the Langtang/Helambu (Central Nepal) and Mt. Everest (Eastern Nepal) regions were investigated to provide information about soil classification, zonal distribution, changes with elevation and climatic conditions, and their relation to the landscape history. The soils are mainly developed from deposits of the last main glaciation, and of Postglacial and Holocene advances. Parent materials consists of metamorphic rocks (mica, schists, gneisses). The soils were classified as Entisols, Inceptisols, and Spodosols according to the U.S. Soil Taxonomy (Bäumler 1994).

Chemical and clay mineralogical analyses indicate a strong influence of the elevation on soil types, and soil forming processes, integrating several factors of climatic conditions and bioclimatic zones (Table 1). Inceptisols predominate in the hill zone and lower tropical mountain zone between 2,000 and 3,000m. They are replaced by Spodosols in the subalpine forest zone and alpine shrub zone up to 4,500m. Eroded sites and locations above 4,500m show shallow and stony Entisols.

A decrease in the intensity of weathering with increasing elevation is shown by the decreasing clay content of the main weathering horizons (Fig. 1), which demonstrates the influence of climate on soil development. From the regression coefficients, an average decrease of clay content of 4.7 % per 1,000m can be calculated between 2,500 and 5,000masl. In masl comparison, the thermal gradient is 5.4 °C per 1,000m (Dobremez 1976).

Independent of it, iron fractionation and the calculation of weathering indices resulted in the differentiation of soils into groups of different soil development. One group of younger soils, with their main zone of weathering in the top horizons, were mainly developed from deposits of the last main glaciation and the Holocene Period. The relative-age estimates of this group of soils could be supported by the radiocarbon analysis of charcoal and buried A horizons (Bäumler et al. 1995). The other group of considerably older, highly-weathered soils was presumably derived from interglacial deposits (Bäumler et al. 1991). In the Solu and Khumbu Himal, indications on the history of the landscape are given by the distribution of these two groups of soils with different intensities of weathering. The highly-weathered soils of the second group are located at higher slope positions in the valleys than soils developed from deposits of the last main glaciation (Bäumler et al. 1991). This might indicate on ice marginal grounds, as the older soils are preserved and were not truncated or eroded by ice.

In the Langtang valley (Central Nepal), the group of young soils could be additionally separated into initial soils developed from deposits of the Little Ice Age or even earlier, and a group of Inceptisols and Spodosols. Those soils are developed on the moraines of the Lirung glacier, deposited between 3,100 and 500 yr. This could be supported by radiocarbon data, which also give evidence of climatic fluctuations at about 6,000 and 4,400 yr. characterised by accelerated solifluction and deposition of eolian material following warmer periods with humus accumulation and soil formation (Bäumler et al. 1995).

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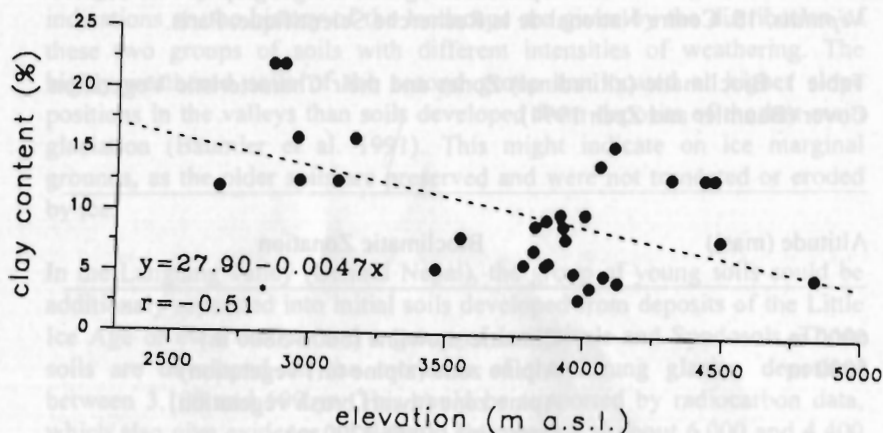
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Table 1: Bioclimatic (altitudinal) Zones and their Characteristic Vegetation Cover (Bäumler and Zech 1994).

| Altitude (masl) | Bioclimatic Zonation   |
|-----------------|--|
| 6000 m          | Climatic snowline (5600-5800 m)  |
| 5000 m          | Alpine zone (alpine turf vegetation)   |
|                 | Alpine zone (dwarf brush vegetation)   |
|                 | forest line (4000-4200 m)  |
| 4000 m          | Subalpine zone (coniferous forests with <i>Betula utilis</i> and <i>Rhododendron spec.</i> ) |
|                 | Upper tropical mountain zone (mixed forests)   |
| 3000 m          | Lower tropical mountain zone (deciduous and evergreen)                                       |
|                 | Tropical mountain forests of Conifers and <i>Quercus spec.</i> )                             |
| 2000 m          | Hill zone (mixed forests of <i>Quercus spec.</i> )   |
|                 | Subtropical zone (coniferous mixed forests of <i>Pinus roxburghii</i> )                      |
| 1000 m          | Tropical zone (semideciduous forests of <i>Shorea robusta</i> )                              |



Figure 1. Correlation between the clay content in the main zone of weathering of soils, developed from deposits of the last main glaciation and earlier and the elevation of the corresponding locations



# INTERDISCIPLINARY ALTITUDINAL TRANSECT AND RIVER CATCHMENT STUDIES IN MOUNTAIN REGIONS

**ALFRED BECKER**

Potsdam Institute for Climate Impact Research, D-144212 Potsdam, Germany

Mountain regions are gaining increasing interest as valuable hydrological and ecological resources. They feed downstream areas with water during dry periods when water shortage is often observed. To better understand the hydrological and ecological regimes in mountain regions, with respect to their dependence on climate and land-use conditions (and potential changes in these), has recently become one of the primary challenges for research. Major international programmes, such as the International Geosphere-Biosphere Programme, the International Hydrological Programme of UNESCO, and the World Climate Research Programme, are increasingly taking this into account and have initiated special research projects and activities including large-scale interdisciplinary field experiments. A brief overview of these activities and initiated special projects is presented in this paper.

It is clear that topography and land-surface heterogeneities related to topography, such as land cover, land use, soil, geology, etc, as well as topography-driven lateral redistributions of water in mountain regions, represent special problems in the understanding and modelling of processes on all relevant temporal and spatial scales. Considering the strong dependence of land-surface features and processes on topography, the application of an approach combining altitudinal transects and nested river catchment studies has been suggested. Coordinated measurements and field studies, supported by areally distributed detailed modelling, are planned to be implemented in selected mountain regions of specific interest.

Results of pilot studies in German and French middle mountain ranges have been presented and briefly discussed. They provide guidance in the further preparation and implementation of the suggested combination of altitudinal transects and nested catchment studies.

# SEDIMENT TRANSPORT IN GLACIER-FED RIVERS IN THE KARAKORAM

**DAVID N. COLLINS**

Alpine Glacier Project, Department of Geography, University of Manchester, Manchester M13 9PL, UK

Estimation of rates of contemporary processes of denudation in catchment areas in the Himalayan ranges is of considerable scientific and practical importance. Exceptionally large quantities of sediment are transferred downstream in the high specific discharges of Himalayan headwaters to the principal rivers of the Indian subcontinent. These sediment yields are of interest in view of possible anthropogenically-accelerated erosion of the lower slopes of the Himalaya which may accompany deforestation. Considerable accumulation of sediment occurs in existing reservoirs utilising runoff from mountain basins and will occur in those currently planned. Sedimentation and flooding problems also characterise the reaches of rivers downstream of the Himalaya. Glacierised basins in the high Himalaya have amongst the highest specific discharges and contribute large quantities of silt to meltwater runoff.

Rates of sediment transportation in rivers draining from glacierised basins within the catchment of the upper Indus basin in the Karakoram mountains were measured during spring and summer months in the years 1986 through 1991. At Batura Glacier, samples of meltwater were collected by an Epic automatic liquid sampler at intervals of from 1 to 3 between April and October 1990 from the single channel draining from the glacier portal, about 0.75km from the glacier terminus before the confluence with the Hunza River. Meltwater samples were collected from the rivers draining from Barpu, Bualtar and Passu glaciers with similar frequency but for shorter periods in 1986, 1988, and 1989, at short distances downstream of the portals. Samples were filtered and sediment concentration was determined gravimetrically. Stages were recorded continuously and discharge obtained from measured stage-discharge rating relationships on each site. The sediment flux was obtained from these data. Since 90% of the discharge

occurs between April and October, annual total sediment delivery from Batura Glacier can be estimated from this information.

The total sediment flux in 1990 from the basin of Batura Glacier, of which 60% is glacierised, was 3.950 Mt, or  $6.086 \text{ kt km}^{-2} \text{ yr}^{-1}$ . Assuming all the sediment was derived from under the ice, specific yield from the glacier would be  $10.144 \text{ kt km}^{-2} \text{ yr}^{-1}$ . By comparison, sediment delivery to the Arabian Sea by the pre-dammed Indus would have been about 460 - 500 t  $\text{Km}^{-2} \text{ yr}^{-1}$ . Batura Glacier provides about 0.5% of the discharge of the Indus from 0.07% of the basin, But 0.87% of the sediment yield. The shorter periods measurements at other glaciers give an indication of the variability of sediment yield in the Karakoram, and allow an estimate of the total sediment yield from the Hunza basin, and from the glacierised area therein. 13.8% of the sediment flux at the mouth of the Indus is derived from the Hunza, 58% of that from the glacierised areas which make up 1.4% of the area.

These data show the importance of glacierised basins in the Karakoram to the sediment budget of the Indus, and demonstrate the high yields of sediment from high mountain areas of the Himalaya, which play a major role in world sediment delivery to the oceans as a whole.

# RESEARCH ON ENVIRONMENTAL CHANGE IN SOUTHERN TIBET

**LEBER DIETHARD AND HÄUSLER HERMANN**

Institute of Geology, Geocenter, University of Vienna, Althanstraße 14,  
A-1090 Wien, Austria

Within an international geoscientific remote sensing-based project, the environmental change in southern Tibet is studied. The aim of the project is to analyse the geomorphological development of southern Tibet in general and the severe erosion phenomena in particular, to understand and interpret today's environmental situation as a possible tool for the prediction of its future development. For this reason, detailed geological and geomorphological investigations were carried out in the Xigatse-Gyangtse-Lhasa test site in southern Tibet as a ground check for digital analysis and interpretation of various remote sensing data (Häusler and Leber 1995 and Leber et al. 1995). In addition, a time series analysis of climatological and hydrological data serves as background information for the evaluation of environmental change within the last 50 years (Leber, in press).

The analysis of data from 29 meteorological stations from the last two decades shows in the annual mean precipitation to be decreasing in general north of the Himalayan range. Only the southernmost meteorological stations in Tibet show an increasing precipitation during the summer monsoon, from 3% up to 25%, when comparing the decades 1981-90 with 1971-80.

The results of the analysis of data from 16 hydrological stations along the Brahmaputra-Yarlungzangpo river and its tributaries will be presented within this paper. In particular, the discharge and suspension load of the rivers are of interest for a semiquantitative estimation of the monthly erosion and sediment transport up to 7,000m- high drainage basins.

