MOUNTAIN ENVIRONMENTS IN CHANGING CLIMATES

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MOUNTAIN ENVIRONMENTS AND CLIMATE CHANGE IN THE HINDU KUSH-HIMALAYAS

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INTRODUCTION

The mountain environments of the Hindu Kush-Himalayas (HKH) have been undergoing rapid transformations in the last three decades at an unprecedented rate. Development imperatives have forced these transformations despite severely inadequate understanding of the biogeophysical processes in these high mountain environments. Development of infrastructures has increased accessibility into these otherwise isolated mountains. Increasing interactions with the outer world have made new demands on available resources as subsistence agriculture is being replaced by market-oriented economy. During the same period these inherently fragile and unstable environments have also witnessed a doubling of the population. Consequently pressure on natural resources has increased enormously, causing widespread degradation of the mountain environments and increasing poverty.

This situation has attracted worldwide attention since the early seventies and has been a major theme of global discussion (Eckholm, 1975, 1976; Myers, 1986; Ives and Messerli, 1989). It was this concern primarily which led to the establishment of the International Centre for Integrated Mountain Development, for the sustainable development of the Hindu Kush-Himalayas and the people living there (Glaser, 1984).

So far, the principal issues of major concern and debate with regard to the degradation of the Himalayan environment were not related so much to climate or climate change but more to overpopulation, deforestation, and soil erosion (Eckholm, 1975, 1976; Bajracharya, 1983; Mahat, 1985; Myers, 1986). However, it is well recognized that lack of reliable and long-term data on the extent and rate of deforestation, as well as on other environmental (including hydrometeorological) parameters for diverse ecosystems of the region, has given rise to serious uncertainty with respect to the degradation of

Myanmar, China, India, Nepal, and Pakistan) of the Hindu Kush-Himalayas. The need for expanding the protected areas to include representative ecosystems of the region cannot be overemphasized. Again there is virtually no information available on partially protected areas in the region, although their role in the conservation of biodiversity and local hydrological balance is equally important.

Another potential impact of global warming on the loss of biodiversity could be due to the melting of permafrost and increased intensity of precipitation adding to greater sedimentation in rivers and streams, thus affecting aquatic life.

Understanding of the intimate relationship between climate and ecology in the HKH is extremely important not only to identify important species and processes but also to know more exactly how the change in the climate could affect the ecology of the region. Studies with such precise objectives are yet to be carried out in the HKH.

Agriculture

Another issue of fundamental concern is the impact of increased production of food and fodder to satisfy the needs of a rapidly growing human and livestock population, on these mountain environments. Intensive cultivation, as well as extension of the cultivated area at the cost of forest, pasture, or other common lands, has not only changed the land-use but also caused widespread degradation of the environment in the region.

For example, the study of two subwatersheds in Nepal has shown that during the last three decades 75 per cent of the total forest land was cleared and grazing/pasture land had almost disappeared (Shrestha, 1992). Similar conditions are not uncommon in other parts of the HKH, although great controversy exists as regards the decrease in forest areas in recent times (Ives and Messerli, 1989). Mountain agriculture has also become more unsustainable and traditional management systems are no longer able to cope with such high demands and intensive use of natural resources (Jodha, 1989 and 1992) as is going to be required in future. Hence, even if we disregard climate change, sustainability of the mountain agriculture and stability of the mountain environment are in question.

The influence of monsoon on agriculture in the HKH needs no elaboration. A major impact of global warming is the possible shift of the ITCZ polewards and consequent enhanced monsoon precipitation. It is not possible to predict for the HKH the potential impact of enhanced monsoon rainfall due to climate change, but it might increase availability of water as well as moisture and contribute towards increased agricultural production. However, intense rainfall might trigger more landslides and mass wasting, and consequently result in a net loss of agricultural land and soil nutrients, causing negative impacts on agricultural production. Atmospheric warming

The climate of this region is essentially dominated by the southwest monsoon which provides most of the precipitation during the rainy summer months (June to September). However, the westerlies which predominate the rest of the year also bring snow and rain during winter and spring, most significantly in the western part of the region. These mountain chains block the northward advancement of the monsoon, which is about 6,000 m high (Mani, 1981: 11; Shamshad, 1988: 14), causing widespread and intense precipitation on the southern side of the Himalayas while, at the same time, making the Tibetan plateau and northern rainshadow areas among the driest in the world. They also intensify the precipitation processes in some preferred areas through orographic lifting, producing extreme examples as mentioned above. In fact, high and intense rainfall in the foothills of the northeastern Himalayas (e.g. Cherapunji) is a direct consequence of intensification of precipitation process by orographic lifting. The HKH mountains, therefore, act as an effective barrier between the lower and middle latitude climatic systems and can be looked upon as a huge climatic wall in the global atmospheric circulation system. The Himalayas, thus, are responsible for much moister summers and milder winters in South Asia than would otherwise be observed.

