Himalayan ecohydrology: An emerging subject for restoration of the mountain system

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1997

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Keywords: mountains, ecology, biodiversity, conservation, hydrology, water resources, snow, glaciers, precipitation, climate change, Himalayas.

ABSTRACT

The article briefly deals with the Himalayan Mountain System and the associated natural hazards due to huge snow and glacier fields at the highest elevation. Due to inherent sensitivity of these apex systems to global climatic change, emphasis is laid to initiate interdisciplinary research in hydrology affecting ecology and environment. Recommendations of a Regional Working Group on Mountain Hydrology are included for serious consideration by decision makers. Some salient aspects of precipitation characteristics of the region are included along with a description of Himalayan water resources. Conservation of mega biodiversity of the region is introduced pointing out the need for collation of available data bases. The urgency for the establishment of scientific data bases for natural resources is emphasised as an inter-departmental national project with a high level support and coordination for sustainable development of mountains and concurrently saving the Indo-Gangetic plains from desertification due to ravaging floods and recurrent droughts.

KEYWORDS: Snow & Ice, Hydrology, Biodiversity, Ecology, Global change

INTRODUCTION:

Himalayan Mountain System is one of the youngest and most sensitive and interactive atmosphere - snow - land - ocean mountain system of our planet. Huge snow and ice conditions result in potential hazards such as avalanches, glacier dams, large landslides, lake outburst floods, surging glaciers etc. These hazards increase and change in time and space depending on the environmental conditions. Due to ultra-high altitudes of the region and inaccessibility, expensive field work, a high level coordination and continued support for such investigations is needed to better understand the natural processes and minimise losses from these natural hazards to create harmonious conditions downstream.

The enormous snow and ice fields not only act as reservoirs for terrestrial and aquatic systems but also for true snow organisms. The melting of snow and ice covers, the retention of the liquid meltwater and the release of soluble nutrients stimulate the growth of complex snow microbial communities. Snow organisms can alter the physical characteristics of snow cover (e.g. reflectance) and also reduce the amounts of readily available nutrients in meltwater discharged to the soil. In this manner they may play a role in both snow - atmosphere and snow ecosystem interactions.

Global warming has caused significant glacier loss since the Little Ice Age (LIA) about 100-150 years ago, resulting in both glacier retreat and thinning. Larger meltwater contributions and catastrophic natural processes triggered by these glacier changes have been responsible for large scale destruction and deaths and modification of the environmental settings.

As the apex snow - glacier system of Himalayan region forms the tallest water tower, it is essential to know the variability of melt water runoff in both space and time to solve the perennial problem of floods and droughts ravaging the associated plains. It may be noted that the summer time precipitation above 3000m results in substantial decrease in melt water discharge even though these precipitation are accompanied by heavy rainfall at lower elevations. Hence it is important to forecast weather events in short and medium turn rate i.e. 1-10 days to regulate operations of water reservoirs in the Himalayan region.

2. MOUNTAIN SYSTEM AND CLIMATE CHANGE

Mountain systems are characterised by substantial gradients in environmental characteristics (Becker, 1996) due to rapid and sharp altitudinal gradients leading to: i) specific dynamics of hydrological processes with important positive and negative consequences (high water yield due to high amount of precipitation, disastrous floods with soil losses resulting in high sediments loads in rivers).
ii) a distinct altitude - specific pattern (zonation) of vegetation structure, composition and functioning.

In general, the high mountain systems are very sensitive environments which offer unique challenges to and opportunities for global change research. Under UNCED - (United Nations Commission on Environment and Development) Agenda 21 entitled 'Managing Fragile Ecosystems - Sustainable Mountain Development' the so-called mountain agenda, special relevance is attached to: a) generating and strengthening the knowledge of ecology and sustaining development of mountain ecosystems.

b) Promoting integrated watershed development and alternative livelihood opportunities.

The expanding economic pressures are degrading mountain ecosystems while confronting mountain peoples with increasing poverty, cultural assimilation and political disempowerment. Global change is a multi-faceted issue incorporating direct and indirect effects of human activity. Direct effect includes land use conversion and intensification and emission of pollutants such as NOx, O3, heavy metals, and acids. Indirect effects include climate changes associated with increase in trace gases emission and stratospheric ozone degradation which subsequently have an impact on climate and UV-B radiation.