The interpretation of the suspension load as a sum-parameter of different erosion and transportation processes on the one hand, and an unknown amount of the totally eroded material (from pebble-size to clay-size) on the other hand, is, of course, very risky. According to the data available, it should be

seen as a first attempt for an estimation of erosion in southern Tibet. To set up a semiquantitative regional erosion model of the test site, the system "rock-weathering - sediment cover - precipitation- runoff - land use" must be calculated. The area consists of mainly granitic rocks north of the Yarlungzangpo river and of sandstones, conglomerates and basic to ultrabasic rocks in the south. Large areas are covered with debris and sand dunes. Natural vegetation is rare, only mountain pastures and scanty shrubs were found. Severe linear and areal erosion can be noticed. In addition, the river basins and adjacent hills are intensively utilised by agriculture. The simple questions, therefore, are first, can a natural change of the environment be evaluated; and second, can an anthropogenic influence be estimated?

Analysing the data of the hydrological stations between Xigatse and Lhasa cities, the relationship between precipitation of the west-moving monsoon rain and the runoff is obvious from the discharge measurements. An increase in precipitation does not cause an increase in discharge immediately as the Yarlungzangpo river flows from west to east. It takes some weeks until the rain covers the whole area of the test site. Therefore, precipitation causes erosion earlier in the east than in the west. From the hydrological station Nugesha, situated west of the Yarlungzangpo gorge, data from 1956 to 1992 are available. Within this record, a maximum precipitation of 150mm was measured in July and August. The runoff doubles from June to July (up to 600m<sup>3</sup> per second) and reaches a maximum of 1,000-1,500m<sup>3</sup>/sec in August and September. A maximum of suspension load is measured between July and September with a total of 1,000-2,000kp per second. As a diminishing precipitation in autumn (September, 80mm; October, 15mm) can be correlated with a decreasing suspension load (1,000kp/sec in September to 80 kp/sec in October), it can be concluded that the maximum mean monthly precipitation, possibly due to heavy rainfalls causing mudflows, is responsible for the maximum erosion in the drainage basins.

The paper mainly deals with time series analysis of precipitation and suspension load; the interpretation of the erosion of drainage basins, and the interpretation of an obvious change in these environmental parameters within the last two decades.

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# EROSION PHENOMENA ON THE OLYMPUS MOUNTAIN, NORTH GREECE

**DIMITRIOS EMMANOULOUDIS**

Department of Forestry, Technological Education Institute (TEI),  
Drama 61 100, Greece

**THEOFANIS PAVLIDES**

Department of Forestry and Natural Environment, Aristotle University,  
Thessaloniki, Greece

Mount Olympus is located approximately 80km SW of Thessaloniki, the capital of Macedonia, Northern Greece. The highest peak of the Olympus (Pantheon), where the Ancient Greeks had placed the abode of Zeus and the Olympian Gods, has a height of 2,917m. This peak is surrounded by two more of similar height (Mytikas 2,911m., Scholio 2,802m.).

The most striking characteristic of the Olympus is that such a height is situated no more than 18km away from the sea, at a horizontal distance. This makes it one of the most precipitous seaside mountains in Europe (cf. Fig. 1).

This fact, combined with the presence of the sea, accounts for the extremely wide variety of climatic factors, that differ according to height. In the first 1,400-1,500m, Mount Olympus has the highest rain level in the Mediterranean, while in the valley situated right below its highest peak (Ennipeas Valley), the mean value of thunders recorded per year is 2,138 (cf. Fig. 2). No wonder Ancient Greeks believed that this was the abode of Zeus, the father of Gods, who cast thunder and lightning on men.

However, climatic factors do not only vary according to height, they also vary according to the time sequence. In other words, extremely rapid changes in weather can be seen quite often and there is consecutive sunshine, fog, clouds, rain, and sunshine.

The above climatic variations, according to height and time, result in an extremely aggressive erosion phenomenon on the slopes of Olympus. Thus,



despite the fact that the rocks on Olympus are hard (marble, limestone, etc.), due to the presence of the mechanism described above, important torrent effects can be seen, such as weathering, erosion of old clastic deposits and debris, minor landslides, etc, which are further aggravated by the permanent presence of snow (freezing, melting, etc). These torrent effects are most obvious in the areas of activity of the numerous torrents that scour the sides of Olympus, the biggest of which include Zeliana, Topoliani, Ennipeas, Xerolakkas.

This paper deals with an in-depth research of these erosion phenomena and examines the effects climatic factors in the area have on these phenomena, both individually and collectively.

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Figure 1. Weathering effects on Scholio peak (2,802m). The coastline is discernible in the background



Figure 2. The valley of Ennipeas. Weathering effects are clearly visible in the right-hand corner



# PROBLEMS OF LATE-GLACIAL AND HOLOCENE ADVANCES IN LANGTANG, NEPAL

**HELMUT HEUBERGER AND HORST IBETSBERGER**

Department of Geography, University of Salzburg, Hellbrunner Str. 34,  
A-5020 Salzburg, Austria

Langtang Lirung (7,234m), just above Langtang Village (3,500m), is by far the highest mountain of the central Langtang Valley. The relation between its former (local) glaciers and the former Langtang Valley Glacier is a key problem in the reconstruction of glacial fluctuations during the Late-glacial and Holocene period. Shiraiwa and Watanabe (1991) refined the moraine systems established by Heuberger et.al. (1984) and Ono's (1986) stratigraphy around Langtang Village. By convincing radiocarbon dates (Ono 1986, Shiraiwa and Watanabe 1991) they interpreted the Holocene glaciation in this area anew. Their reconstruction shows a Holocene advance of the (eastern) Lirung Glacier into the Langtang Valley (at the present-day Kyangjin Kharka and Gyaltsan Gompa, 3,900m) and extending along the main valley almost till the present-day Langtang Village.

That means, the (eastern) Lirung Glacier should have extended, during this Langtang Stage, to a length of about two thirds more than during the maxima of the Little Ice Age. This is, in comparison to the Holocene glaciation of the Himalaya and other mountains, an exceptional result.

In 1991, the authors carried out a field survey in this area, sponsored by the Fonds zur Förderung der wissenschaftlichen Forschung (Vienna), without knowledge of the new Japanese chronology. Our results only partly fit the results of Shiraiwa and Watanabe (1991) and Ibetsberger (1993).

A deciding item of Shiraiwa and Watanabe's (1991) hypothesis is their interpretation of the big sediment step across the main valley just above Langtang Village as a local terminal moraine, that is not of the Langtang Valley Glacier, but the (eastern) Lirung Glacier coming along the main valley. But the hypothetical connection between this terminal moraine and the oldest

lateral moraines of the (eastern) Lirung Glacier near Kyangjin Kharka is glaciologically not possible as the positions of the lateral moraines are too low.

The authors found the continuation of the mentioned lateral moraines at the left side of the (eastern) Lirung Glacier at Kyangjin Kharka, and even the left part of the terminal moraine following the terminal moraines of Shiraiwa and Watanabe's (1991) newly defined Lirung Stage.

Shiraiwa and Watanabe's (1991) radiocarbon dates and stratigraphy (Upper Till) giving evidence of the Langtang Stage and its Holocene age, are restricted to the area around Langtang Village and upvalley till Shingdum. But if this complex terminal moraine (just above Langtang Village, and Upper Till upvalley until Shingdum) are neither originating from the (eastern) Lirung Glacier nor from the Langtang Valley Glacier, to which glacier do these most important deposits of the Langtang Stage belong?

These glacial deposits are most probably originating from the Middle Langtang Glacier on the steep southern slope of the Langtang Lirung top, which can be seen on the map "Langtang Himal, West" of the Alperverein, 1990. Its two tongues terminate at above 4,800m. But grown during the holocene advances this glacier must have sent ice avalanches down to the bottom of the Langtang Valley around Shingdum and Möndrong, similar to what the Western Lirung Glacier did west of Langtang Village (Shiraiwa and Watanabe 1991), forming a secondary (regenerated) glacier. Some characteristic features of the Upper Till, after Ibetsberger's analyses, support this hypothesis.

The Langtang Stage, therefore, did not exist. The late glacial and post glacial fluctuations in the Central Langtang Valley must be discussed anew.

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# VARIATION OF EROSION AND SEDIMENT YIELDS IN MOUNTAIN AREAS OF LIAONING PROVINCE

YIN HSUEH-CHUN

Central Hydrological Station of Liaoning Province, Sheyay 110003, China

Soil erosion and its related sediment transport is one of the major environmental issues and is of central importance in considerations of environmental change. Using long-term records on precipitation and sediment transport, the characteristics and variation of erosion and sediment yields in mountainous regions of Liaoning Province are analysed in the paper.

There are different characteristics and variability of erosion and sediment yields in different parts of the province. The strength of soil erosion in the eastern part is small (modulus of annual sediment yield is 100-500 tonnes per square kilometre), as it has a high percentage of forest cover (30-45%), and resistance against soil erosion is strong. The strength of soil erosion in the western part is large (modulus of annual mean sediment yield is 1,000-5,000 tonnes per square kilometre) due to the quality of soil in the western parts and the low percentage (5-20%) of forest cover with weak resistance against soil erosion.

Analysis of annual sediment yields shows that the peaks occur in the same year as those of annual precipitation. The ratios of the maximum to the minimum annual sediment yields are 200-800 in the eastern part of the province and 100-500 in the western part which are far greater than similar ratios of annual precipitation 2-3 in the east and 2.5-3.5 in the west, and runoff 6-27 in the east and 10-35 in the west part.

Owing to many years of water and soil conservation work, including planting of trees, for several decades, annual sediment yields of river basins in the western mountain region of the province are decreasing greatly. For example, in the Jinzshou basin of the River Xiaoling, the five-year mean value of sediment yields in the eighties is 70-80% less than that in the

sixties under the same average areal precipitation (Table 1). However, in most of the eastern mountain region of the province, this is decreasing slightly. The five-year moving mean value of sediment yields in the later eighties is 20-50% less than the early sixties, under the same moving mean of precipitation as in the later eighties (figs. 1 and 2).

But in a few basins in the eastern mountain region of the province, annual sediment yields are increasing due to forest denudation. This is seen in the ten-year moving mean graph of annual precipitation, runoff, and sediment yields in Shalizhai station on the River Dayang (Fig. 3). It can be seen that the ten-year mean value of precipitation in the eighties is equal to that of 15 years earlier, but the ten-year mean value of sediment yields in the eighties is nearly 30% more than 15 years earlier.

It is observed from the above that the variation of sediment yields is easily effected by human activities. Owing to water and soil conservation, forest environment in basins will be improved. As forest cover increases, erosion in basins will lessen, sediment yields of streams will, correspondingly decrease. If water and soil conservation is neglected, forest environment will be harmed. As forest cover decreases, erosion intensifies, and sediment yields of streams will correspondingly increase. This should make our authorities aware of the great importance of water and soil conservation in reducing erosion and sediment yield.

