Water resources management in the Himalayan region

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ABSTRACT

The article introduces the importance of fresh and clean water for human survival and maintenance of ecosystem on land. It outlines the concept of integrated water resource management and its essential ingredients for sustainable development. The atmospheric, geospheric and biospheric interactions in Himalayas are briefly dealt with. Himalayan snow & ice reservoirs, its lake systems and river systems are discussed. The development of water resources for creating storage reservoirs & generating hydropower are described and measures for soil water conservation on a watershed basis are dealt with before dealing with environmental constraints and natural disasters. Global change research thrust in the mountain areas is outlined and emphasis laid on development of data bases for resources utilisation with a few concluding remarks on the importance of snowcover monitoring, establishment of hydro meteorological observatories network and district biogeodata bases to evolve sustainable development plans in the ecofragile mountain region.

CONTENTS

INTRODUCTION:

Availability of freshwater is essential for human survival and for maintenance of ecosystem on land. It is a key factor in development, particularly in Indian conditions with large areas under arid and semiarid conditions, where water availability is directly linked to food production for hundreds of millions. Clean water is required for drinking and personal hygiene; irrigation is needed for agricultural production; dams are required for hydropower generation; inland waterways are required for transportation of goods/people and freshwaters are important for recreation and habitats. Rising water consumption, rapidly growing population, is causing increasing pressure on the available water resources in the fragile Himalayan region. This situation will worsen in future unless water supplies are augmented based on integrated long-term water resource management.

Environmental quality has become firmly established as a major objective of water resources management in all parts of the world during last two decades. The concept of water resource management in a region involves a holistic approach. It needs to address water quantity and quality concerns through an integrated system. It integrally links land-use patterns with sustainable water management. The approach recognises water as an economic good and promotes cost-effective interventions. It also supports participatory and innovative approaches for improving resource productivity and water use-efficiency. To achieve these objectives, the following essential elements for action are considered necessary :

i. All efforts should be made for proper assessment of water resources

ii. A comprehensive framework for water resource management be considered in preference to sectoral approach.

iii. Interventions in water sector should move from curative to preventive ones.

iv. A broad range of investments should be made on a continuous basis with ability to operative and maintain investments effectively.

v. Infrastructural improvements must be complemented with measures to strengthen institutions, develop human resource and promote public awareness.

vi. Promotion of water user's associations and increasing user participation.

vii. The participation of the private sector in water management should be deliberately pushed forward.

2. WATER AND ITS ATMOSPHERIC, GEOSPHERIC AND BIOSPHERIC INTER ACTIONS IN HIMALAYAS

The exchange of heat and water at the interface between the soil, the vegetation and the atmosphere is of fundamental importance for driving the global earth's system. Although most of the energy received by the atmosphere comes as latent heat released over the ocean, the input of energy over land surfaces is also a very important part of energy and water cycles of the atmosphere. It is indeed known that a large amount of water evaporated over the continents is likely to go back to neighbouring surfaces as precipitation, as locally enhanced convective systems have a rather short lifetime. The amount of water evaporated over land surfaces is equivalent to 12 Wm-2 (in terms of energy exchange), is also of crucial importance for the sustenance and development of vegetative life at the earth's surface. Many feedback mechanisms have indeed been identified, which intimately relate to the water cycle, and particularly its continental part, with vegetation and more generally the biospheric process (Andre, 1993). These processes are poorly understood for the Himalayan region. As the Himalayan Mountains are the youngest, the tallest and most fragile system on our planet - the earth, forming a unique environment, we have to conduct landsurface experiments in India in order to better understand the coupling between atmosphere, geosphere & biosphere. The salient known atmospheric, geospheric and biospheric aspects are broadly stated as follows :

2.1 Atmospheric Aspects :

The climate of the Himalaya consist of four broad and contrasting regions (Mani, 1984).

- the rain forest of the East, ranging in altitude to 2000m.

- the wet Alpine zone above tree-line rising to 6000m or more.