In this international workshop, three activities were identified after a lot of group discussions. These are :
i) study hydrological and ecological processes and their interaction along with altitudinal gradients as a function of land surface characteristics. ii) develop measurement protocols and models to use ecological and hydrological characteristics of mountain regions as indicators of global change.
iii) develop concepts for sustainable development based on altitude - specific relations between socio-economic conditions and ecological/hydrological characteristics in mountain regions.

Each of the above activity was further sub-divided into research tasks to be pursued for improved understanding of the natural processes affecting the mountain ecosystems. All the research efforts need to be integrated involving meteorologists, hydrologists, ecologists and social scientists from various disciplines for a meaningful outcome.

3. MOUNTAIN HYDROLOGY

Regional Working Group supported by UNESCO (2) on Mountain Hydrology (March 1992), recommended that: - Scientific studies to further the understanding of snow and ice processes including glacier dynamics and atmospheric processes influencing them in the high mountain environment be promoted and encouraged in the Hindu Kush-Himalaya (HKH) region.

Long-term monitoring programmes on snow and ice resources as well as on changing climatic conditions based on already existing programmes, taking account of local conditions and utilizing local expertise, be actively promoted. Models and other techniques for forecasting water supply, sediment load and flood hazards relative to the HKH region be further developed and applied with particular attention to the mitigation of glacier lake outburst floods. Data bases on snow and glacier hydrology should be developed for practical end uses and should be made freely available so that rational water management decisions may be made. Innovative techniques including remote sensing and GIS be encouraged in order to collect, store and analyse data efficiently.

Consideration be given by the countries of the region, in cooperation with the International agencies, in conducting a Himalayan Experiment (HIMEX) similar to the ALPEX initiative in the Alps. Setting up of experimental watersheds to include glacierized areas be actively encouraged to promote integrated watershed management and to facilitate environmental impact assessments. Dialogue between scientists and water managers be encouraged through the holding of meetings, workshops and symposia on a regular basis. Training of technicians and managers be undertaken on an on-going basis and in a structured programme. Coordination of scientific monitoring and training activities be promoted at a central location with the active involvement of ICIMOD, WMO, UNESCO, governments and institutions of the region and external support agencies as appropriate.

The above recommendations need be seriously considered by the Himalayan Development Authority (HDA) proposed by the Planning Commission.

4. PRECIPITATION CHARACTERISTICS OVER HIMALAYAN MOUNTAIN

All the available precipitation data of Indian stations was analysed (Bahadur, 1993). The precipitation amounts have different seasonal distribution from west to east and also whether its contributions are due to orographic features, prevailing winds and nearness to the source of moisture.

Table-1
OROGRAPHIC INCREASE IN PRECIPITATION IN mm/100m

REGION	ANNUAL	SUMMER	WINTER
		(May-Sept)	(Oct - Apr)
a) J & K	-37	-30	-7
b) Punjab & H.P.	72	3	69
c) H.P.	-13	-60	+47
d) U.P.	41	35	6
e) Sikkim	-33	-32	-1
f) Eastern Nepal	-87	-	-
g) Sikkim-Southern			
h) Tibet			

Table-2
OROGRAPHIC INCREASE IN PRECIPITATION IN mm/100m IN DIFFERENT ALTITUDE RANGES.

ALTITUDE RANGE	ANNUAL	SUMMER	WINTER
		(May-Sept)	(Oct-Apr)
Less than 1000	111	76	35
1000-2000	34	39	-5
2000-3000	-13	-58	+45
3000 and above	174	179	-5

The orographic contributions were found to be greater at the foot hills and at elevations over 3000m. The summer and winter seasons have shown varying amounts of increase in precipitation and may be due to interactions with altitudinal varying microclimates and presence of alternate moist and dry layers over the mountains needing further detailed investigations. Middle and high level clouds may affect the highest peaks especially in association with westerly associations in winter. As clouds are the product of complicated interaction of moist convective turbulence with large scale circulations, radiation, ground hydrological and microphysical processes, we have to improve network of observations in the mountains. Further, as cumuliform clouds are horizontally subgrid scale while stratiform clouds are vertical subgrid scale systems, we have to integrate all information from ground and satellite based observations for assessing aerial precipitation and development of appropriate theoretical models for forecasting the precipitation amounts (Bahadur, 1996).