Table 1. Comparison of Five-year Average Areal Precipitation and Sediment Yield in Jinzhou Basin

| Period    | Average Areal Precipitation (mm) | Sediment Yield ( $10^4$ tonnes) |
|-----------|----------------------------------|---------------------------------|
| 1963-1967 | 439                              | 588                             |
| 1983-1987 | 444                              | 132                             |



Fig. 1 Five year moving mean graph of hydrologic elements in basin Caohe

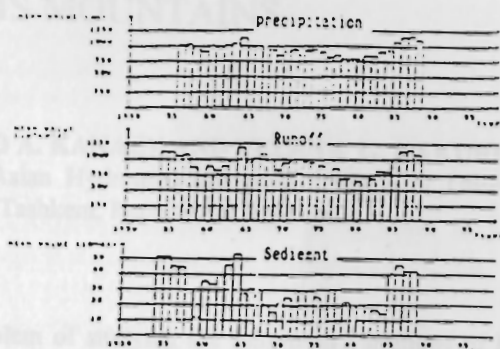
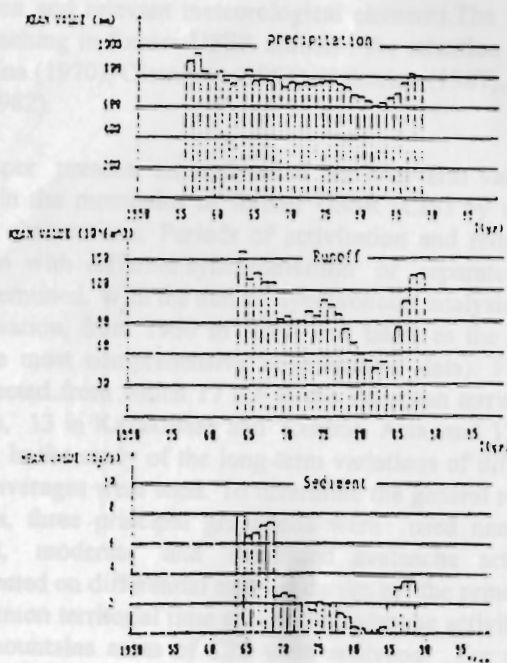


Fig. 2 Five year moving mean graph of hydrologic elements in basin Gengwangzhuang



# SOME RESULTS OF LONG-TERM VARIABILITY OF AVALANCHE ACTIVITY OF CIS MOUNTAINS

**LEONID A. KANAEV AND YELENA G. KAKURINA**

Central Asian Hydrometeorological Institute, 72, Observatorskaya Str.,  
700052, Tashkent, Republic of Uzbekistan

The problem of studying the long-term variations of hydrometeorological characteristics, e.g. precipitation, river flow, and avalanche activity, is of great scientific and practical importance. Druzhinin (1970) determined that sudden change in the sun's activity is the cause of the turning point of the long-term trend of numerous natural processes, including atmospheric circulation and relevant meteorological elements. The long-term variations in avalanching in former USSR attracted the attention of scientists such as Turmanina (1970), Oleinikov (1983), Kakurina (1987), Okolov (1986), and Sezin (1982).

This paper presents an analysis of the long-term variation of avalanche activity in the mountains of former USSR (CIS) by using the data from regular observations. Periods of activation and reduction of avalanche formation with different synchronisation of separate groups of regions were determined. With the aim of synchronous analysis, the 30-year period of observation, from 1960 to 1990, was taken as the most representative (with the most comprehensive observational data). Forty-three stations were selected from which 17 are in the European territory of CIS and the Caucasus, 13 in Kazakhstan and Central Asia, and 13 in Siberia and the Far East. In the study of the long-term variations of different elements, the running averages were used. To determine the general regularities of cyclic variations, three principal gradations were used namely the phases of increased, moderate and decreased avalanche activity. These phases were detected on differential integral curves by the principal turning points. The common territorial time curves of avalanche activity derived for 11 of the 13 mountains areas of CIS were analyzed. For the Tian Shan and Caucasus, the general tendencies of long-term variation of avalanche formation were differentiated in more detail. For some regions, the

relationship is established between the avalanche formation and climatic factors (air temperature, winter precipitation).

The diagram (Fig.1) was constructed for a clearer idea of the spatial distribution of long-term variations in avalanche activity. Considerable similarity is observed in the change of phase of cyclic variation in avalanche activity, practically in all regions except Tian Shan and Zabaikalje. Up to the mid 70s, a phase of weak avalanche activity is observed everywhere, which was followed by an increase in the activity.

The sampled cycles of the long-term variations in avalanche activity for the Tian Shan and Pamirs were tested on independent observational data. The data of observations from different snow-avalanche stations were used for 1990 to 94. The decreasing tendency of avalanche activity in the Tian Shan subregions and the tendency to increase in the Pamirs was confirmed; besides, from 1990 to 92 a change of the increase in avalanche activity was recorded on the Pamirs, and in 1992 and after that the decrease in avalanche activity was recorded as it can be expected following the choozen phase of definite duration.

Despite the obtained practical effect, it is rather untimely to draw the conclusion that every new cycle of avalanche activity variation is a repetition of the preceeding one. That is why the forecast of avalanche activity intensity on the basis of the derived tendencies needs to be studied further.

Nevertheless, the determined regularities are not only presented as a basis for independent testing but they also serve as the definite experimental corroboration of possible long-term variations in climate as an argument determining avalanche activity.

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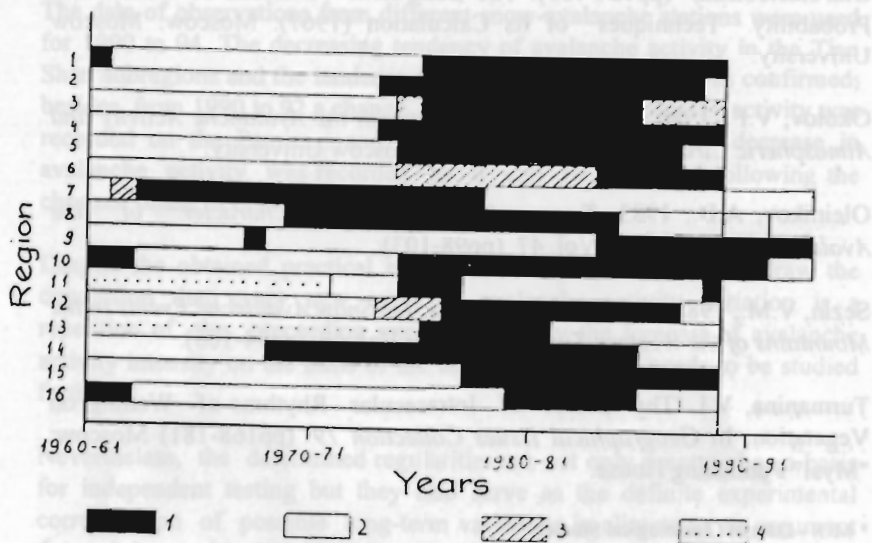
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\* MGI - Data of Glaciological Studies

Figure 1. Diagram of cyclic variations in avalanche activity in the mountain regions of the CIS

1 - low activity, 2 - high activity, 3 - moderate activity, 4 - data is absent.

The numbers of regions (Y-axis) correspond to 1. Khibins, 2. Carpathians, 3. Northern Caucasus, 4. Caucasus type 1, 5. Caucasus type 2, 6. Zailiyskiy Alatau, 7. Tian Shan 1 type, 8. Tian Shan type 2, 9. Tian Shan type 3, 10. Pamir, 11. Altai, 12. Kuznetskiy Alatau, 13. Baikal region, 14. Zabaikalje, 15. North East, and 16. Sakhalin



# HYDROLOGIC ASPECTS OF THE SIERRA NEVADA ECOSYSTEM PROJECT

**RICHARD KATTELMANN**

Sierra Nevada Aquatic Research Lab, Star Route 1, Box 198,  
Mammoth Lakes, CA 93546 USA

The Sierra Nevada Ecosystem Project is an evaluation of environmental conditions in the entire Sierra Nevada mountain range. It was requested by the United States Congress in 1992 and will be completed in December 1995. The basic goal of the project is to assess the status of the entire set of ecosystems in the Sierra Nevada, including their social, economic, and ecological conditions. This information should provide an improved basis for managing the natural resources of the Sierra Nevada in a sustainable manner. The project should provide an interesting example of a current approach to assessing environmental conditions throughout a large mountain range.

Water is central to the resource issues and conflicts of the Sierra Nevada. Changes in water availability, streamflow quantity and timing, flooding, quality of surface and ground water, aquatic and riparian habitat, and soil erosion and sedimentation have occurred throughout the range as results of land disturbance and resource management. However, the magnitude of such changes, their relative importance, and the ability of natural and human communities to adapt to or recover from alterations in hydrologic processes in the Sierra Nevada are largely unknown. Concern about degradation of water quality is widespread in public reaction to past and proposed resource management activities. However, Sierra Nevada streams and their drainage basins have been considered to be more resilient to forest management activities and other disturbances than other mountain areas of the western United States. The water resources evaluation of the Sierra Nevada Ecosystem Project has attempted to determine whether the primary water source of California, the Sierra Nevada, is functioning well in general and what problems need attention.

The Sierra Nevada generates about 25 cubic kilometres of runoff each year, out of a total of about 88 cubic kilometres for California. This runoff from the Sierra Nevada accounts for an even larger proportion of the developed water resources and is critical to the state's economy. The rivers of the Sierra Nevada supply most of the water used by California's cities, agriculture, industry, and hydroelectric facilities. The storage and conveyance systems developed to utilise the water resources of the Sierra Nevada are perhaps the most extensive hydrotechnical network in the world. Major water supply systems have tapped several rivers to meet the urban needs of several large cities in California. Irrigated agriculture throughout California consumes more than the annual runoff of the Sierra Nevada and accounts for more than 90 per cent of the consumptive use in the state. More than 150 power houses on the Sierra Nevada rivers produce about 24 million megawatt-hours of electricity per year. Sierra Nevada rivers support extensive aquatic and riparian communities and maintain the Sacramento-San Joaquin Delta and San Francisco Bay ecosystems.

The Sierra Nevada seems to be fundamentally intact as the preeminent water source for California society, agriculture, and industry. The hydrotechnical structures that facilitate exploitation of streams for social uses create the greatest impacts for those very uses as well as for aquatic ecosystems. The sophisticated management of the water system has created artificial patterns of streamflow in the lower reaches of most rivers and their principal tributaries. There are not many opportunities for further development of water resources in the mountain range, given the existing infrastructure and water rights. Existing groundwater development near foothill communities limits the availability of subsurface water as a dependable supply for future growth. The managed flows and physical barriers to movement of water, sediment, and biota have substantially altered aquatic and riparian ecosystems to something other than natural. Changes in reservoir management practices may offer the best hope for improving aquatic ecosystems where they are known to be impacted by artificial flow regimes. In general terms, almost any shifts back toward a natural hydrograph, such as seasonally fluctuating flows or occasional flushing flows, will be beneficial to the local biota.

Compared to the intentional alteration of streamflow through water management, hydrologic side effects of changes in land use are difficult to detect. Major changes in water and sediment regimes have not been observed in the main rivers and their larger tributaries as a result of shifts in land use. There may be a signal, but it is not obvious. Rapid expansion of

foothill communities has theoretically altered runoff and erosion processes enough to cause noticeable impacts in downstream channels, but quantitative and documentary evidence outside the Lake Tahoe Basin is lacking. Conversion of forest lands to roads associated with timber harvesting may have increased annual water yields and peak flows somewhat at the small watershed scale. However, decades of successful fire suppression may have increased evapotranspiration comparable to a pre-1850 fire regime and compensated for the flow increases attributed to roads and harvests. The offsetting magnitudes of either impact cannot be quantified at this time. The legacy of fire suppression creates substantial risks of serious hydrologic impacts from potential conflagrations.

Overall, chemical water quality remains very high, but cannot be considered pristine. A few local problems are very serious in Lake Tahoe, some abandoned mines, and some communities. The quality of receiving waters from the larger cities in the foothills has been degraded. Excessive sediment production is the most widespread nonpoint-source problem, but its extent and severity are unknown. Studies in other areas suggest that roads are the overwhelming source of sediments that end up in wildland streams. Disturbance in and near stream channels generate the vast majority of sediment transported by the streams. Information about sediment yields in the Sierra Nevada rivers is largely obsolete, and new reservoir sediment surveys are necessary to determine whether changing land use has accelerated sedimentation in the past few decades. Because of the importance of flowing water in diluting and dispersing pollution, alteration of streamflow by storage and diversion may be the fundamental water quality problem in the Sierra Nevada.