- transitional semi-wet region in the central portion of the mountain

- an arid region in the Hindu Kush far to the west

These altitudinally varying microclimatic conditions of the mountain system could be further classified as follows:

Table-I

MICROCLIMATIC REGIONS IN HIMALAYAS

Microclimates	Altitude ranges (m)
Tropical	300-900
Warm Temperate	900-1800
Cold Temperate	1800-2400
Cold	2400-3000
Alpine	3000-4000
Glacial	4000-4800 (10 Months below OøC
Perpetually frozen	above 4800 (cold deserts with no vegetation).

The physical dimensions and the rugged topography of these mountains affects atmospheric circulations on all scales of time and space. The uniqueness could be outlined as follows :

- the largest massiff brings out largest disturbances to atmospheric motions. The intensity of disturbances & the frequency of occurrence of synoptic (space scale : 100-1000 Km; time scale : days) and mesoscale systems (space scale : 5-10 Km; time scale : hours) and the instability of the atmosphere are unparalleled when compared to other regions of the same latitude.

- the seasonal variation of thermal and dynamic effects over the massiff are the motivating mechanisms of seasonal adjustments of the planetary long waves of the northern hemispheric circulations.

Due to lower mass of air at high altitudes, the changes of heat and moisture are much more magnified as compared to those existing at the sea level, thereby increasing the atmospheric sensitivity of the high mountain. It is known that the precipitation increases with altitude and the areas of maximum precipitation lie near the equilibrium line (altitude - 5200m) but we do not have a network of high altitude observations for assessment of quantum of areal precipitation in the region. We will have to depend on satellite imageries for the purpose.

2.2 Geospheric Aspects :

The Himalayan terrain abounds in thrusts and faults which have profound effect on slope stability. It has an inbuilt fragility and is susceptible to rapid structural collapse. This is due to the geotectonic processes which have been and are still building it.

The Himalayas are the result of collision between the Indian Plate and the Eurosian Plate which were originally separated by an ocean, now named the Tethys. As a result of northward movement of Indian plate, it has been drawn downwards and thrust below the Euroasian plate. The long process led to marine sediments being compressed, crumpled & then squeezed up into a mountain chain. The shortening of the original extent of the sediments caused by the collision of these plate is so great that, if all the folds of the Himalaya now crammed into a horizontal space of 150 km were to be stretched out flat, they would stretch for 650 Km. The uplift is still continuing & is manifested in the form of regular earthquakes of varying magnitudes in all parts of the mountain range. Due to very high altitudes, a large area lies above the snow line creating extensive snow and icefields. The fluctuations of these fields creates problems of frequent occurrences of natural disasters e.g. avalanches, mudflows landslides flash floods, glacier surges and glacier lake outburst floods - adding a new dimension to the geodynamic behaviour of the tallest water tower.

2.3 Biospheric Aspects:

Biogeographically, the Himalaya is a complex region. A sharp and distinct contrast characterises the eastern i.e warm & humid and western i.e. cold and arid conditions with a blend of these elements for the central region. The whole region has been divided into five biotic processes under two biogeographical zones i.e. Boreal and Indo-Malayan (Gujaral and Sharma, 1996). It is estimated that about 20% of Indian Himalaya is degraded. Urgent steps are therefore needed to correct the situations based on scientific data so that the mountain resources are conserved and the associated plains are saved from desertification for the well-being of millions of human lives.

Himalayan agro-ecosystems have been continuously evolving. The land is not so fertile and is prone to erosion and irrigation facilities are poor. Traditional farming is practised and the crops mature at different times. Agriculture and animal husbandry are not practised in isolation but in combination as agri-silvicultural, agri-pastoral and agri-silvi-pastoral systems. The cultivars may be individually poor in productivity but collectively the crop mixes are reasonably productive.

Himalayan biodiversity is the manifestation in genes, populations and ecosystems. It is rich in both plant and animal variety. Himalayan biodiversity presents a truly Himalayan task in inventorization, conservation and sustainable uses. 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 (Khoshoo 1996).