5. MOUNTAIN WATER RESOURCES

There is no detailed scientific evaluation available for Himalayan water resources. This is partly due to insufficient network of observations for both precipitation and stream discharge measurements. However, the available estimates show that the water yield from a high Himalayan catchments is roughly double that from an equivalent one located in peninsular India and this is mainly due to additional inputs from snow and ice melt contributions from high altitudes.

According to irrigation commission, 1972, 200 Km3/yr are added to Himalayan streams from areas lying outside the catchments of national boundaries. Murthy (1978) estimates that the Himalayan water resources are 245 Km3/yr; Gupta (1983) and Kawosa (1988) estimated that 8634 Km3/yr is the total amount of water flowing from the Himalayas to the plains. Bahadur & Dutta (1996) reported that a very conservative estimate gives at least 500 Km3/yr from snow and ice meltwater contributions to Himalayan streams. Alford (1992) reports that the specific runoff in the Himalayas is at a maximum in an altitude belt of considerable human activity - 1500 to 3500m and this is about 515 km3/yr from the upper mountains. Bahadur (1988) re-evaluated that 400-800 Km3/yr. flows down as meltwater contributions from the snow and glacier fields in the high mountain region as against earlier conservative estimates of 200 Km3/yr to 500 Km3/yr.

We should seriously consider development of water reservoirs at altitudes 3000 - 4000m to increase the period of water availability to downstream users. This will be helpful in reducing the surface run off and also severity of the freeze - thaw cycle. Longer availability of water in the high altitude region will be helpful in generating cheap hydroelectric power and maintaining the greenery thereby reversing the environmental degradation of the mountain system.

5.1 Himalayan Snow & Ice Reservoirs:

The Himalaya - the abode of snow and ice contains over 50% of permanent snow and icefields outside the polar regions. This region covers an area of 4.6 million Km2 above 1500m, 0.56 million Km2 above 5400m and 3.2 million Km2 above 3000m (Upadhyay, 1995). The altitude of permanent snow line is highly correlated with the freezing level (Zero degree C) altitude of the free atmosphere. The following gives the distribution of permanent snow and ice in these mountains, having a significant cooling effect on their neighbourhood, regional and global environment.

Table-3
DISTRIBUTION OF PERMANENT SNOW & ICE IN THE HIMALAYAN REGION

SUBREGION	VOLUME	SURFACE AREA
	(Km3)	(Km2)
HINDUKUSH	930	6,200
KARAKORAM	2,180	15,670
HIMALAYAS	5,000	43,000
TIBET	4,820	32,150
TOTAL	12,930	97,020

In these high mountains, it is estimated that 10 to 20% of the total surface area is covered by glaciers while an additional area ranging from 30to 40% has seasonal snow cover. There are of course variations in depths of snow and ice from place to place depending on the location. The importance of meltwater contributions from these natural freshwater reservoirs diminishes from west to east, being greatest in the Indus basin and least in the Brahamputra. In Nepal, Japanese studies have shown that the glaciers on the southern (or the Ganges) slope of the southern Himalayas are "warmer" and more active than those on the northern slopes. Detailed studies of the high snowfields and glaciers could provide much useful information from a hydrological perspective.

5.2 Natural Lake Systems:

Both saline and freshwater natural lakes exist in high altitude region. Saline lakes abound in arid region while those lakes which are extremely poor in electrolytes are abundant in humid region, nurtured by monsoon. These lakes are situated at altitudes varying from 600m to 5600m and are exposed to climatic conditions that vary from cold deserts of Ladakh to wet humid of Manipur. Very few studies are undertaken on the Himalayan lake ecosystems and the water management programmes are either completely lacking or grossly inadequate (Zutshi, 1985). The inflow of high silt load from glaciers is rendering the lake waters turbid and unfit for biological activity and are gradually filling these lakes. The other impact is from pollution from agricultural, industrial, human and cattle wastes. Restoration plans for the lake systems should be undertaken on ecological considerations following their geophysical environment and annual rhythm in chemical and biological compositions.