# HAZARDS OF EROSION AND ITS EFFECTS ON THE WATER RESOURCES OF PAKISTAN

**M.H. MALIK**

Institute of Geology, Punjab University, Lahore, Pakistan

**M. SALEEM KHAN**

Khanpur Dam Project, WAPDA, Haripur District, Hazara, Pakistan

The economy of Pakistan is fundamentally based on agriculture and its surface water storage reservoirs play an important role in providing irrigation water to the largest canal-irrigated system of the world. To establish the adverse effects of soil erosion and sedimentation or silting in reservoirs resulting in reduction in storage capacity, a study was carried out in the catchment areas of the Tarbela, Mangla, and Khanpur dams. Due to the high rate of precipitation in some parts of the catchment area, geological setting, and erodibility of clay in the predominant alternate hard and soft formational lithology, the silting rate has gained considerable proportions. A total of 13% reduction in surface-water storage capacity has occurred since the construction of these dams, threatening the supply of water for irrigation in future. In Tarbela, a total of 8.28% reduction has occurred since 1974, while the Mangla reservoir has reduced its capacity by only 4.6% since 1967 due to the high quality management of the watershed soon after its construction.

It is found that in addition to high precipitation, differential erosion in alternate hard and soft formations prevailing in the area, deforestation and unstable slopes, particularly in high seismic zones of the catchment area, are the main causes of silting.

In order to demarcate different zones susceptible to high erosion, data on geology (geological maps on different scales), precipitation, seismicity, slope instability, and geomorphic variations were used. Stabilisation of soils, construction of checkdams, and proper management of watershed are recommended.

# SOIL EROSION AND GEOMORPHODYNAMICS IN THE HIGH MOUNTAIN REGION, EASTERN CENTRAL HIMALAYA. A CASE STUDY IN THE BAMTI/BHANDAR/SURMA AREA, NEPAL

**JOHANNES B. RIES**

Department of Physical Geography, University of Freiburg, Werderring 4, D-79085 Freiburg, Germany (EU)

The report deals with the Himalayan Lowland Interaction Complex, the link between the Himalayas and the lowland plains, and the effects of geomorphodynamic processes in the mountain regions on the low-lying areas within the mountains and the foothills. This cause and effect is known as the 'Himalayan Environmental Degradation Theory'.

Since the mid-eighties, there have been some quantitatively-oriented erosion studies which tried to quantify soil loss and runoff by means of testplots. The results differ greatly and seem to be influenced by regional factors as well as the project targets and layout of the testplots. Also unknown is the magnitude of human impact on soil erosion compared with natural impacts like the development of valleys and slopes and spontaneous mass movements. If human impact is slight, afforestation and man-made protection from erosion cannot affect the flooding of the lowlands. The proportion of man made and natural influences, comparing soil erosion and runoff in a quantitative way, has not been investigated anywhere in the Eastern Nepal Himalaya. The present study documents new approaches in this area.

The research area Bamti/Bhandar/Surma is located on the western slope of the Likhu *Khola* Valley, one of the large cross valleys running north-south in the Himalayas. Bamti/Bhandar/Surma, with altitudes ranging from 1,450 to 3,400 masl, offers all the altitudinally-dependent cultivation systems and crop rotations of the southern declivity of the Eastern Himalayas, from paddy-rice cultivation in the valleys to various maize-millet combinations, field-pasture shifting cultivation, and grazing at the subalpine level. Zones with differing

degrees of usage were identified for investigation: Zone 1, the Bamti Zone, with a high degree of usage, is situated between 1,450 and 2,100 masl. Zone 2, the Bhandar Zone, with a medium degree of usage, is situated between 2,000-2,800masl. Zone 3, the Surma Zone, with an extremely small degree of usage, is situated between 2,200 and 3,410 masl. This division into zones reflecting varying degrees of usage makes it possible to estimate human impact in the research area.

Amounts and intensities of precipitation, temperature, and humidity were all recorded in the three main climate stations; the amount of precipitation was determined daily at seven meteorological stations and with 42 rain gauges in order to calculate the precipitation in the area. Daily soil erosion and runoff rates were measured on ten testplots during the monsoon months from May to September of 1990 and 1991. The testplots were of 14m<sup>2</sup> and 28m<sup>2</sup>. The amount of discharge and suspended sediment concentration in the three catchment areas were recorded. The water level was continuously monitored at four water-level recording stations, and the discharge hydrograph was determined by the current metre. From April to September, water samples were taken daily (for heavy rainfall, several per hour were taken) in order to determine the suspended sediment delivery from the levels of suspended sediment concentration.

The cartography of recent geomorphodynamics represents the connection between the testplot measurements and the results of the catchment area level. A plethora of form elements were recorded in the areas of erosion and accumulation on the expanses and in the gullies. Careful watch was kept the human impact. Expansive washouts in the farmlands; gully erosion; crumbling terrace edges, especially creep in paddy rice terraces; and the construction of grazing-land borders with a ditch and wall as protection against pasture animal were also recorded.

Surprisingly small rates of erosion were observed in the areas in question, with the exception of the extensively-used field-pasture shifting cultivation land during the crop year. The pre- and early monsoon convective precipitation in the *bukma* fields in May and June cause the highest erosion rates in the test area. Determining factors are the splash-effect due to the absence of vegetative cover and high runoff as a result of insignificant infiltration in the grazed topsoil section. The *bukma* fields produce the highest erosion rates in the entire test area, but these rates are not concurrent with the highest runoff rates on the testplots, but are dependent on the splash effect and vegetative cover in the pre- and early monsoon periods. The soil erosion and runoff rates on all

testplots document that the extensive field-pasture shifting cultivation (*bukma*) of the Bhandar Zone produces higher soil erosion rates and runoff rates in the crop year and first fallow year than the intensively and continually cultivated terraced land with medium slopes near the houses. The chronological difference between erosion in fields and suspended sediment delivery in the small catchment areas raises the question of the origin of the material in the rivers.

Looking at the erosion and accumulation on the fields in the High Mountain Region, a unexpectedly low geomorphodynamic process activity and density appears. Also, rainstorms with more than 100mm precipitation daily and very high erosivity indices cause rill and gully development only on a small scale. The high ground cover of dense vegetation during the main and late monsoon season in July, August and September can be seen as the main reason for this. In contrast, falls and slides are concentrated along the main riverbeds. These spontaneous mass movements happen mainly during the months of July and September, with the maximum flood discharge caused by high runoff. Hence, they influence the suspended sediment transport of the rivers to a high degree. The extensively-used grazing-land with *bukma* fields can be seen as the main factor responsible for high runoff rates. Considering the fact that 15% to 25% of precipitation becomes runoff, which is 5 to 8 times more than in forest areas, many breaks and slides along the rivers can be interpreted as a reaction to increasing incision after the clearing of forest and conversion to grazing land. However, it is necessary to mention that this process of clearing the forest started with the settlement in the area more than 300 years ago and was finished at the latest in the 1950s. Over the past 25 years, extensification of land use has been observed as well as an increase in forest and scrubland.

There was a noticeable difference between the small amounts of suspended sediment delivery in the investigated small catchment areas and that of the large rivers of Eastern Nepal. One can conclude from the data in the research area that the contribution of suspended sediment in small catchment areas of the High Mountain Region, which show the same or similar geographic features as the study area, to the sediment in the main rivers is very slight. The results show that the Himalayan Environmental Degradation Theory cannot be applied to the High Mountain Region of Eastern Nepal.

# SOIL EROSION AND NUTRIENT DYNAMICS IN A MIDDLE MOUNTAIN WATERSHED

**H. SCHREIER, M. CARVER AND S. BROWN**

Resource Management and Environmental Studies,  
University of British Columbia, Vancouver, B.C. V6T 1Z2, Canada

**P.B. SHAH, G. NAKARMI AND B. SHRESTHA**

Mountain Resource Management, International Centre for Integrated  
Mountain Development (ICIMOD), Kathmandu, Nepal

Stream flow, soil nutrients and sediment dynamics were examined in the Jhikhu *Khola* Watershed, a 1100ha basin located 35km east of Kathmandu. A set of 5 automated hydrometric stations, five tipping bucket raingauges, and five erosion plots were installed in the watershed in 1991 and a detailed monitoring programme was carried out from 1992 to 1994. The focus of the research was to determine the dynamics and impact of major storms on soil erosion, nutrient losses, and sediment transport over the annual hydrological cycle. To link the hydrological regime with land use, soil surface conditions, land-use activities, and nutrient contents in soils were determined using field surveys, sample analyses, and aerial photo interpretations. A digital topographic map on a scale of 1:5000 was drawn and this provided the basemap for evaluating the soil-sediment-nutrient relationships and dynamics using Geographic Information Systems (GIS) techniques. The carbon and phosphorus content and major cations were determined in 200 field sites under irrigated and rainfed agriculture, forests, as well as grazing lands. The sediment quantity and phosphorus and carbon content of 250 sediment samples originating from three erosion plots and five hydrometric monitoring stations were also determined. The sediment samples from the stream stations and the erosion plots covered most of the major storms which occurred over the 1992-1994 period.

As shown by Carver et al. (1995), premonsoon storms produced sediment rating curves that were significantly different from those obtained during the monsoon season. The regression line intercept of the premonsoon sediment rating curve was significantly higher and the slope significantly less steep than the monsoon regression line. This trend was consistent in all

stations and in all three years. The implications of these findings are that soil and nutrient losses are more severe at low flow during the premonsoon season but approach the same level at peak stream flow. In addition, 75% of the annual losses of soil and nutrients usually occur in two or three storm events. The impact of storms, during the premonsoon season, is most critical because they occur at a time when the plant cover of soils is minimal and when the fields are prepared for cultivation and planting of the most productive crop in the annual cycle of double and triple-crop rotations. It is also a time when nutrients in the form of compost are incorporated into the soils. The impact of these premonsoon storms on sediment generation and nutrient dynamics is clearly evident when analysing samples from the erosion plots located in rainfed agricultural fields in the upper parts of the watershed and the sediments collected at two hydrometric stations below the plots. The quantity of sediments and the sediment phosphorus content both show the same differences between the premonsoon and monsoon periods.

The factors that play important roles in controlling the nutrient variability in soils are soil type and land use. The soil and land use maps were combined with the soil fertility conditions which are based on data from 200 reference sites. With GIS overlay techniques, it was possible to produce soil fertility maps that can be used as a basis for initiating conservation measures. Phosphorus was found to be a good indicator for monitoring nutrient dynamics because it is tied up in the soil and sediment materials and has low solubility. The GIS analysis enabled us to produce a digital phosphorus map of the watershed which forms the basis for conservation management. Available phosphorus, as shown by Schreier et al. (1995), is usually the most limiting nutrient for agriculture in this part of Nepal and based on the GIS map, the areas where early vegetation cover would prevent key losses of phosphorus can easily be identified. The timing of these early premonsoon storms are difficult to predict, and to establish a vegetation cover during the dry period is difficult because of water shortages. Establishing an intercropping or relay system could enable farmers to maintain some vegetation cover in their best fields during this critical period and thus prevent significant soil and nutrient losses. Exchangeable cations (Ca and Mg) are also lost in significant amounts during the pre-monsoon season, and continuous leaching during the remainder of the monsoon season leads to soil acidification. With the help of the GIS overlay technique, exchangeable cation, base saturation, and pH maps were produced. These can be used as tools to indicate locations where lime application would benefit crop production and reduce soil acidity. Given the high annual cropping intensity and the inherently low soil pH, these cation and acidity maps can be used to

determine where selective soil management could reduce soil and nutrient losses. The link between soil fertility, soil loss, sediment transport, and sediment redistribution is a key to sustainable management of rainfed agriculture fields in the Middle Mountains of Nepal. The results of this research provide a better understanding of the dynamics and dominant processes that govern the nutrient cycles in steeply-sloping agricultural terraces in the Middle Mountains of Nepal.