These mountain chains deflect the course of the summer monsoonal flow near the Bay of Bengal towards the northwest and there is a general decrease in monsoonal rainfall from east to west along the Himalayas. Thus, while the eastern Himalayas (Assam) have about eight months of rainy season (March–October) with fairly active pre-monsoon activities, the central Himalayas (Sikkim, Nepal, and Kumaun) have only four months (June–September) of rainy season. In the western Himalayas (Kashmir) the summer monsoon is active only for two months (July–August) (Mani, 1981: 9). Mean annual precipitation and monthly normals (1901–50) for some selected stations are given in Table 24.1 (Domroes, 1979), indicating the variation of rainfall from east to west as well as between trans-Himalayan and outer-Himalayan regions.

From Table 24.1 it is seen that whereas the outer Himalayas (e.g. Pasighat, Darjeeling) receive the highest rainfall, the trans-Himalayas (e.g. Kargil, Ladakh) is the region of lowest precipitation. The trans-Himalayan region gets its rain mostly from the western disturbances during winter. In general rainfall increases with altitude up to about 2,000 m south of the Himalayas but decreases sharply towards the north of the Himalayas. Similarly, rainfall generally increases from west (e.g. Simla: 1,542 mm) to east (e.g. Pasighat: 4,494 mm) in the HKH.

In general, the advent of the monsoon is characterized by the change in the direction of seasonal winds and the northward shift of the Inter Tropical Convergence Zone (ITCZ), from its normal position south of the Equator. The beginning of the monsoon season is not clearly defined in the mountains in contrast to the 'burst' of monsoon in the plains of India. Pre-monsoon

The only way to remove such uncertainties is to intensify research for better scientific understanding of the natural and anthropogenic factors, including global warming, that are impacting or are likely to impact on these mountain environments. As the origin of the uncertainties is associated with the absence of pertinent data and/or because they are unreliable, scanty, and even conflicting, a serious and sustained effort is needed to develop a comprehensive and reliable data base on pertinent environmental and hydroclimatic parameters of the region.

Better understanding of these processes in the mountains regions of the Hindu Kush-Himalayas is critical for the sustainable development of this region on all fronts. Without such an understanding and knowledge base, the rich potential natural energy resources (solar, wind, and forest), as well as biological resources (including use and conservation of its richness in biodiversity), cannot be fully and sustainably developed. Similarly, the modern infrastructure and agricultural revolution that is required in this region to eradicate endemic mass poverty cannot be implemented without a proper understanding of the climate and hydroclimatic processes. The July 1993 disaster unleashed by intense rainfall in the southern part of central Nepal, which damaged or destroyed bridges, roads, and dams, has once again demonstrated the futility of investment in the construction of infrastructures without a proper understanding of the hydroclimatic and other bio-geophysical processes in the mountain ecosystems. Hence, efforts to develop a minimum data base (Messerli, 1985) on such parameters should be given highest priority at both the national and regional levels.

Development of such a comprehensive data base will be a long-term programme demanding much human effort and financial resources. However, some initiatives are already underway in the region, and a number of recommendations can be formulated, as given below.

- Although establishment of a network of monitoring stations to match the diversity of climate in the region should receive high priority, the first step in this direction will be to make an inventory of climate-related programmes and available data on hydro-meteorology from the existing network of stations in the countries in the region. This will also contribute towards a global inventory of climate observation programmes which is considered as extremely important (Barry, 1992).
- Much could be undertaken for sustainable research on climate-related environmental issues in the region through a greater involvement of universities and academic institutions at various levels, if they were to be provided with adequate funds and if hydro-meteorological data were made accessible for research. Presently, hydrological data are neither easily accessible nor easily shared by researchers in the region. Major initiatives in this regard have to come from the countries of the region.
- Building a systematic knowledge and data base on mountain environ-

Himalayan environments and sustainable development (Thompson *et al.*, 1986; Ives and Messerli, 1989).

Any possible impact of global warming and climate change on the mountain environments of the Hindu Kush-Himalayas will further add to this uncertainty as regards the causes and consequences of such environmental degradations.

Significant research work on assessment of impacts of climate change has hardly started in the region. Subsequent discussions are based on the review of limited literature and data that were available at the time of writing. Conclusions on possible impacts of climate change in the region are tentative and drawn by extending the general conclusions of the IPCC (Houghton *et al.*, 1990; Tegart *et al.*, 1990) to this region.

GENERAL ASPECTS OF CLIMATE AND ECOLOGY OF THE HINDU KUSH-HIMALAYAS (HKH)

High diversity in climate and ecology are unique features of the HKH. Rising from a few metres above sea level to almost tropospheric heights, these highest mountain chains possess such enormous climatic and ecological diversity that within a span of less than 200 km they capture almost all types of climate that exist on earth and provide an unparalleled pool of genetic resources and biodiversity. Figure 24.1, which represents the cross-section for Central Nepal showing the dramatic rise in altitude and its diverse eco-zones between India (south) and the Tibetan Autonomous Region of China (north) within a horizontal distance of 174 km, illustrates this point. Similar situations are found throughout the length (about 2,500 km) and breadth (about 200 km) of the HKH. These diversities in climate and ecology have also been the source of sustenance for the people and their rich cultural diversities in these mountains.