5.3 Indus - Ganga - Brahmaputra River Systems

World's largest highland-lowland interactive system consisting of three major Himalayan river systems i.e. Indus, Ganga and Brahmaputra whose long term average annual runoff is given as follows (Stone, 1992).

Table-4
AVERAGE ANNUAL RUNOFF OF INDUS, GANGA AND BRAHMAPUTRA RIVERS RIVER BASIN

MEASUREMENT STATION	AVERAGE ANNUAL RUNOFF (Km3/yr)
INDUS	
NEAR ARABIAN SEA	207.8
GANGA	
HARDINGE BRIDGE	494.3
BRAHMAPUTRA	
BAHUDURABAD	510.4
TOTAL	1,212.5

In mountain regions, the most central factors are topography and meteorology for hydrological purposes. The interactions of topography with meteorology results in the following: precipitation varies complexly with the aspects at altitude and terrain. Evaporation losses decrease with altitude steep mountain slopes cause water produced by rain or snowmelt on the surface to runoff quickly into stream channels.

Shallow mountain soils and impermeable geologic formation provide little storage for soil moisture and groundwater. Vegetation may be zoned based on both altitude and aspect, limiting hydrological impact of either removal or replacement to within narrow geographical limits.

The range of specific annual and average discharge in terms of depth of water from three mountain watersheds (Alford, 1992) are given below:

Table-5

ANNUAL SPECIFIC AND AVERAGE DISCHARGEOF WATER FROM HIMALAYAN MOUNTAIN WATERSHEDS

Mountain River Basin	Range Of Annual Specific Discharge(mm)	Average(mm)
UPPER INDUS	270-910	460
UPPER GANGA	473-2818	975
UPPER BRAHMAPUTRA	119-2587	1039

The above needs a comparison with the water yield from whole river basin to understand the higher water availability in mountains due to orographic lifting of moisture followed by precipitation.

Table-6
COMPARISION OF SPECIFIC WATER YEILD FROM MOUNTAINOUS AND WHOLE RIVER BASIN

RIVER BASIN	MOUNTAINOUS WATERSHED (mm)	RIVER BASIN AS A WHOLE (mm)
INDUS	460	163
GANGA	975	473
BRAHMAPUTRA	1039	222

The large fluctuation in temperature generates in a severe freeze - thaw cycle resulting in greater erosion of soil and rock formations. Another important factor for excessive soil erosion is very intense monsoon rainfall (from a few hundred mm to thousands of mm in 24 hrs.). Measured sediment yields range from less than one ton/ha/year to over 100 tons/ha/yr. It is normally assumed that the sediment yield of Himalayan rivers is about 16.4 ha.m/100 km2/yr which is about three to five times higher than the value assumed by the Indian designers of water resource storage projects. These estimates are not totally representative of the sedimentation regime and represent only the suspended sediments. No quantitative estimates are available for bed load sediments which play an important role for high mountain turbulent streams. Hence, we have to develop strategies for sediment harvesting for efficient water resources management for harmonious development.

The variations in the monthly flows of Ganga and Brahmaputra as shown by their hydrographs give a clue for linking the two rivers to utilize and harmonize the variations between the lean and peak periods to avoid regional conflicts (Verghese & Iyer, 1993). We must consider transferring excess waters from east to west to deal with the double nuisance of excess of water (floods) and deficit of water (droughts).