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# ASSESSMENT OF EROSIONAL HAZARDS IN THE HIMALAYA: A CASE STUDY OF CHAMOLI DISTRICT IN UTTAR PRADESH (INDIA)

**JAGBIR SINGH**

Department of Geography, Delhi School of Economics,  
University of Delhi, Delhi - 110007, India

The needs of Man, the most intelligent and able living being on earth, are growing day by day with the rapid advancement of human civilisation . To fulfil his needs, Man has been exploring and exploiting Nature, regardless of the crucial intricate interrelationships within ecosystems. As a result, ecosystems are deteriorating, which may ultimately threaten the very survival of the human race.

Chamoli, an administrative unit in the state of Uttar Pradesh in India, is situated on lofty, sharply precipitous slopes. The area is extremely vulnerable to concentrated thunderstorms, high rainfall, structurally crushed folded and faulted rock strata, weak geology, and poor and highly-erodible soil which is subjected to faulty practices. Chamoli, being located in a geostrategic and sensitive area on the border of India and China, has received some attention; and for efficient communication, roads are being constructed on the high and steep mountains. Keeping in mind the ecological vulnerability, strategic location of the area, and the soil being the fundamental resource, erosion hazards in the district have been taken as the topic of research in this paper.

We must leave to future generations a healthy environment, complete with all its diversity and beauty. For successful management programmes, an explicit understanding of the structure and function of the ecosystem is the need of the day.



# TEMPORAL CHANGES IN HIGH MOUNTAIN ECOSYSTEMS AND ECOHYDROLOGY: TWO CASE STUDIES FROM THE AUSTRIAN ALPS AND THE CHILEAN ANDES

**HEINZ VEIT**

Chair of Geomorphology, University of Bayreuth, 95440 Bayreuth, Germany

## INTRODUCTION

High mountain ecosystems are very sensitive to climatic changes. Much is known about the consequences of Holocene climatic variations on vegetation and glacier dynamics. However, there are scarce data concerning the Holocene hydrological evolution. Two case studies, from the Austrian Alps and the Chilean Andes, show frequent reactions of the fluvial dynamics within a wide altitudinal range, even to minor climatic changes. Due to different environmental conditions in both areas, the causes of fluvial variability are not identical. Whereas in the Alps temperature seems to be the major factor, precipitation variability appeared more important in the Chilean Andes.

## AUSTRIAN ALPS

Paleoecologically the Alps belong to the best studied high mountain regions of the world. Fig. 1a shows the periods of glacier advances in the eastern Alps and the occurrence of at least two pronounced fluvial accumulation phases in eastern Tyrol (Fig. 1c), which are separated by an intense phase of erosion (Veit and Höfner 1993). The Early Holocene was apparently dominated by linear erosion and soil evolution, at least during the Holocene Climatic Optimum. The fluvial accumulation in the valleys is interpreted as a consequence of the decline of the periglacial ecotone in relatively winter dry-cool phases, characterised by a reduced vegetation cover (Fig. 1b, 1c, Veit 1993a). Monitoring of fluvial erosion and periglacial processes in a high alpine/subnival environment during the last years supports this interpretation and may lead to quantitative modelling.

## NORTHERN CHILEAN ANDES

During the Holocene period, the northern Chilean Andes were characterised by a frequent change in fluvial dynamics (Fig. 2). Because of high aridity, temperature variations played a minor role. The variable influence of the southern hemisphere westerly storm tracks has been considered one of the main reasons (Veit 1993b, 1993c). Therefore, fluvial accumulation and alluvial fan activity might be correlated with intense winter snowfall and a corresponding snowmelt during springtime, associated with intensified westerlies. The chronology shows parallels to the Holocene fluvial evolution on the Bolivian-Peruvian Altiplano and to the water-level fluctuations of Lake Titicaca.

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Figure 1. Holocene chronology of glacier advances (a), solifluction phases (b) and fluvial dynamics (c) in the central eastern Alps (Patzelt 1977, Veit 1993a, Veit and Höfner 1993)

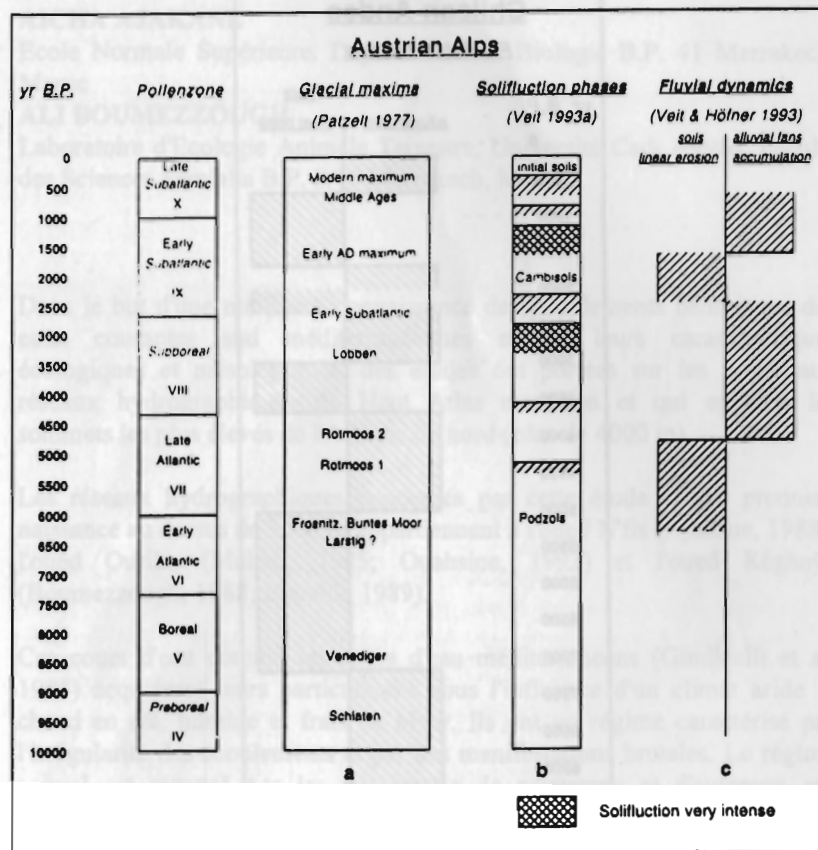
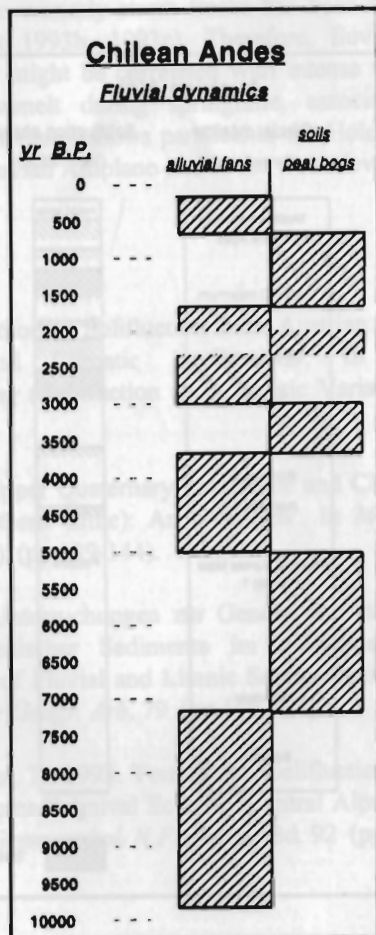


Figure 2. Holocene fluvial chronology of the Chilean Andes between 27-33° S (Veit 1993b, 1993c)



# ECOLOGICAL CHARACTERISTICS OF BENTHIC MACRO INVERTEBRATES FROM HIGH ALTITUDE STREAMS (MOROCCO)

**AICHA AJAKANE**

Ecole Normale Supérieure. Département de Biologie B.P. 41 Marrakech, Maroc

**ALI BOUMEZZOUGH**

Laboratoire d'Ecologie Animale Terrestre, Université Cadi Ayyad, Faculté des Sciences Semlalia B.P. S/15 Marrakech, Maroc

Dans le but d'une meilleure connaissance des peuplements benthiques des eaux courantes sud méditerranéennes et de leurs caractéristiques écologiques et mésologiques, des études ont portées sur les principaux réseaux hydrographiques du Haut Atlas marocain et qui englobe les sommets les plus élevés de l'Afrique du nord (plus de 4000 m).

Les réseaux hydrographiques concernés par cette étude et qui prennent naissance au dessus de 3000 m appartiennent à l'oued N'fis (Ajakane, 1988), l'oued Ourika (Mohati, 1985; Ouahsine, 1993) et l'oued Réghaya (Boumezzough, 1988; Bouzidi, 1989).

Ces cours d'eau comme les cours d'eau méditerranéens (Giudicelli et al. 1985) acquièrent leurs particularités sous l'influence d'un climat aride et chaud en été, humide et frais en hiver. Ils ont un régime caractérisé par l'irrégularité des écoulements et par des manifestations brutales. Le régime annuel est marqué par les maximums de printemps et d'automne qui amènent de brusques variations de débit et souvent des crues violentes qui modifient temporairement l'écosystème et les communautés lotiques (Badri et al., 1987) et par un étiage d'été sévère, accentué dans le Haut Atlas par les prélèvements accrus de l'eau pour des besoins domestiques et agricoles allant jusqu'à la mise à sec de certains secteurs aval.

La faune benthique du Haut Atlas est surtout de type paléarctique. Les groupes d'invertébrés (Ephéméroptères, Plécoptères et Trichoptères) montrent une diversité plus faible que dans les cours d'eau d'Europe. Cette

pauvreté de la richesse spécifique relève soit de causes paléogéographiques, soit de causes écologiques, telles que le régime thermique, les ressources trophiques ou le degré de minéralisation des eaux.

L'analyse de la répartition des groupes taxonomiques cités dans le Haut Atlas montre que de nombreuses espèces paléarctiques remontent à des altitudes supérieures à leur limite amont de leur distribution altitudinale dans les cours d'eau européens. Cette remontée vers l'amont relève de deux causes :

- Les températures élevées en été obligent ces espèces à étendre leur zone d'habitat vers le cours supérieur où les conditions thermiques sont plus favorables pour les espèces qui dans les régions paléarctiques se cantonnent habituellement dans les cours d'eau d'altitude moyenne ou basse.
- La faible diversité intra-générique permet à la plupart des espèces d'étendre leur spectre écologique, en l'absence de leurs congénères. Ces mêmes espèces dans le reste de leur aire européenne ou paléarctique, vivent généralement en sympatrie avec plusieurs espèces congénères au sein des mêmes réseaux hydrographiques et occupent, de ce fait des niches plus étroites.