In the case of the HKH, generalization in terms of their ecology and climate is complicated because studies are sparse and relevant data are not easily available. However, it can be said that the ecology and climate of any particular area in this region are essentially characterized by altitude, topography, and the seasonality in precipitation induced by the monsoonal system. Thus this region abounds in extreme contrasts in terms of ecology and climate due, basically, to variations in these factors. For example, if Cherapunji in Meghalaya (northeast India) lying south of the main Himalaya, receives one of the highest rainfalls in the world (*c.* 11,000 mm per annum), then Leh, which lies in the rainshadow in the northwest Indian Himalaya, is one of the driest areas in the world (*c.* 75 mm per annum). Similar contrasts exist in vegetation, from the moist tropical and subtropical forests of *Shorea* in the southern plains, to the cold high alpine juniper forests and meadows, and the vegetation of arid deserts of Tibet and the trans-Himalayan areas of higher elevations in the north.

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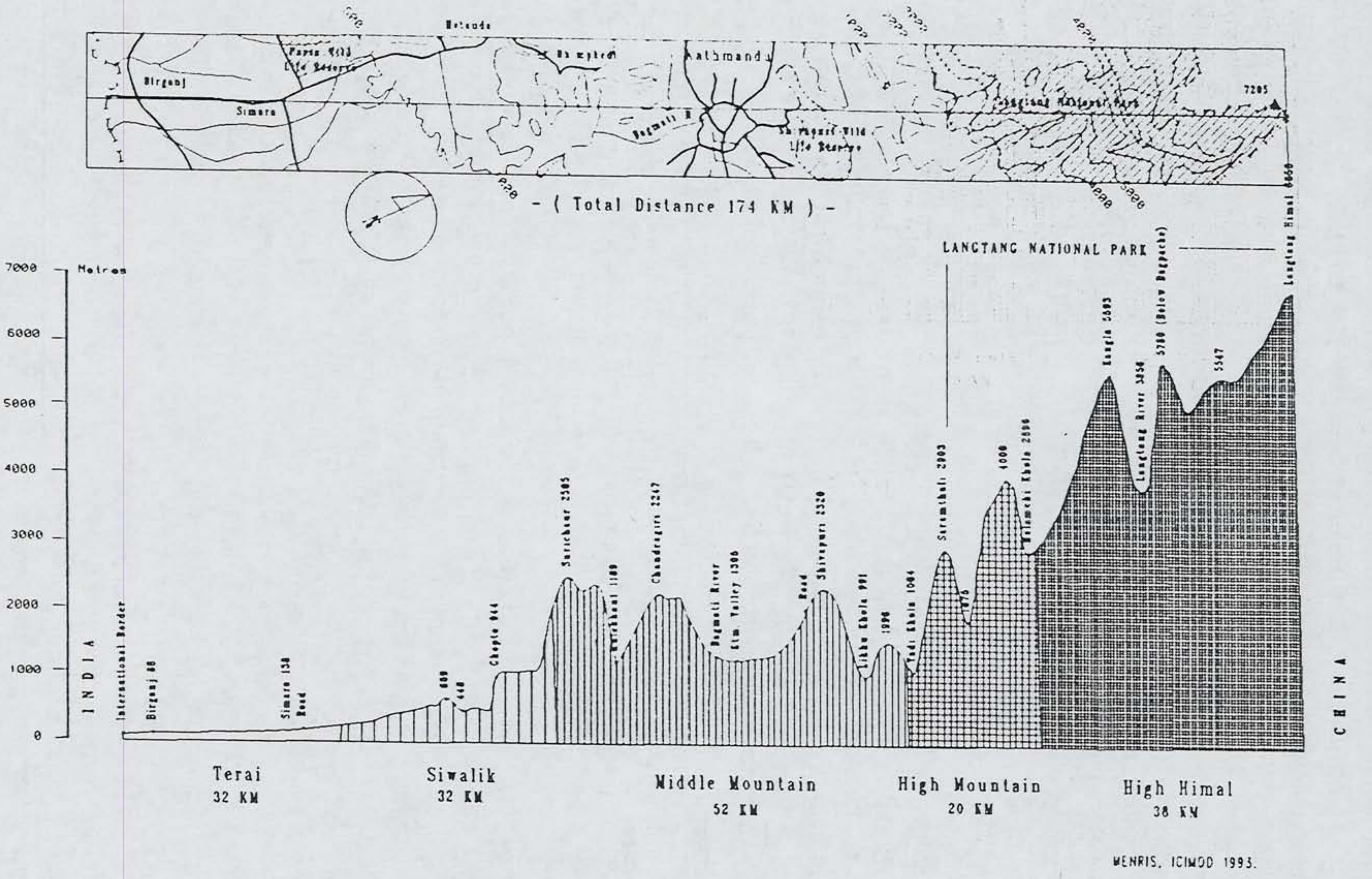

Figure 24.1 Cross-section of Central Nepal.