3. HIMALAYAN 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 (1989) 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 (1998) revaluated 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 save submergence of existing forests, villages and farmlands from reservoirs at lower altitudes) to increase the period of water availability to downstream users. This will be helpful in reducing the surface run-off i.e. the floods and also soil erosion due to moderation of 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.

3.1 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 Celsius) 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-2

DISTRIBUTION OF PERMANENT SNOW & ICE IN THE HIMALAYAN REGION

(Upadhyay, 1995)

SUBREGION	VOLUME (Km3)	SURFACE AREA (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 30 to 40% has seasonal snow cover. Of course, there are 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 cold and arid west to warm and humid east, being greatest in the Indus basin and least in the Brahamputra. In Nepal, Japanese studies have shown that the glaciers on the southern slope of the Ganges 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.

3.2 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, being 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.

3.3 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-3

A) AVERAGE ANNUAL RUNOFF OF INDUS, GANGA AND BRAHMAPUTRA RIVERS

(P.B. Stone, 1992)

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

B) ANNUAL SPECIFIC AND AVERAGE DISCHARGEOF WATER FROM HIMALAYAN MOUNTAIN WATERSHEDS

(Alford Donold, 1992)

Mountain River Basin Specific Discharge	Range of Annual (mm)	Average (mm)
Upper Indus	270-910	460
Upper Ganga	473-2818	975
Upper Brahmaputra	119-2587	1039

C) COMPARISION OF SPECIFIC WATER YEILD FROM MOUNTAINOUS AND WHOLE RIVER BASIN

River Basin	Moutainous Watershed (mm)	River Basin as a whole (mm)
Indus	460	163
Ganga	975	473
Brahmaputra	1039	922

The range of specific annual and average discharge in terms of depth of water from three mountain watersheds (Alford, 1992) are given above in Table-3 (B). The higher water availability in mountains due to orographic lifting of moisture followed by precipitation is shown in table-3 (C). It is much higher for Indus and reduces for Ganga to Brahmaputra.

The large fluctuation in temperature during the annual cycle, generates 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 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 (seclude sediments for other uses) for efficient water resources management for harmonious development of the region.

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) and for the welfare of a large human and animal population.

4. DEVELOPMENT OF WATER RESOURCES DURING LAST 50 YEARS.

The assessment of potential and utilisable water resources of the Himalayan river systems as recently assessed is shown in the table-4.

Table-4

Potential & Utilisable Water Resources of Major River

Systems in Himalayan Region*

		River Basins			
S.No.	Item	Indus	Ganga	Brahmaputra	Meghna
1.	Water Resource Potential (Km3)	73.3	525	537.2	48.4
2.	Utilisable Surface Water (Km3)	46.0	250	24.0	
3.	Groundwater Potential (Km3)	25.5	171.7	27.9	1.8
4.	Per Capita Annual Availability of Water (m3)	1757	1473	18417	7646
5.	Per Hectare of Culturable Area Annual Avail- ability (m3)	7600	8727	44232	43447

*Source: Reassessment of Water Resources-CWC Publication March 93

4.1 Water Reservoir Storages & Irrigation

We have more than 2900 completed dams at present; 500 are older than 30 years, 900 older than 20 years and 2000 older than 10 years. The storage capacities in the Himalayan rivers is evaluated till 1993 is given in table-5 showing that only 14.26% of the average annual flow of water has so far been planned to be stored. The percentage for Indus, Ganga, and Brahmaputra. Barak being 23.2, 16 and 11.25 percent respectively leaving a substantial scope for development of water resources.

According to a more recent publication on Water Resources Development in India (1947-1997) from the Ministry of Water Resources, it is reported that 46 cubic Km. is utilisable water from Indus basin (potential being 73.3 cubic km.). The live storage capacity in the basin has increased from 0.01 cubic km. in the 1st plan period to 13.8 cubic km. In addition, a storage quality of over 2.4 cubic km would be created on completion of projects under construction with further increase of 0.3 cubic km on execution of projects under consideration.