L'étude biocénotique réalisée dans le réseau du N'fis a mis en évidence :

- Une succession amont aval des espèces selon un gradient thermique croissant dans cinq zones écologiques distinctes : Les sources, les torrents et ruisseaux de haute montagne issus des névés permanents, les ruisseaux de haute altitude à température estivale élevée, les ruisseaux et les petites rivières de moyenne montagne et en fin les rivières de piémont ou de basse altitude.
- Une remontée en altitude du potamon par rapport aux réseaux européens due au réchauffement des eaux en été.
- l'existence d'une zone écologique originale exclusive du versant nord du Haut Atlas (2400-3800 m) qui ne s'intègre pas dans le schéma général de la zonation d'Illies et Botosaneanu (1963). Elle héberge des espèces sténothermes d'eau froides endémiques du Haut Atlas (*Rhithrogena giudicellorium*, *Beatis berberus*, *Siphonoperla lepineyi*, *Similium toubkal*,

*Simulium berberum*....) adaptées à la vie dans les ruisseaux issus de névés permanents.

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# WATER CYCLE AND VARIATIONS IN SOIL-WATER CONTENT IN A JUNIPERUS THURIFERA STAND IN THE HIGH ATLAS MOUNTAINS OF MOROCCO

**WADI BADRI**

Département de Biologie, Fac. Sci. Semlalia, Univ. Cadi Ayyad. BP: S. 15 Marrakech, Maroc

**THIERRY GAUQUELIN**

Lab. d'Ecologie Terrestre, UMR 9964, Univ. P. Sabatier, 39 Allées Jules Guesde, 31062 Toulouse cedex, France

La variabilité du régime hydrique, une des caractéristiques du climat de haute montagne marocaine, rend difficile la caractérisation du cycle hydrique dans ces régions difficilement accessibles (Gauquelin, 1988). S'intéressant aux recherches concernant les écosystèmes à Genévrier thurifère (*Juniperus thurifera* L., arbre de haute montagne par excellence au Maroc) les auteurs ont étudié dans une Thuriféraie du Haut Atlas occidental, entre autres, la variabilité pluviométrique, inter-annuelle et intra-annuelle (1982-94), la redistribution des précipitations incidentes, par le couvert de l'arbre, et la quantification des différentes fractions qui en résulte (écoulement, égouttement et interception) et enfin l'évolution du stock d'eau dans le sol.

La formation étudiée occupe 398 ha sur le versant sud-ouest du Jbel Tizrag dans le massif de l'Oukaimeden (grès rouge) dans le Haut Atlas de Marrakech, entre 2200m et 2600m d'altitude. Ce peuplement est constitué essentiellement de *Juniperus thurifera* L. d'une hauteur moyenne de 7.5 m, d'un recouvrement moyen de 54% et ayant une densité de 204 individus par hectare. Cette région présente un quotient pluviothermique Q2 égal à 77.2, se situant dans le bioclimat subhumide à hivers froid (Badri et al., 1994).

Dans une parcelle (1000 m<sup>2</sup>) mise en défens à 2450m d'altitude au sein de cette forêt, nous avons installé 34 pluviomètres en plastique, dont 8 à l'extérieur du couvert des arbres, pour mesurer les précipitations incidentes



(Pi) et 26 sous les arbres pour évaluer l'égouttement à travers le feuillage (Eg). Quant à l'eau qui est drainée par le feuillage et les branches et qui s'écoule le long du tronc (écoulement: Ec), elle a été collectée à l'aide de gouttières mises en place difficilement (en raison de la forme tourmentée des troncs du *Thurifère*) autour de 4 troncs. L'interception (I) du peuplement, qui correspond à la fraction des précipitations incidentes qui n'atteint pas le sol soit évaporée ou absorbée (...) au niveau des cuticules des feuilles, est calculée par la relation suivante:  $I = Pi - (Eg + Ec)$

Le suivi de la teneur en eau du sol a été fait par la méthode neutronique (Badri, 1990), à l'aide d'un humidimètre à neutrons. Les mesures ont été effectuées dans 5 tubes en aluminium implantés dans la parcelle, trois de ces tubes se trouvant hors de l'influence du couvert (Gauquelin et *al.*, sous presse).

Le volume moyen (1982 -94) des précipitations annuelles est de 536.3 mm, se produisant sur 101 jours par an (Tab I). Les chutes de neiges se répartissent sur 48 jours essentiellement en Hivers. D'une manière relativement contradictoire sous climat de type méditerranéen, c'est au mois d'Août que les chutes de pluies *sensu stricto* sont les plus fréquentes (10.5 jours de pluie), mais la moyenne des précipitations de ce mois reste cependant la plus faible de l'année (18.7).

La variabilité des précipitations inter-annuelles est importante : le maximum des précipitations annuels, enregistré durant la période d'étude, est de 744.1 mm alors que le minimum est seulement de 379 mm. Cependant cette valeur, égale à 23%, est nettement inférieure à celle mesurée dans la vallée de N'fis à l'ouest de Marrakech: 34% et 48% (Maselli, 1993). Cette variabilité est par contre plus importante si on étudie les régimes pluviométriques mensuels (Janvier: 105 %, Tab I).

Cette variabilité se répercute sur le cycle hydrologique. Ainsi au cours du suivi des deux années le régime hydrique a presque doublé d'une année à l'autre (382.1 mm pour la 1<sup>o</sup> année et 670 mm pour la 2<sup>o</sup> année). Cependant les différentes fractions (Eg, Ec et I) exprimées en pourcentage moyen des précipitations incidentes ne varient pas significativement d'une année à l'autre (Eg: 54.7% la 1<sup>o</sup> année et 53.3% la 2<sup>o</sup> année, Tab II). Les valeurs d'égouttement varient mensuellement de 0% à 82% de Pi, avec une moyenne générale pour les deux années de 54%. Valeur nettement moins élevée que celle mesurée sur différents peuplement de résineux: 78.5% sur le *Pinus halepensis* (Rapp et *al.*, 1968), 70.5% sur *Pinus pinea* (Ibrahim et *al.*,

1982). Seuls Aussenac et *al.* (1980) ont signalé un taux comparable sur *Pseudotsuga menziesii* (53.4%).

Le taux d'écoulement moyen est de l'ordre de 2.2 % soit une valeur proche de celle signalée par Ibrahim et *al.* (1982) sur *Pinus pinea*.

Au delà des résultats mensuels et en étudiant les différents événements pluvieux, nous avons mis en évidence une forte corrélation entre l'intensité des précipitations et la quantité d'eau arrivant au sol. Les équations obtenues sont significatives au seuil 0.001:

|    |   |          |               |
|----|---|----------|---------------|
| I  | $Eg \text{ (mm)} = 0.650 \text{ Pi (mm)} - 2.530$ | $n = 34$ | $r^2 = 0.944$ |
| II | $Ec \text{ (mm)} = 0.029 \text{ Pi (mm)} - 0.187$ | $n = 34$ | $r^2 = 0.776$ |

La capacité de saturation du houppier, hauteur d'eau maximum susceptible d'être retenue sur la surface des feuilles, des branches et des rameaux, nommée aussi seuil d'égouttement, est calculée à partir de l'équation I :

$$\text{Seuil } Eg = -b/a \quad \text{soit } 3.89 \text{ mm}$$

L'interception varie de 14.8 à 100% avec une valeur moyenne de 43.8%. Cette fraction est à l'origine de l'hétérogénéité de la teneur en eau dans le sol de la Thuriféraie (milieu sous couvert et milieu hors couvert).

Pour les cinq années de mesure de l'humidité du sol (Fig 1), on observe en général la même dynamique des variations du stock (0 à 105 cm de profondeur). A l'extérieur du couvert la recharge automnale permet au stock de dépasser la capacité au champ, alors que sous le couvert ce stock reste en automne à peine supérieur à celui du point de flétrissement permanent (pfp), la réhumectation complète ne se réalisant qu'en hiver. A partir du début du printemps et jusqu'à la fin de l'été, le stock décroît et atteint des valeurs inférieures au pfp hors couvert.

Donc, si d'une part le couvert du Thurifère diminue la quantité des précipitations arrivant au sol sous les arbres, il permet, d'autre part, de maintenir une certaine humidité dans le sol pendant les périodes de dessèchement. Des effets similaires du couvert sur la dynamique de l'eau du sol ont pu être montrés dans des formations à *Acacia caven* au Chili (Ovalle et *al.*, 1988 et sur *Quercus ilex* en Espagne (Joffre et *al.*, 1988).

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|        |       |      |       |       |     |        |       |
|--------|-------|------|-------|-------|-----|--------|-------|
| Mar-89 | 68.8  | 14.8 | 83.6  | 1.98  | 2.8 | 10.28  | 14.8  |
| Avr-89 | 82.0  | 6.8  | 88.8  | 2.25  | 2.4 | 27.79  | 30.2  |
| Mai-89 | 100.0 | 0.7  | 100.7 | 3.16  | 2.6 | 4.34   | 22.2  |
| Jui-89 | 100.7 | 1.0  | 101.7 | 0.9   | 2.4 | 23.98  | 63.0  |
| Ju-89  | 70.5  | 2.4  | 72.9  | 1.49  | 2.0 | 45.80  | 64.0  |
| Aoû-89 | 41.1  | 12.0 | 53.1  | 0.45  | 0.4 | 25.18  | 70.0  |
| Total  | 670.0 | 27.0 | 697.0 | 14.39 | 2.1 | 298.70 | 346.0 |

Table I. Mean and Maximum Precipitation, Pluviometric Variability (v %) and Mean Number of Precipitation (rain "pl", snow "ng") Days at Oukaimeden (Meden Usually Means Middle or Central)

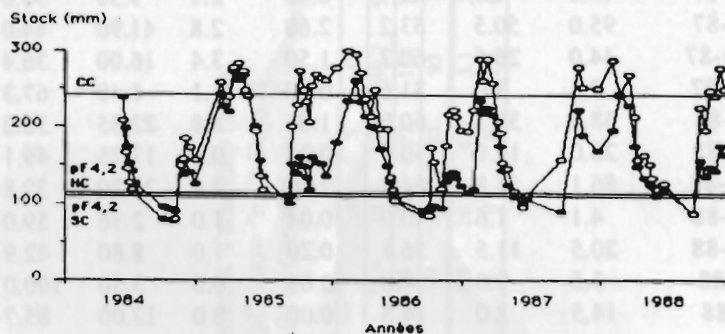
| Mois     | J    | F    | M    | A    | M    | J    | J    | A    | S    | O    | N    | D    | Année |
|----------|------|------|------|------|------|------|------|------|------|------|------|------|-------|
| P moy    | 55.4 | 78.4 | 75.8 | 56.9 | 47.1 | 23.0 | 26.9 | 18.7 | 25.7 | 39.2 | 50.0 | 39.2 | 536.3 |
| en max   | 221  | 212  | 165  | 140  | 100  | 50   | 86   | 50   | 72   | 104  | 110  | 90   | 744.1 |
| mm v%    | 105  | 64   | 57   | 99   | 64   | 86   | 99   | 107  | 85   | 93   | 70   | 74   | 23    |
| j. de pl | 0    | 2.1  | 2.9  | 5.3  | 7.5  | 5.0  | 8.5  | 10.5 | 6.0  | 3.1  | 2.0  | 1.0  | 53.9  |
| prc ng   | 9.0  | 10.0 | 10.0 | 3.8  | 2.0  | 1.0  | 0    | 0    | 0    | 1.2  | 6.0  | 4.5  | 47.5  |