Table 24.2 Seasons and associated weather in Nepal (in terms of local months)

	Months	*Associated Weather Type*
1	Baisakh-Jeth (mid-April to mid-June)	Mainly hot and dry summer with rain and hail (due to thunderstorms and north westerlies)
2	Asar-Sawan (mid-June to mid-August)	Heavy monsoonal rains
3	Bhadra (mid-August to mid-September)	Hot and moist with scattered rainfall
4	Ahoj-Kartik – mid-Mangsir (mid-September to November)	Mild and fair with light rain or snow (due to Westerly disturbances)
5	Mid-Mangsir – Poush – Magh (December to mid-February)	Cold and dry with some rain or snow (due to Westerly disturbances)
6	Fagun-Chait (mid-February to mid-April)	Mild, fair and dry

Note: These local perceptions of associated weather with local calendar months show a remarkable degree of correlation with actual weather conditions during such periods and their annual cycle is quite regular. Baisakh is the first and Chait the last month of the Nepali calendar.

farming systems and farming calendars in terms of local months and calendars. Table 24.2 illustrates this for Nepal. Farmers across the HKH have surely no choice than to continue the use of such traditional calendars for a long time to come. Any significant and, particularly, abrupt change in such calendars as a result of climate change would cause disasters in local farming practices.

Over the centuries of isolation people across the HKH have learned to live with climatic disasters. Each year they have to survive either too much rain (causing landslides, floods, and debris flows) or too little (causing droughts). Hail is another much dreaded disaster which by its highly localized character is essentially unpredictable. Farmers have developed their own strategies to survive such disasters although such practices have no scientific justification. For example, in the middle hills of Nepal, local Buddhist priests (Lamas) are entrusted by villagers to ward off hail from their village (H. Gurung, personal communication, 1992). This is widely practised in Nepalese middle hills, probably because science has yet to reach there and the people still believe that climatic disasters are acts of God, and hence beyond human control and comprehension. Similarly it is widely believed in Nepal that climatic events and disasters have a 12-year cycle, which tends to agree with actual climatic events such as floods, in many cases. There are also traditional examples where cropping pattern, choice of diverse crops and a deliberate choice to have farm lands (big or small) in different localities and altitudes have helped the farmers to cope with climatic disasters.

Traditional knowledge of local climates and hydrologic events have not been well documented and it will be worthwhile to do so in selected examples of both advancing and retreating glaciers have been reported from the Karakoram and Kunlun Mountains (Zhang, 1984; Wang *et al.*, 1984; Chen *et al.*, 1989; Zheng *et al.*, 1990). It is difficult to relate these fluctuations to climate change, although they indicate some warming of the atmosphere in the region.

IMPLICATIONS OF POTENTIAL IMPACTS OF CLIMATE CHANGE ON MOUNTAIN ENVIRONMENTS IN THE HKH

As relevant data on the concentration of greenhouse gases are not available for the region, it is difficult to discuss the possible impacts of global warming in the HKH due to sources from, or outside, the region. General deterioration in the quality of air is visible in many parts of the region, particularly in urban areas, and especially in urban areas located in the valleys (e.g. Kathmandu), which are significantly affected by growing urbanization, industrialization, and increased use of fossil fuels. Problems of air pollution are also exacerbated by climatic factors, such as low-level inversions, particularly during winter in the mountain valleys. The following discussion is based essentially on the extension of the IPCC's climate change impact scenarios (Houghton *et al.*, 1990; Tegart *et al.*, 1990) to the HKH.

Despite uncertainties involved in climate change scenarios, potential impacts of global warming (Houghton *et al.*, 1990; Tegart *et al.*, 1990) which might affect the HKH are: increased monsoon rainfall due to seasonal shift of ITCZs polewards; enhanced precipitation; general shift of agro-ecological zones towards higher elevations, and shrinking of the areas under snow and permafrost. The possible implications of such changes with respect to some basic issues concerning the mountain environments of the HKH are discussed below. These discussions deal mainly with those issues concerning emissions of CO_2 and CH_4, which are most relevant in the context of the mountain environments of the region.

Ecological issues: use and conservation of forest and biodiversity

The mountain environments of the HKH are already under stress through the combined pressures of human and livestock population on its natural resources, principally forest, land, and water. With a conservative estimate of 2 per cent growth rate, the present human population of 118 million (Sharma and Partap, 1993) will double within 35 years. Similarly the present livestock population of nearly 70 million (Bhatta, 1992) is also expected to grow at the same rate and double within that period. The total impact of additional demands for food, fodder, fuel, and fibre will be on the existing forests (Nautiyal and Babor, 1985) not only because additional lands will be needed to produce more food but also because of almost absolute dependence of

—— (1992) *Mountain Hydrology in the Hindu Kush-Himalayan Region*, Report of the Second Consultative Meeting of the Regional Working Group on Mountain Hydrology, 16–18 March 1992, UNESCO/ICIMOD, Kathmandu.

Upreti, B.N. (1985) 'The park–people interface in Nepal: problems and new directions', in J.A. McNeely, J.W. Thorsell and S.R. Chalise (eds), *People and Protected Areas in the Hindu Kush-Himalaya*, KMTNC/ICIMOD, Kathmandu, pp. 19–24.

Verghese, B.G. (1990) *Waters of Hope*, Oxford and IBH, New Delhi.

Wang, W., Huang, M. and Cheng, J. (1984) 'A surging advance of Balt Bare Glacier, Karakoram Mountains', in K.J. Miller (ed.), *The International Karakoram Project*, Cambridge University Press, Cambridge, pp. 76–83.

WRI (1991) *World Resources 1990/91*, World Resource Institute, New York.