In Ganga river basin, 250 cubic km is a utilisable water (potential of 525 cubic km). Live storage capacity in the basin has increased significantly since independence. From just about 4.2 cubic km in the preplan period, the total live storage capacity of the completed projects has increased to 37.8 cubic km. Another 17 cubic km would be created on completion of projects under construction with addition of another 29.6 cubic km after completion of the projects under consideration.

For Brahmaputra - Barak basin, 24 cubic km is the utilisable water (potential of 585.6 cubic km). From just about 0.1 cubic km in the 3rd plan period, the total live storage capacity of the completed projects has increased to 1.1 cubic km. Another 2.4 cubic km. would be created on completion of projects under construction with further addition of over 63.4 cubic km on execution of projects under consideration.

4.2 Hydropower Generation :

Hydropower potential of Himalayan river systems is about 78% of the total Indian hydropower resources. This potential of Indus, Ganga and Brahmaputra river basins is assessed to be 19, 988, 10,715 & 34,920 MW at 60% load factor respectively. Several studies have shown that hydropower has small share in environmental degradation which can be largely compensated by environmental protection measures (Naidu, 1995). Large benefits such as irrigation, flood control etc. outweigh their small environmental cost Table-6. It may be pointed out that the developed countries the world over have tapped hydroresources before moving to fossil fuels. It is high time, the country focus on hydropower to ensure its energy security.

It may be interesting to note that a small hydropower plant (130 KW) was established near Darjeeling in 1897. The installed capacity of hydropower station progressively increased from 508 MW in 1947 (production-2195 million units) to 21,891 MW in 1997-98 (production - 74388 million units).

It may be pointed out that Norway's share of hydropower to the total power in that country is 99.4% while it is reduced to 24.6% in 1997-98 from 45.7% in 1965-66 for India with its enormous Himalayan potential still to be harnessed. As on 31.4.94 hydroelectric potential of Himalaya rivers to be developed for Indus is 80.4%, for Ganga it is 73.5% and for Brahmaputra it is 97.8%.

4.3 Soil & Water Conservation - A Watershed Management Approach

In the country, it is estimated that 144 m ha. is affected due to water and wind erosion 8.5m ha is under water logging, degradation due to salinity and sodacity is spread over 5.5m ha and 3.9 m ha area; 4.8 m ha and 4.0 m ha area are affected due to shifting cultivation and ravines; nutrient loss to the time of 5.37 to 8.4 m occurs due to soil erosion per year; 85.65 m ha of cultivated land is affected due to soil physical constraints; 0.38 m ha is disturbed by mining per year (Das,1998)

A number of soil and water conservation programmes are being implemented by the Central as well as State Governments under various sponsored schemes e.g. river valley projects (RVP), Flood Prone Rivers (FPR), Drought Prone Area Programme (DPAP), Desert Development Program (DDP), National Watershed Development Programme for Rainfed Agriculture (NWDPRA), Soil Water and Tree Conservation in the Himalayas (Operation Soil Watch), Operational Research Project on Integrated Watershed Management, Reclamation of Alkali Soil (User) in the State of Haryana, Punjab and U.P. Ravine Reclamation in the Dacoit Prone Areas of UP, M.P. & Rajasthan to accurate their Development and Control of Shifting Cultivation. The RVP and FPR cover about 90m ha spread over in most of the states and UTs of the country spread over 900 priority watersheds. The activities under NWDPRA schemes are confined to 107 model watershed.