Table II. Monthly Values for Drainage, Flow, and Interception over a Two-year Period

| Première<br>année | Pi<br>(mm) | Égouttement<br>(mm) | %    | Écoulement<br>(mm) | %   | Interception<br>(mm) | %     |
|-------------------|------------|---------------------|------|--------------------|-----|----------------------|-------|
| Sep-87            | 19.0       | 9.1                 | 47.9 | 0.40               | 2.1 | 9.50                 | 50.0  |
| Oct-87            | 95.0       | 50.5                | 53.2 | 2.60               | 2.8 | 41.90                | 44.0  |
| Nov-87            | 44.0       | 26.5                | 60.2 | 1.50               | 3.4 | 16.00                | 36.4  |
| Déc-87            | 9.5        | 3.0                 | 31.6 | 0.10               | 1.1 | 6.40                 | 67.3  |
| Jan-88            | 58.5       | 35.1                | 60.0 | 1.05               | 1.8 | 22.35                | 38.2  |
| Fév-88            | 28.0       | 14.0                | 50.0 | 0.25               | 0.9 | 13.75                | 49.1  |
| Mar-88            | 86.1       | 55.8                | 64.8 | 2.10               | 2.4 | 28.20                | 32.8  |
| Avr-88            | 4.1        | 1.6                 | 40.0 | 0.04               | 1.0 | 2.36                 | 59.0  |
| Mai-88            | 20.5       | 11.5                | 56.1 | 0.20               | 1.0 | 8.80                 | 42.9  |
| Jui-88            | 3.5        | 0.0                 | 0.0  | 0.00               | 0.0 | 3.50                 | 100.0 |
| Jlt-88            | 14.5       | 2.0                 | 14.3 | 0.00               | 0.0 | 12.00                | 85.7  |
| Aoû-88            | 0.0        | 0.0                 | 0.0  | 0.00               | 0.0 | 0.00                 | 0.0   |
| Total             | 382.1      | 209.1               | 54.7 | 8.30               | 2.2 | 164.70               | 43.1  |

| Deuxième<br>année | Pi<br>(mm) | Égouttement<br>(mm) | %    | Écoulement<br>(mm) | %   | Interception<br>(mm) | %    |
|-------------------|------------|---------------------|------|--------------------|-----|----------------------|------|
| Sep-88            | 16.0       | 5.1                 | 31.9 | 0.20               | 1.2 | 10.70                | 66.9 |
| Oct-88            | 92.5       | 48.7                | 52.6 | 1.60               | 1.7 | 42.20                | 45.7 |
| Nov-88            | 127.7      | 69.0                | 54.0 | 2.02               | 1.6 | 56.68                | 44.4 |
| Déc-88            | 0.0        | 0.0                 | 0.0  | 0.00               | 0.0 | 0.00                 | 0.0  |
| Jan-89            | 34.3       | 18.0                | 52.5 | 1.20               | 3.5 | 15.10                | 44.0 |
| Fév-89            | 83.6       | 47.8                | 57.2 | 3.40               | 4.1 | 32.40                | 38.7 |
| Mar-89            | 68.9       | 56.8                | 82.4 | 1.90               | 2.8 | 10.20                | 14.8 |
| Avr-89            | 92.0       | 62.0                | 67.4 | 2.21               | 2.4 | 27.79                | 30.2 |
| Mai-89            | 6.7        | 1.7                 | 25.4 | 0.16               | 2.4 | 4.84                 | 72.2 |
| Jui-89            | 36.7       | 11.8                | 32.2 | 1.01               | 2.8 | 23.90                | 65.0 |
| Jlt-89            | 70.5       | 24.3                | 34.5 | 0.40               | 0.6 | 45.80                | 64.9 |
| Aoû-89            | 41.1       | 11.8                | 28.7 | 0.15               | 0.4 | 29.15                | 70.9 |
| Total             | 670.0      | 357.0               | 53.3 | 14.30              | 2.1 | 298.70               | 44.6 |

Figure 1. Changes in soil-water content from depth of 0 to 105 cm, under the shade and without shade



# HYDROLOGY OF NAKHU WATERSHED - BEFORE AND AFTER THE 1981 DISASTER

**JAGAT K. BHUSAL**

Senior Divisional Hydrologist, Department of Hydrology and Meteorology

## INTRODUCTION

The Nakhu *Khola* watershed in the central mountain region of Nepal was severely affected by debris flows on 30 September 1981. The watershed is surrounded by hills more than 2,000m in altitude. Six per cent of the area is below 1,500m; 3 per cent is between 1,500m to 1,750m (8%- 40% hill slope); the area between 1,750m to 2,000m (6% to 40% hill slope) is 44 per cent; and the area above 2,000m (more than 50% hill slope) is 19 per cent. The longitudinal profile of Nakhu *Khola* with its main tributaries is given in Fig. 1.

The rock types are limestone, sandstone, slate, phyllite, quartzite, etc. The downstream area from Tika Bhairab/Champi consists of alluvium deposit. The land utilisation map (1984) study shows 37.5 % as forest area; 23.8% as sloping terraces; 23.9% covered by shrubs, and 14.8% as agricultural land and alluvium (including the river course and terraces).

The average maximum and minimum temperature records of Godawari (elevation 1,400m) is presented in Table 1. The area is connected by motorable roads. The natural resources are forest, water, sand, and stone.

The total population in the major seven villages (1) of the watershed has changed in the last 30 years from 1,97,343 (in 1971) to 29,707 (in 1981) and 31,738 (in 1991). The low rate of population growth (1981 - 1991) is due to migration from one local community to other and partly due to people's awareness of the advantages of a small family.



## **FLOOD/DEBRIS FLOW - 1981 :**

Okamoto et al. (1) made a preliminary assessment of the 1981 flood/debris flow. The flood peak estimated by a rational approach and from Manning's formula, based on the information of the local people, is  $600\text{m}^3/\text{s}$  and  $1,150\text{m}^3/\text{s}$  respectively.

After the experiences of the flood disaster of 1993 in Central Nepal, the author has revised the flood peak by readjusting the rainfall intensity. The maximum rainfall intensity observed during 1993 storm at Tistung is  $53\text{mm/hr}$  and  $45\text{mm/hr}$  at Nibuwater. With the help of this information, the flood peak of the 1981 disaster is estimated to be about  $500\text{m}^3/\text{s}$

## **PRECIPITATION AND STREAM FLOW**

There were no rainfall stations within the watershed before 1993. So the rainfall data (1971 - 1990) of the two neighbouring rainfall stations (Godawari and Panauti) are used to compute the basin rainfall (Table 2). The average stream flows from 1963 to 1980 of Nakhu *Khola* at Tika Bhairab were used to compute the runoff in the basin. The monthly runoff values are listed in Table 2.

## **THE RUNOFF-RAINFALL RELATIONSHIP**

One of the objectives of the study is to generate the missing record of stream flows. Linear regression analysis (Fig. 2) is carried out on rainfall and runoff data (1971 - 1980). The regression showed very low correlation ( $r = 51\%$  only). The observed and estimated stream flows are shown in Fig. 3. One of the causes of poor correlation could be the errors in stream flow computation because the river is the main source of irrigation water.

## **CONCLUSION**

The extreme rainfall on steep and weak hill slopes of Lele *Khola* and Nallu *Khola* watersheds had produced debris torrents which resulted in the loss of human lives and property. The extreme rainfall of 1981 is found to be a random meteorological event (cloudburst) which occasionally happens in one part of the country or the other. Due to poor correlation between rainfall and runoff data, the consequences of the 1981 disaster in the water balance of the watershed could not be judged.

Human interference (development activities) as well as ground coverage (vegetative cover and agricultural practices), soil and rock type (geology), terrain slope (topography), etc were other factors which, directly or indirectly, had accelerated the damages. The urbanisation thrust in Kathmandu Valley has now been slowly spreading to the villages of this watershed.

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Table 1. Monthly Maximum and Minimum Temperature at Godawari  
(Elevation 1400m)

| Months   | Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  |
|----------|------|------|------|------|------|------|------|------|------|------|------|------|
| Max.(°C) | 17.6 | 20.5 | 24.7 | 28.2 | 29.5 | 28.7 | 27.5 | 26.6 | 26.7 | 25.1 | 21.3 | 18.7 |
| Min.(°C) | 0.4  | 1.9  | 4.5  | 7.3  | 11.1 | 14.1 | 16.8 | 15.8 | 14.9 | 9.4  | 5.1  | 2.4  |

Source : DHM

Table - 2 : Mean Monthly Total Rainfall and Runoff (1971 - 1990)

| Months       | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Rainfall(mm) | 16  | 22  | 32  | 58  | 123 | 281 | 458 | 347 | 261 | 79  | 6   | 18  |
| Runoff(mm)   | 14  | 11  | 13  | 10  | 10  | 88  | 196 | 210 | 151 | 60  | 26  | 18  |

Source : DHM

Figure - 1: Stream profile

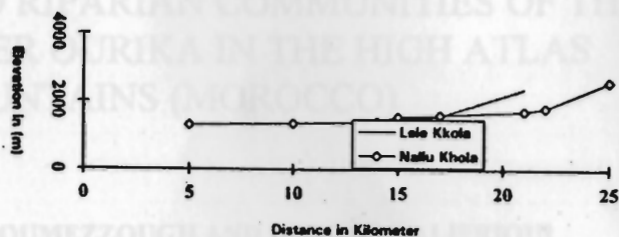


Figure - 2: Rainfall - Runoff  
[ $Q = 0.486 \cdot P - 24.93$ ]

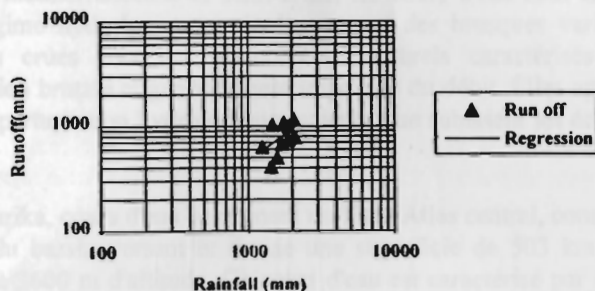
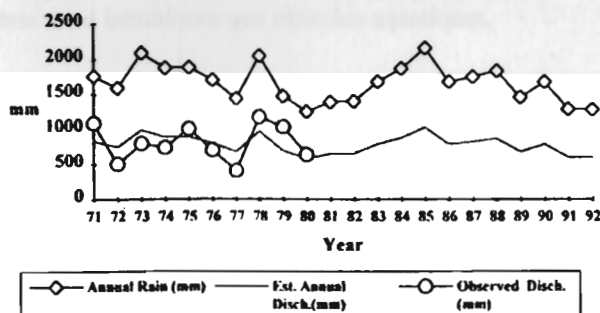


Figure - 3: Annual Rainfall and Runoff



# THE IMPACT OF FLOODS ON THE BENTHIC AND RIPARIAN COMMUNITIES OF THE RIVER OURIKA IN THE HIGH ATLAS MOUNTAINS (MOROCCO)

**ALI BOUMEZZOUGH AND BOUCHRA ALIFRIQUI**

Laboratoire d'Écologie Animale Terrestre, Université Cadi Ayyad, Faculté des Sciences-Semlalia, B.P. S/15, Marrakech - MAROC

En région méditerranéenne et semi-aride, les cours d'eau sont caractérisés par un régime hydrologique irrégulier et par des brusques variations du débit. Ces crues sont des phénomènes naturels caractérisés par une augmentation brutale et généralement imprévue du débit. Elles apparaissent comme la perturbation hydrologique majeure que subissent les écosystèmes lotiques.