Zhang, X. (1984) 'Recent variations of some glaciers in the Karakoram Mountains', in K.J. Miller (ed.), *The International Karakoram Project*, Cambridge University Press, Cambridge, pp. 39–50.

Zheng, B., Jiao, K.Q., Li, G. and Fushimi, H. (1990) 'The evolution of Quarternary glaciers and environmental change in the West Kunlun Mountains, Western China', *Bulletin of Glacier Research*, (Japan) 8: 61–72.

ecosystems across the HKH. With further refinement, such knowledge could also provide useful and practical guidelines for improved agricultural practices and in developing strategies to face climatic disasters in future. As it is difficult to imagine that the network of hydro-meteorological stations could be expanded in the near future to generate meaningful data for the understanding of local climates and hydrology in the HKH mountains, it would be unwise to ignore such a useful and practical knowledge of local climates and hydrology possessed by local people in the region.

CLIMATIC FLUCTUATIONS IN THE HKH: USUAL OR UNUSUAL?

Climatic variability from year to year is more the rule than the exception in any locality in the HKH due to the diverse causes discussed in the preceding sections. Again, climatic fluctuations on different time scales and due to various natural causes have been known to occur during various geological periods (Kutzbach, 1976). As long-term climatological data for the mountainous areas of the Hindu Kush-Himalayas are lacking and the issues concerning global warming and impacts of climate change have started to receive some attention only very recently (Gupta and Pachauri, 1989), it is difficult to discuss quantitatively the impacts of global warming and climate change in the region. Some studies indicating fluctuations in atmospheric temperature in the region are discussed below, although they cannot be linked to the impacts of climate change without further studies and evidence.

Noontime temperature distribution in Kathmandu (1802–1803 and 1968–1990)

Hamilton's famous book on Nepal based on his fourteen months of stay during the years 1802 and 1803, also contains the oldest temperature records available so far for Kathmandu and its suburbs from 19 April 1802 to 16 March 1803 (Hamilton, 1990: 322–44). Unfortunately, it does not provide information on measurement, site, and equipment used, and temperature records are not available continuously for the subsequent years up to 1968. On the basis of Hamilton's records and the present availability of data (1968–1990) a comparison is made of the distribution of monthly means of noontime temperatures which is shown in Figure 24.2. Hamilton's original temperature records were on the Fahrenheit scale and they have been converted here to Celsius for convenience. Data for other hours of the day could not be used for comparison with the present records.

From Figure 24.2 it is seen that between the months of August and March mean monthly noontime temperature during 1968–1990 is higher than the monthly noontime temperature during 1802–1803. Between the months of April and July, Hamilton's records lie within the range of 1968–1990,

Hamilton, F.B. (1990) (second AES reprint; first published 1819) *An Account of the Kingdom of Nepal*, Asian Educational Services, New Delhi.
HMGN (1974) *Mechi Dekhi Mahakali* (in Nepali): Part IV, HMGN, Ministry of Communications, Department of Information, Kathmandu, pp. 477–8.
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Mani, A. (1981) 'The climate of the Himalaya', in J. Lall and S. Moddie (eds), *The Himalaya. Aspects of Change*, Oxford University Press, Delhi, pp. 2–15.
Mayewski, P.A. and Jeschke, P.A. (1979) 'Himalayan and trans-Himalayan glacier fluctuations since AD 1812', *Arctic and Alpine Research*, 11 (3): 267–87.
Melillo, J.M., Callaghan, T.V., Woodward, F.I., Salati, E. and Sinha, S.K. (1990) 'Effects on ecosystems', in J.T. Houghton, G.J. Jenkins and J.J. Ephramus (eds), *Climate Change*, IPCC, WMO/UNEP, Cambridge, pp. 283–310.
Messerli, B. (1985) 'Stability and instability of mountain ecosystems. An interdisciplinary approach', in T.V. Singh and J. Kaur (eds), *Integrated Mountain Development*, Himalayan Books, New Delhi, pp. 72–97.
Miller, M.M. (1989) 'Comparative accumulation regimes of Himalayan and Alaskan neves and the issue of global warming', *Environment and Society in the Manaslu-Ganesh Region of the Central Nepal Himalaya*, Foundation for Glacier and Environmental Research and University of Idaho, Idaho, pp. 89–96.
Miller, M.M. and Marston, R.A. (1989) 'Glacial response to climate change and epeirogency in the Nepalese Himalaya', *Environment and Society in the Manaslu-Ganesh Region of the Central Nepal Himalaya*, Foundation for Glacier Research and University of Idaho, Idaho, pp. 65–88.

heavy showers associated with convective clouds occur during the afternoon accompanied by thunder and lightning. According to Ueno and Yamada (1989), diurnal variation in precipitation in the Lamgtang Valley in Central Nepal is associated with three types of precipitation at different hours of the day. The mechanism of each type of precipitation is strongly influenced by the local circulation, topography, and the monsoon activity.

High intensity of rainfall is characteristic of the Himalayas (Domroes, 1979; Nayava, 1974). True measurements of rainfall in the Himalayas are problematic and of limited value not only because of the difficulty in installation, maintenance, and running of stations but also because of only local-scale validity of the observations obtained (Domroes, 1979). The daily rainfall in the Himalayas has not been given particular scientific attention so far, and detailed studies on this subject are necessary. The general rule that with increasing precipitation its variability decreases is of practical significance for flood control and for agriculture and soil management.