Adoption of appropriate soil and water conservation practices on a watershed basis is considered to be the only way to control soil erosion and improve our environment in the mountainous regions. The measures are to be adopted in conformity with the concept of integrated land use planning for development and improvement of catchment and command area. Efforts must be directed towards utilizing the maximum amount of rain to meet the human, animal and crop needs and at reducing to the minimum the damage by floods and soil erosion. Excess water should be stored in the catchment areas which will reduce the fury of flash floods, recharge the ground water and improve the environment. Runoff collection ponds in the catchments, though they might get silted up in a few years, will be more useful than the measures in the lower reaches. To prevent rapid siltation of tanks, the contributing catchments (even if they are not cultivated but used for grazing or forestry purposes) need to be well managed so that soil erosion is prevented. All common lands should be put under fuel/fodder trees. Planting of barren areas, especially on slopes, with grass cover is an important component of integrated watershed management programme. Grazing should be completely restricted. After the area is completely protected from grazing, better grasses can be planted. The grasses of industrial importance should also be planted so that there is some economic return to the farmers as well. The surface vegetative cover will not only protect the land from the beating action of rain drops and bind the soil particles but would also decrease the velocity of flowing water and cause less of soil erosion. Present land utilisation in the Himalayan status is shown in table-7.

The watershed approach, however, has to be followed on a community basis and no individual farmer can do it. This programme is difficult to implement without the help of government agency and non-government organisations. There has to be a proper coordination between the departments of forests, agriculture, soil conservation, horticulture and animal husbandry for the development and implementation of watershed programme on a community basis. Unfortunately, this is not happening effectively in the hilly areas. Unless something is accruing directly or indirectly in the form of a benefit to the farmers, they are not willing to participate in any developmental programme. Assured water supply for irrigation is the primary demand of farming community.

4.4 Drinking Water Scenario

During the last 50 years, safe drinking water has become hard to find in the hilly terrain due to poor performance of water supply schemes. The problem is further enhanced due to increasing population and pollution of natural sources of water supply in both rural and urban settings. District-wise physical status of rural water supply schemes of Kumaon region in Uttar Pradesh as on 1.4.94 is included as an illustration for poor management of drinking water schemes in the Central Himalayan region.

Table-8

DISTRICT-WISE PHYSICAL STATUS ON RURAL WATER SUPPLY SCHEMES (AS ON 1.4.94)

Sl. District Total Functional Partially Defunct No. Schemes Functional

-- 1. Nainital 329 109 152 68 2. Almora 1333 603 368 357 3. Pithoragarh

1097 779 201 117 4. Dehradun 284 239 14 31 5. Pauri 852 447 209 196 6. Chamoli 742 534 172 36 7. Tehri 736 603 88 45 8. Uttarkashi 431 392 28 11 Total 5804 3711 1232 361 Percentage 64% 21% 15%

It is generally agreed that the solution for the mismanagement lies in improving the awareness in the process of planning and management of nature's bounty in the numerous torrents, springs, streams, rivulets & rivers of this tallest water tower.

5. ENVIRONMENTAL CONSTRAINTS

The landscape of the Himalaya is founded on an immature geology and on unconsolidated rock systems, Problems thus arising are compounded by the heavy rainfall and fast moving streams, and as a result the geomorphology of the Himalaya has changed and will continue to change. The long history of human occupation and survival in the Himalayas did not cause too many drastic changes in the delicate mountain ecosystem until very recently.

The high seismicity of the Himalayan region is rooted in its recent orogenic evolution, as a result of which the Himalaya is still rising. Several estimates of this uplift have been made and they vary between 2 and 10 mm/yr. Extensive studies on Tibetan plateau have shown a rate of about 5 mm/yr over last 10,000 yrs. In designing any structure in the Himalaya, the implications of the resulting tremendous locked-in energy have to be taken into account in the light of progressive failures of slopes and the creation of landslides of large volumes. Whether it is road construction, or dam building or house construction, ground tremors and movements along the faults constitute a very serious constraint. Earthquakes in the past have been disastrous because of human incapacity to anticipate their impacts. The question of the prevention of earthquake damage has come to the fore in the case of projected high dams in the region.

The 'strain energy release' maps for the entire Himalaya show large seismic gaps exist (particularly in NW Himalaya), where no appreciable energy has been released during the last few decades. One of the major problems concerning the interpretation of seismicity in the Himalayas is precise determination of epicenter and depth of foci. For this we need denser network of seismic stations equipped with standard instruments. From the available data, it is estimated that the return period of earthquakes of magnitude 8 on the Ritcher Scale is 30 yrs. for the entire Himalayan region.