L'Oued Ourika, cours d'eau permanent du Haut Atlas central, constitue l'axe principal du bassin versant et draine une superficie de 503 km. Il prend naissance à 3600 m d'altitude. Ce cours d'eau est caractérisé par un régime hydrologique très irrégulier dû à des phénomènes naturels tels que les crues causées par les fortes précipitations hiverno-printanières et les fontes de neiges et également par des dérivation d'eau en vue d'irrigation des champs de cultures lors des périodes d'étiage (Mohati, 1985). Cette irrégularité du cycle hydrologique est déterminante dans la répartition des communautés animales aussi bien benthiques que ripicoles aquatiques.

L'évolution des divers constituants abiotiques des écosystèmes aquatiques ont été analysé à travers des mesures mensuelles des composantes physico-chimiques. Dans le même sens, pour mettre en évidence les modalités de répartition des taxons dans les différents sites, nous avons procédé à des campagnes d'échantillonnages le long des transects et durant les différentes phases hydrologiques du cours d'eau.

L'analyse des divers caractéristiques mésologiques nous a permis de mettre en évidence l'impact des crues qui se traduit par :

- un bouleversement du milieu physique et une modification de la structure granulométrique du substrat-fond et des berges.
- une diminution de la minéralisation des eaux.
- une augmentation des matières en suspension particulières, de la charge organique dissoute suite à la percolation des eaux de ruissellement à travers les bassins versants et les champs de cultures.

L'analyse de la structure des peuplements benthiques et ripicoles aquatiques de l'Ourika à travers les descripteurs classiques nous a permis de montrer que la faune est représentée par un nombre assez important de taxons et qu'il y a spécialisation du peuplement selon les conditions mésologiques.

Le passage des crues a des répercussions différentes vis à vis de l'évolution temporelle de la richesse et de l'abondance des taxons, ceci selon l'intensité et la gravité de l'événement (crue inondante) : Les crues hivernales soudaines et brutales provoquent un bouleversement complet du biotope et une réduction voire même une disparition quasi-totale des invertébrés benthiques peuplant le chenal. La recolonisation des biotopes s'effectue, progressivement, lors de la décrue par l'intermédiaire des taxons qui ont pu résister au flux en se réfugiant dans les rives aquatiques (Gaschnig, 1984; Badri et al., 1987 et Henry and Amoros, 1995) ou qui ont été transportés depuis l'amont par le courant (Chavanon, 1979). Les résultats (Fig. 1) montrent qu'au niveau des stations du piémont, il y a apparition et prolifération de taxons rhéophiles tels que (*Perla bipunctata*, *Ephemerella ignita*, *Rhithrogena* sp., *Simuliidae*, *Diamesinae*, *Elmidae*). L'étude des indices de diversité montre que le cycle annuel présente un déséquilibre de la structure des communautés au moment des crues et lors de la prolifération des Orthocladiinae en périodes automnale et hivernale.

Par ailleurs, les crues printanières, issues de la fonte des neiges, induisent au niveau du chenal (Fig. 1A) une augmentation du nombre de taxons alors que le nombre d'individus des communautés benthiques diminue légèrement par rapport au mois d'Avril. Par contre au niveau rivulaire aquatique et terrestre (Fig. 1B et C), le passage de la crue induit une réduction de la diversité spécifique. L'augmentation du nombre d'individu est lié au fait que les microorganismes benthiques fuient les grands débits et se réfugient au niveau rivulaire. En période d'été et début automne, du fait de l'assèchement du cours d'eau, on note une réduction progressive du nombre de taxons.

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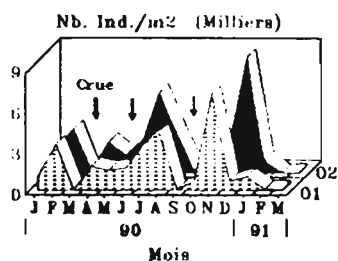
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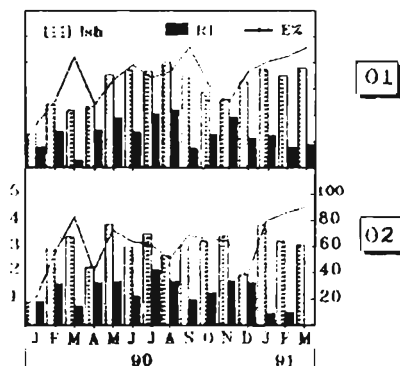
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Evolution over time of the biotic characteristics of the benthic community of the Ourikan Riverbed (Ourika River) (Wadi)



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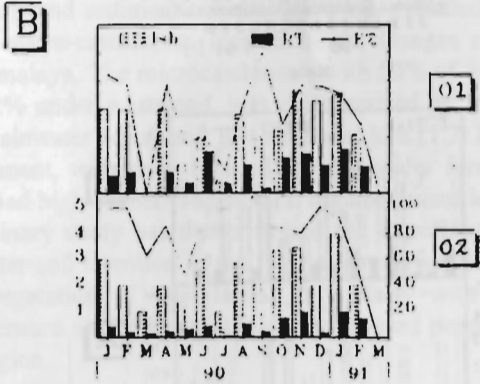
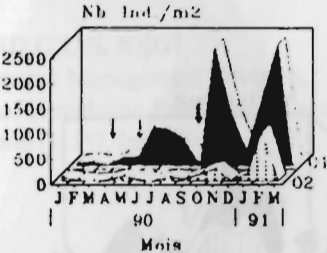


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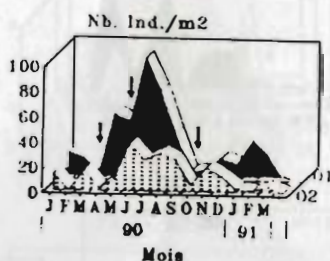
USE STUDIES OF TWO MICRO-CATCHMENTS OF THE WESTERN HIMALAYA, INDIA

VARUN JOSHI A  
Land and Water Resour  
O. A. Park Institute  
Unit, Srirangar-Gang

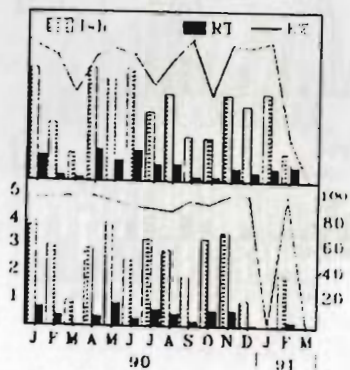
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the HKM region



Evolution over time of the biotic characteristics of the evolved riparian community of the Ourika River



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# **SURFACE RUNOFF, SOIL LOSS AND LAND USE STUDIES IN TWO MICRO-CATCHMENTS OF THE WESTERN HIMALAYA, INDIA**

**VARUN JOSHI AND G.C.S. NEGI**

Land and Water Resource Management Division,  
G. B. Pant Institute of Himalayan Environment and Development, Garhwal  
Unit, Srinagar-Garhwal (U.P.), India

Surface runoff and sediment transportation were studied in relation to land use in two micro-catchments located in the Ganges river system in the Garhwal Himalaya. The microcatchment, with 50% of its area under forests and only 12% under wasteland, was characterised by low runoff (2.4% of the annual rainwater input) and low sediment loss ( $1.7 \text{ t ha}^{-1} \text{ yr}^{-1}$ ). The other micro-catchment, with only 10% of its area under forest and 53% under wasteland, had high runoff (36.5%) and high sediment loss ( $10.8 \text{ t ha}^{-1} \text{ yr}^{-1}$ ). This preliminary study has demonstrated the important role of vegetative cover in water-soil retention in the fragile Himalayan watersheds, and calls for the revegetation of wastelands, particularly with multipurpose tree species, to ensure socioeconomic acceptability and people's participation in the HKH region.

# IMPACT OF TOURISM ON ECOHYDROLOGY IN THE HEADWATER REGION OF BEAS, HIMACHAL HIMALAYA

**B.W. PANDEY AND R.B. SINGH**

Department of Geography, University of Delhi, Delhi - 110007, India

The present research is an attempt to understand, investigate, and analyse the major changes in utilisation trends and conservation methods of water resources before and after the boom of tourism and concomitant urbanisation in and around the Manali area. Besides analysing their impact on the mountain geosystem at the micro level, the study also highlights the basic interactions between indigenous and modern techniques within the social and institutional dynamics of ecohydrological sustainability.

Water is an important constituent for the sustenance of life as well as the socioeconomic development of mankind. The present research has been carried out in the Upper Kulu Valley, Himachal Pradesh, where water resources have historically been utilised and managed for domestic as well as agricultural purposes through springs (*Kuhl*), and directly from rivers and streams. Research findings highlight that the process of urbanisation in the Manali region has brought a significant change in the trend of consumption, supply, and management of mountain water resources in the area. Both the positive and negative impacts have been identified in this study. Among the positive indicators, distribution of pipelines, storage tanks, and, at places, sewerage lines are important, while pollution, open garbage dumped into streams, and storage of water through privatisation of sources are important negative impacts of the urbanisation process. The rapid coming up of hotels and guest houses to provide infrastructure for tourism have led to water crises in this region. The springs which were earlier managed and utilised by the community are now being managed by hotel owners, creating water crises for the villagers.

The change in the biophysical system of the valley has a direct bearing on the hydrological set up of the watershed. The two major factors responsible for this are deforestation and change in the land-use pattern along with

cropping intensity. The mass felling of trees during the 1950s and 1960s, and the clearing of large tracts of forests have made the ecosystem more vulnerable by reducing the biodiversity of the region. The decrease in the amount of snowfall and increase in the degree of temperature for the last few decades have reduced the water resources' potentiality. Similarly, the introduction of irrigation due to change in cropping patterns has increased the consumption of water, thereby affecting the hydrological set up of the entire watershed.

B.W. PANDEY AND R.B. SINGH

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# CONSERVATION OF ENVIRONMENT: A CASE STUDY OF THE CENTRAL HIMALAYA (INDIA)

**GURINDER SINGH**

Department of Geography, Punjab University, Chandigarh, India

The Himalaya has been badly degraded owing to unprecedented anthropogenic influences beyond their carrying capacity and also because of geographical constraints and historical reasons.

In the Central Himalaya, of the total reporting area (4,880 thousand hectares) 46.7 per cent is under forest, and 36.2 per cent of the land is also not available for cultivation. Only 17.1 per cent is under agriculture. The region is ecologically fragile because of its recent origin and seismicity. The area is overwhelmingly rural, with 90 per cent of the total workforce engaged directly in agriculture and animal husbandry. The population density on the cultivated land is nearly four times greater than in the plains. In contrast to other Himalayan states, where the areas up to 3,000m and above are also populated, most of the central Himalayan population is distributed below 2,000m.

The landholdings are small and fragmented. On an average, over 80 per cent of the total landholdings are below 2 hectares and less than 10 per cent of the cultivated land is irrigated and under high-yielding varieties.

The problem zone (area having extensive biotic pressure all the year round) lies below 2,000m where most of the human settlements are located. Because of the high level of geological activities, the central Himalaya is vulnerable to landslides and landslips even without human interference. The susceptibility to land erosion is further aggravated by deforestation, as the catchments are subsurface systems. Most of the water is transmitted laterally to channels via a subsurface 'quick flow' process. In such systems, the soils are shallow and saturate with water rapidly and, consequently, landslides and landslips occur.

Environmental problems in the Himalayas, such as rapid population growth, continued clear felling in the forest, overgrazing and fire, cultivation on steep slopes and marginal lands, encroachment of agriculture and horticulture on forest land, underplanned/ill-planned development, ill-planned construction of roads and buildings in hazard prone zones, mining and quarrying, etc are briefly discussed.

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