SEASONALITY AND TRADITIONAL KNOWLEDGE OF CLIMATES IN THE HKH

The climate of the Hindu Kush-Himalayas is essentially seasonal in character and seasonality has greatly influenced the agro-ecological practices here. Essentially, there are four main seasons in the region – winter (December to February); pre-monsoon or summer (March to mid-June); monsoon (mid-June to mid-September); and autumn or post-monsoon (mid-September to November) (Mani, 1981: 6).

The rhythm of seasonal changes in climate is interestingly quite uniform as is evidenced by the farming practices in the mountains. For example, the hill farmers of Nepal have developed their own local farming calendars over the centuries, based on intimate knowledge of local climates and the regularity in their seasonal changes. These calendars are still the basis of farming in the Nepalese mountains, using either the solar or the lunar calendar, and have been remarkably successful in helping the farmer to plan ahead and to choose crops suited to local climatic conditions. The unique rice planting calendar of Jumla (altitude *c.* 2,400 m) in western Nepal is one such example which is still being followed (HMGN, 1974). Similar traditional farming calendars are widely in use in other parts of the Hindu Kush-Himalayas as evidenced by rice cultivation at very high altitudes in the region. According to Uhlig (1985) the highest altitudes at which rice is cultivated is found in the HKH region.

A remarkable feature of these local calendars is their dependability from year to year for planning and managing agriculture and farming. This clearly indicates that through trial and error over the centuries farmers have obviously been successful in identifying the key climatic features of their local ecosystems, and have applied such knowledge in developing local

Increase in non-combustive use of wood will not only reduce the build-up of carbon dioxide in the atmosphere, but will also provide economic opportunities to the poverty stricken people of these mountain environments. A concerted effort to increase such use of wood and wood products as much as possible, at the regional as well as at the global level, will provide incentives for better management of existing forests as well as encourage increased afforestation in the region on a sustainable basis. A global co-operative programme to develop renewable energy resources to provide alternatives to fuelwood in the region in the long term also needs to be considered.

Another important ecological issue which is again linked directly to deforestation or degradation of forests is the need for the conservation of biological diversity in which this region is exceptionally rich. Phytogeographically the Himalayas as a whole are considered as an autonomous region, distinct from other regions such as the Sino-Japanese, Indian, and Central-Asiatic (Dobremez, 1976: 245). In terms of ecosystems, the Hindu Kush-Himalayan region is the meeting place of Palaeoarctic realm of the north and the Indo-Malayan realm of the south. This region is also at the crossroads of five major biogeographic sub-regions (Train, 1985: 9). These add to this region's unique richness in biological resources. For example, more than 100 species of mammals and 850 of birds have been recorded here and about 10,000 indigenous plants have been reported of which over 6,000 species are indigenous to Nepal only (Upreti, 1985: 19).

Loss of biodiversity is an issue of global concern. The Himalayas have, since ancient times, been considered as a reservoir of rare medicinal plants having recognized healing properties. *Taxus baccata*, a native species of Himalaya has recently attracted considerable interest in the western world as a potential drug against cancer. Several species of plants that are yet to be studied might be lost because of a poleward shift of climatic zones, estimated at 200–300 km per degree of warming. It is also estimated by WHO that 80 per cent of the people in developing countries depend on traditional medicines, of which 85 per cent involves the use of plant extracts (Tegart *et al.*, 1990: 3–25). Loss of useful species from the HKH will also be a global loss.

Conservation of such diverse ecosystems and *in situ* protection of the rich biodiversity of these mountains are therefore extremely important. Global and national attention has been drawn to this important issue and there is a good network of protected areas in the region. There are about 300 protected areas of all categories (as per IUCN's classification) covering approximately 101,000 sq km distributed over the entire region (Stone, 1992: 124–5). Although these areas do provide some protection to several endangered species of plants and animals in major ecosystems of the region, it may be useful to note that the existing network covers less than 2 per cent of these mountains in the eight countries (Afghanistan, Bangladesh, Bhutan, may cause an upward shift of agro-ecological zones and could make more land available for agriculture, although the soil condition may not be able to support crops. Again, local climates might be affected, and local calendars on the basis of which mountain people have been planning and managing their agriculture so far, could become no longer useful.

Greater availability of water might also encourage farmers to bring more land under rice cultivation with a consequent rise in methane production. Reliable studies on methane production by paddy rice in the region are yet to be carried out, and controversy about the estimated amount of paddy and animal methane production from the developing world already exists (Agarwal and Narain, 1991; WRI, 1991).

Enhanced monsoon rainfall might bring more water to the fields than could be handled by traditional farmer-managed irrigation systems which so far have made agriculture, particularly rice cultivation, possible in the HKH. Disruptions in local irrigation and water management systems would be disastrous for agriculture and slope-land management in these mountains.