Mass wasting is very wide spread constraint faced in all parts of the Himalaya. It is a general term to describe a variety of processes through which large masses of earth move downhill under gravity, both in slow creeping mode or as rapid landslides. Among the most important factors behind the widespread occurrence of mass wasting are :

i. steep slope with high relative relief

ii. seismicity

iii. groundwater flow accentuating land slips

iv. cloud bursts and intense rainfall

v. nature of rock (soft sedimentary, foliated metamorphic or fractured igneous.

vi. toe undercutting by torrents and floods.

These are aggravated by anthropogenic factors e.g. loss of forest cover; extension of agriculture onto steep slopes; opencast mining without environmental control and road built without regard to geological factors.

Most important concerns of most water resource developments relate to watersupply, and the risk of shortfalls in supply in mountain rivers (having snow and glaciers) where monitoring and knowledge to forecast their behaviour is poor. Hydrological risks of such rivers involve hazards associated with the behaviour of snow and ice e.g. avalanches, glacier dams, large landslides, glacier outburst floods (GLOFS), surging glaciers should be considered before undertaking water resources developmental projects in high Himalayas.

Very often, the Himalayan glacier meltwater runoff (3 to 6 m/yr) causes disastrous phenomena like glacial mud flows, outbursts of glacier dammed lakes, land slips and floods. Glacier Lakes Outbursts floods (GLOF) are due to sudden bursts of water from glaciers and glacier dammed lakes. These are principally controlled by hydraulic considerations and one of the most economic solution is to syphon out the water to mitigate disastrous floods. The sudden flood waves of 100m amplitude due to GLOFs have been recorded from glacierized regions. If these are continuously monitored one can issue warnings to downstream inhabitants for saving lives and properties.

Incidence of intense solar radiation at the high altitude warms up the Himalayan environment resulting in severe freeze - thaw cycle leading to greater erosion of soil and rock formation. it is presently estimated that the rates of erosion is 100 cm/1000 yrs. compared to 21 cm/1000 yrs. in the past 40 million years demonstrating the severeness of the problem due to a high temperature oscillations. The occurrence of landslides, soil creeps and slumping are due to gusty rains and heavy squalls. The impact of waves generated on large body of water during rainy season aggravates the problem of slope failure resulting in excessive sedimentation. An approximate estimate of sediment yield from Himalayan rivers is about 16 Ha-m/100Km2 /yr.

Cloudbursts take place due to convective activity and occurrence of thunder storms. Severe storms in Himalayas cause considerable loss of crops, lives and properties due to lightning, high winds, tornado, hail and intense precipitation. As these storms are only 15 to 30 km. across, they escape present sparse observation network. Avalanches occur whenever deep snow accumulations on slopes exceeding critical inclination. Avalanche activity is a function of structural weakness of the snowcover accumulations on slopes exceeding critical inclination. Most of our glaciers are also fed by avalanches from high-slope terrain in the glacierized region. A Defence Research Institute on Snow and Avalanche Study Establishment is located at Manali for forecasting and control of avalanches. More scientific inputs for observations and forecasting are needed adopting a multidisciplinary approach.

Presently, it is surmised that a sudden fall of air temperature by 5øC for the globe results in an advent of an ice age. The studies conducted in 1993 at the International Institute of Environment and Development, London shows that the Indian sub-continent is likely to be warmed up by 1øC by 2100 A.D. In the North, warming will be greater than in the South and for Himachal Pradesh annual temperature rise of about 3øC and annual precipitation variation of ñ20% are predicted.

In order that ecosystem based decisions on water management can be taken, strengthening scientific information on the whole basin is essential. This is especially true for hydrological and meteorological data. The current restrictive policy on availability of data for international rivers needs to be reviewed. Long-term research related to flood and water conservation in various parts of the basin, on seismic risks for large dams, sedimentation and impact assessment of water-related projects should be undertaken openly at an early date. Joint participation of NGOs and professionals from various river basins should be encouraged for common good in the region by reducing deepening water crisis and widespread economic losses from improved understanding of the natural environment.