6. BIOLOGICAL DIVERSITY AND ITS CONSERVATION

Biological diversity i.e. Biodiversity is related to the multiplicity of life forms and is the property of living systems of being distinct, i.e., different and unlike (Solbrig, 1994). Biodiversity, categorised at different levels owes its origin to a variety of macromolecules, most notably DNA and proteins. In essence, Himalayan biodiversity is the manifestation of variety and variability in genes, populations and ecosystems. Himalayan biodiversity presents it truly Himalayan task in inventorization, conservation and sustainable uses. Documentation is extremely important especially since the Himalayan region is one of the world's richest ecosystems in terms of biodiversity. The region is also characterised by diverse ethnic groups which have developed their own cultures based on available natural resources, giving rise to cultural diversity, at par with the high level of biological diversity (Khoshoo, 1996). There has been a remarkable change in the status of biodiversity over the past several years and coupled with this, there is also been a significant change in peoples perceptions of biodiversity. We have literally moved from the era of sports hunting to game reservation, followed through the phase of wild life protection, to the current approach of conserving the habitat and biological diversity as a whole.

The conservation of biological diversity is defined as the management of human interaction with the variety of life forms and ecosystems so as to maximise the benefits, they provide today and maintain their potential needs for future generation's needs and aspiration. For this, the hydrology and water management plays a crucial role as we have to deal with ecosystems in changing moisture and temperature conditions on the ground depending on altitude and location (latitude, longitude and distance from ocean - the source and the snow and ice fields - the sink).

The information available on different aspects of biodiversity in Himalaya is grossly inadequate and these issues can be addressed meaningfully by making policy planners, bureaucrats and politicians realise the importance of identifying biodiversity conservation as central to all developmental planning. It serves as a rich repository of plant and animal wealth in diverse ecological systems. These ecosystems reflects mosaic of biotic communities at various spatial and organisational levels. The concurrent changes in topography, altitude, precipitation, temperature, and soil conditions contributed to diversity of bioclimatic.

Biogeographically, the Himalayas is a complex region. A sharp and distinct contrast characterises the eastern (warm and humid) and western (cold and arid) limits with a blend of their elements in the centre. The region has been divided into five biotic provinces under two biogeographical zones i.e. Boreal and Indo-Malayan (Gujral et al 1996). It is estimated that about 20% of the total geographical area of Indian Himalaya is degraded. Urgent steps are therefore needed to correct the situation based on scientific data, so that the mountains are conserved on one side and the associated plains are saved from desertification for the well being of millions of lives.

7. DATABASE ON BIODIVERSITY

The underlying rationale for database is the necessary conversion of informal and oral traditions into a formal database so that the indigenous knowledge is shared and constantly updated. This needs involvement of communities at the grassroots such as farmers, teachers, students, retired Govt. and defence personnel and others. In addition to this historic database there is a need to develop scientific databases on weather, climate, water, land, soil, flora, fauna, forests, agriculture, animal husbandry, fisheries etc. Development of Indian natural resources database of this region is possible, as Government of India has been considering forming Himalayan Development Authority (HDA). For the establishment of this data base on atmosphere, geosphere and biosphere, it is suggested that a Standing Committee at Secretary level is formed of Department of Science and Technology for Coordination; Defence for manpower deployment in snowy terrain; Environment and Forests for resource data in vegetated region; Agriculture for data on agricultural production and natural hazards mitigation and Space for repeated coverage by satellite imagery and preparation of maps for monitoring the environments in nearly real space and time. This has assumed greater significance as the population in mountain towns has shown a higher rate of increase threatening the existing infrastructure; forest covers are depleted causing severe soil erosion, extensive water run-off and land degradation problems; sub-marginal lands under cultivation have resulted in poor soil and water conservation and silting up of drainage channels; shifting cultivation dislodged huge volumes of soil; indiscriminate hunting is threatening unique fauna and unplanned tourism is creating problems of pollution control and waste disposal - all throwing challenges to evolve data based management strategies for peace, increased productivity and sustainability in the fragile environment.

CONCLUDING REMARKS

Global Scientific community is taking keen interest in Hydrology and Ecology where the conservation of mega biodiversity of the Himalayan region is the central issue. We must quickly prepare ourselves for the Himalayan task as sufficient infrastructure is now available for continuous snow monitoring, improved weather forecasting and establishment of bio-geo-data bases for ecosystem monitoring and modelling. The regional data networking with the neighbouring countries can be arranged through International Centre for Integrated Mountain Development (ICIMOD), Kathmandu.

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