Water and energy resources

The countries of the HKH region are passing through rapid economic transformations in order to meet the growing aspirations of the people for their overall development, and the demand for energy for diverse developmental needs has grown enormously in the region in recent years. Sole dependence on fuelwood for all the energy requirements in the past was the most critical factor for deforestation in the region. For the bulk of the population this dependence, for their own needs as well as for the needs of their livestock, still persists. However, wood is no longer considered the principal source of energy, and water is now seen to be the principal source for rapid economic development (Verghese, 1990).

Considering that the HKH is one of the richest regions on earth in terms of hydro-power potential, such hopes are not illogical. However, a proper and systematic assessment of the hydro-power potential (including mini- and micro-hydro) of all the big and small rivers of the region has yet to be made. For example, the hydro-power potential of Pakistan, which comes largely from the Indus system, is estimated to be 20,777 MW (Quershi, 1981 in Sharma, 1983: 262) and that of the Ganga-Brahmaputra-Barak basin on the order of 200,000–250,000 MW, of which half or more is considered to be viable for harnessing (Verghese, 1990: 169). Similarly, countries such as Nepal, which alone has a theoretical potential of 83,000 MW (Chalise, 1983), and Bhutan are extremely rich in hydro-power, with potentials to transform their economies dramatically if such power could be harnessed and shared in the region. Despite such a huge potential only a negligible percentage of it has been utilized so far by the countries of the region.

There are three major hurdles in harnessing this rich potential, namely ments should also start immediately by recording and documenting the knowledge of the local people about their climate and natural resources (land, water, flora, and fauna). Traditional knowledge of the mountain people in diverse cultural and ecological settings must be documented and recorded before they are wiped out by the onslaught of rapid changes that are sweeping these mountains (Pei, 1991).

- Solutions to the problems of the HKH region will have to be found through work carried out in the region. Scientific and technical principles and approaches which might have been successful elsewhere in developing natural resources do not constitute a sufficient guarantee for their replication in this region. This is clearly exemplified by the frequent damage or destruction of vital infrastructures, constructed at huge cost, through floods, landslides, and debris flows, which are primarily caused by excessive and intense precipitation. As these damages often affect neighbouring countries also, governments in the region should co-operate and accord priority to monitor Himalayan watersheds for hydroclimatic and geo-ecological studies. Donors who often provide funds for the development of infrastructure can play a crucial role in initiating such research. Further delay will only perpetuate the waste of scarce national and international resources.
- Support for initiatives already taken by national or international institutions, such as the Regional Programme on Mountain Hydrology launched jointly by UNESCO and ICIMOD (UNESCO/ICIMOD, 1990, 1992) would be a good start. Similar regional programmes on mountain climate, and climate change studies, should be launched as soon as possible. Similarly, one of the regional centres of the International Geosphere Biosphere Programme (IGBP) could be devoted to problems of mountain environments (Barry, 1992) and located at ICIMOD for the HKH region. A concerted effort by all concerned with research and studies on climate and impacts of climate change, such as UNESCO, UNEP and WMO, to influence government donors through specific programmes for this region will probably be more effective. ICIMOD, being located in the region, should be encouraged to initiate and implement such programmes in close collaboration with national institutions of the countries of Hindu Kush-Himalayas.

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Relevant data bases for large-scale harnessing of solar and wind energy need to be developed. However, the potential impact of climate change due to increased availability of moisture and increased rainfall could result in more cloudy days, and this might adversely affect the prospects of solar energy utilization in the region.

Hazards and disasters

With the highest mountain chains which are geologically young, active, and still rising, the Hindu Kush-Himalayan environment is highly vulnerable to natural hazards and disasters. These mountain environments are commonly associated with earthquakes, landslides, mass-wasting, floods, and droughts. Most of the disasters commonly faced by the people are climate-induced and are generally considered as acts of God in the region. Sometimes these disasters become catastrophic such as the 1988 floods in Bangladesh (Rogers *et al.*, 1989), the 1992 floods in Pakistan, and the more recent floods, landslides, and debris flows in the southern part of central Nepal in July 1993. Failure in monsoon rain often causes serious droughts, which sometimes can also be calamitous, such as those in north India during 1985 and 1986. Hail is another climatic hazard which the people have to face quite frequently, as mentioned earlier.

A change in the climatic pattern in this region could further increase the incidence of such disasters. Increased monsoon rainfall, increase in rainfall intensity, melting of snow, ice, and permafrost with a consequent decrease in their surface areas (which in turn could diminish lean period discharge), all of which are envisaged as potential changes due to global warming, could singly or in combination with other factors induce more incidences of disasters in the region, although it is not possible to consider the magnitude or frequency of such disasters at this stage. Such potential impacts of climate change further add to the confusion and uncertainty particularly with respect to the impacts of deforestation on downstream flooding and increased sedimentation in the rivers. It is an issue which has the potential to spark off regional conflicts as, for example, the floods in Bangladesh are assumed to be linked to deforestation in the Himalayas despite the fact that there is no factual and scientific evidence of such linkages (Ives and Messerli, 1989; Bruijnzeel and Bremmer, 1989; Carson, 1985; Alford, 1992).

CONCLUSIONS AND RECOMMENDED ACTIONS

From the foregoing discussions it is obvious that the implications of potential impacts of global warming and climate change for the mountain environments of the Hindu Kush-Himalayas are uncertain although the impacts could be more adverse than benign. Obviously this is going to add further to the uncertainty that is attributed to these environments.