6. GLOBAL CHANGE RESEARCH IN MOUNTAIN REGIONS

Mountain regions occupy about one-fifth of the Earth's surface. They are home to approximately one-tenth of the global population and provide goods and services to about half of humanity. Accordingly, they received particular attention in "Agenda 21", endorsed at United Nations Commission on Environment and Development (UNCED) held at Rio de Janerio focusses on mountain regions, and states :

"Mountain environments are essential to the survival of the global ecosystem. Many of them are experiencing degradation in terms of accelerated soil erosion, landslides, and rapid loss of habitat and genetic diversity. Hence, proper management of mountain resources and socio-economic development of the people deserves immediate action."

Moreover, mountain regions often provide unique opportunities (sometimes the best on Earth) to detect and analyse global change processes and phenomena :

i. Due to the often strong altitudinal gradients in mountain regions, meteorological, hydrological (including cryospheric), and ecological conditions (in particular vegetation, soil and related conditions) change strongly over relatively short distances. Consequently, biodiversity tends to be high, and characteristic sequences of ecosystems and cryospheric systems are found along mountain slopes. The boundaries between these systems (e.g., ecotones, snowline and glacier boundaries) experience shifts due to environmental change and thus can be used as indicators; some can even be observed at the global scale by remote sensing.

ii. Many mountain ranges, particularly their higher parts, are not affected by direct human activities. These areas include many national parks and other protected, "near-natural environments". They may serve as locations where the environmental impacts of climate change alone, including changes in atmospheric chemistry, can be studied directly.

iii. Mountain regions are distributed all over the globe, from the equator almost to the poles and from oceanic to highly continental climates. This global distribution allows us to perform comparative regional studies and to analyse the regional differentiation of environmental changes processes as characterised above.

Initiative on Global Change Research in Mountain Regions enunciated by International Geosphere and Biosphere Programme (IGBP) in association with International Human Dimension programme (IHDP) is based on an "integrated approach" for observing (detecting, monitoring), modelling and investigating global change phenomena and processes in mountain regions, including their impact on ecosystems and socio-economic systems. Both environmental aspects - in particular land use / land cover changes and climate change - and socio-economic aspects - in particular social, economic and political driving forces and changes - as well as their complex interactions and interdependencies will be taken into account in their mountain-specific forms.

The ultimate objectives of the approach are :

* to develop a strategy for detecting signals of global environmental change on montane environments;

* to define the consequences of global environmental change for mountain regions as well as lowland systems dependent on mountain resources; and

* to develop sustainable land, water, and resource management strategies for mountain regions at local to regional scales.

It is understood that, at least in the coming decades, socio-economic changes are likely to be at least as important as environmental changes in mountain regions. The environmental changes may significantly threaten sustainable development in these regions, and both environmental and socio-economic changes may reduce the ability of these regions to provide critical goods and services to society in the mountains as well as downstream and elsewhere; for instance, in terms of water and energy supply, biodiversity, attraction to tourist, and measures to avoid or mitigate damaging effects of disastrous events (floods, debris flows).

The implementation plan for global change research in mountain regions is structured around the following four overarching themes;

i. Long-term observation systems to detect and analyse signals of global change, as the mountain-specific component of the Global Observing Systems

ii. Integrated modelling framework for analysis, vulnerability assessment and predictive studies, including the development of scaling and regionalisation methods for mountain regions

iii. Environmental-change-related mountain specific process studies, in particular along altitudinal gradients and in associated headwater basins

iv. Development of strategies to ensure sustainable development in mountain regions, and to avoid or mitigate damaging effects of disastrous events.

The above considerations need to be seriously considered for the harmonious development of Himalayan region.

CONCLUDING REMARKS

Himalayan forms the most active and interactive snow-land-ocean atmospheric system. In general, energy exchange - mechanisms between the Himalayan land and atmosphere are altitudinally controlled. In the high altitude region (over 3500m), the energy releases are in the form of snow avalanches and glacier lake outburst floods (GLOFs) while flash floods, landslides and mudflows assumes disastrous dimensions in the altitude range from 500 to 3500 m. Extreme weather affects smaller watersheds 50 km2 where flash floods and debris flow are triggered by intense rainfall events. We have to adopt a combination of traditional and modern control measures adopting bioengineering techniques for sustainable development. Integrated long term planning is needed with local participation as an essential development strategy for water resource development of the tallest water tower of the world.

In an effort to know and quantify the force of couplings between geosphere, biosphere and atmosphere, an Himalayan experiment (HIMEX) was proposed on the lines of ALPEX-82, the Alpine Experiment and PYREX-90 (Pyrennes' experiment) which demonstrated improved understanding of the mountain environment and resulted in accurate weather forcasting. Framework of HIMEX outlines both long term and mesoscale measurement networks to be established for land surface experiments in different biomes (the life zones of interrelated plants and animals determined by the climate). The knowledge will be extremely useful in reducing the adverse effects of weather and water based natural hazards for a harmonious living in the region. This assumes a greater relevance as the Himalayan mountain environment is the highest and most fragile system having frequent extreme weather events on one side and substantial glacier ice loss due to glacier retreat and thinning as a result of global warming in last few decades. The main recommendations of a national brainstorming session on HIMEX (see Appendix) held in December 1995 were snowcover monitoring, high altitude hydro meteorological observation network and establishment of district bio-geodata bases to evolve sustainable development plans. This has to be a inter-departmental effort involving departments of science & Technology, Defence, Space, Environment, Agriculture and Water Resources with a high level national support and international cooperation.

APPENDIX

THE HIMALAYAN EXPERIMENT (HIMEX)

The Himalaya is the world's mightiest mountain system having 14 peaks over 8000 m and hundreds over 7000 m. It is known as the store - house of snow and ice. Himalayan snow and ice fields rival those in the polar regions, and the cryosphere is highly related to the atmosphere through heat and moisture exchanges. The monsoon is a gift of the high Himalayas. The mountain system attracts moisture from the Atlantic, Arctic, Indian and Pacific Oceans. It provides intense freeze - thaw cycles with diurnal changes up to 25øC, resulting in strong erosion. The mountain has micro - climates ranging from tropical (300 - 900) to perpetually frozen (above 4800m) and is rich in flora and fauna. It is one of the mega bio -diversity zones of our planet.

As the Himalayan natural resources support much economic activity, there is a need to understand atmospheric processes and circulations in order to manage the fragile environment for sustained development. With this in mind, a

Himalayan Experiment (HIMEX), along the lines of ALPEX, has been proposed with the following scientific objectives:

* To improve the understanding of mountain waves and mountain roughness representation in large - scale atmospheric models.

* To appreciate spatial variability in meteorological parameterisation at sub - grid scales for GCMs.

* To develop meso - scale and regional numerical models with detailed parameterization of land - surface processes for local specific operational weather forecasts.

* To study the air flow, mass and moisture fields over and around the mountain ranges under various synoptic conditions.

* To study precipitation patterns and orographic contributions at different altitude ranges during summer and winter seasons.

* To determine the role of diabetic heating associated with lee cyclogenesis over the Bay of Bengal for cyclone forecasting .

* To understand dynamic and physical processes associated with storm activity (thunder storms, Nor'westers) better.

* To study the modifying effect of radiative cooling on weather systems over the cold north - west region.

* To study the modifying effect of diabetic heating on weather systems over a warm southeast region.

* To help establish a data base for the cold Himalayan region for collecting, storing and dissemination information on seasonal/perennial snow and ice processes, interaction with the physical environment and effect on climate and its change.

The project (HIMEX) will need a high - level on national, regional and international coordination for its implementation.

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