Table 24.1 Monthly rainfall normals, mm (1901–1950)

Station	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Kathmandu Nepal 1324 m	10	42	15	26	129	246	373	347	182	36	2	8	1416
Simla, Kumaun Himalaya 2200 m	65	70	64	46	60	149	416	419	182	33	10	2	1516
Nainital Kumaun 1953 m	70	73	53	38	84	391	769	750	363	61	13	2	2667
Pithoragarh Kumaun	44	56	40	28	73	183	300	287	149	33	7	22	1222
Pasighat/Tirap Frontier Tract, NE Assam	55	97	138	273	466	967	975	622	585	261	33	24	4496
Darjeeling, 2265 m	11	32	54	113	231	597	792	643	446	142	25	6	3092
Kyelong, N Punjab Himalaya	59	64	102	79	56	23	33	33	52	21	7	26	555
Srinagar, Kashmir Himalaya	70	74	94	90	60	34	56	63	40	28	13	37	659
Kargil, Ladakh 2682 m	37	38	60	42	25	7	7	10	10	6	3	21	266

Source: Domroes (1979)

activities gradually merge with the monsoon rains particularly on the eastern part, while in the western part its arrival is sudden with abrupt changes in cloudiness, temperature, winds, and rainfall (Mani, 1981).

Earlier attempts at generalization of climates in the Himalayas have been largely based on the relationship between climates and vegetation, and, to some extent, cultural practices at various altitudes (Schweinfurth, 1957, quoted by Ives and Messerli, 1989; Troll, 1967; Bagnouls and Meher-Homji, 1959; CNRS, 1981). Taking into consideration the horizontal and vertical variations in climate and vegetation, Troll (1967) has made a comprehensive classification of the Himalayas from west to east into the following divisions: the Indus Himalayas, the Punjab Himalayas, the West Nepal–Garhwal Himalayas, the East Nepal–Sikkim Himalayas, and the Assam Himalayas. More recently remote sensing techniques have been used to classify the Himalayas (Kawosa, 1988). Altitudinal zonation of climate and vegetation has also been the basis of a broad classification of the climates in the Nepal Himalayas (Dobremez, 1976; Hagen, 1980) and this has been the best approach to understand the general nature of climate and vegetation at different altitudes in the region. In their recent study, Ives and Messerli (1989) have provided excellent details on a new attempt undertaken by the Geographical Institute of the University of Berne on the regionalization of climates in the Hindu Kush-Himalayan region.

Difficulties in the generalization of climate in the Himalayas are largely due to the absence of long-term data and extremely limited number of meteorological stations particularly at elevations above 2,500 m. These traditional mountain farming system on forest in the HKH (Mahat, 1987).

The total area under forest in the HKH including pastures and protected areas is presently estimated as 227.714 million ha (Bhatta, 1992). The area under forest cover is estimated at around 86.3 million ha covering about 24 per cent of the land area of the HKH, and the rate of deforestation is estimated as between 141,000–354,000 ha/annum (Bhatta, 1992). Despite the 'uncertainty' that usually surrounds forest data in the region (Thompson *et al.*, 1986) the rate of deforestation is certainly going to exceed the above figures in the coming years, unless some drastic measures are taken to lessen the traditional dependence of farming on forests.

The role of forests and vegetative covers in stabilizing the slopes, controlling soil erosion, sedimentation, and mass wasting, modulating soil temperature extremes and the hydrologic regimes are well recognized. Equally important is the possible role of forests in absorbing carbon dioxide from the atmosphere and hence retarding or controlling the rate of global warming through increased afforestation on a large scale despite the enormity and complexity of the task involved (Melillo *et al.*, 1990). Although lack of relevant and reliable data on both climate and forest cover in the HKH does not permit us to draw any conclusion on the impact of one on the other, loss of forest cover does imply a net shrinking of the global carbon sink and hence increases in CO_2 and atmospheric warming. The burning of wood, principally as fuel for cooking and to a certain extent to keep warm during the cold period is another important issue connected to deforestation as well as increased CO_2 in the atmosphere. It is estimated that 80 per cent of the total wood used in developing countries is for burning as fuel (Jaeger, 1983). This is true for the HKH too.

It therefore appears that the deforestation and burning of wood which is occurring in the HKH is, to a certain extent, contributing towards increased CO_2 in the atmosphere. However, fuelwood adds much less CO_2 to the atmosphere than fossil fuels, and if forests are managed sustainably to supply fuelwood then much of the carbon released will be reabsorbed by forests (Houghton, 1989). This makes fuelwood a more benign energy source than is generally believed. Effective protection of existing forests and increased afforestation are, therefore, very important for the HKH. This could convert the HKH into a net carbon sink as part of a concerted effort towards reafforestation in the Indian Himalayas (Singh *et al.*, 1985). Cooperation among the countries of the region to increase the green cover in the HKH will be an important contribution towards achieving such objectives (Khoshoo, 1990a, 1990b, 1990c).

Similarly, encouraging people to plant trees in their marginal lands through a scheme which will guarantee the supply of food to mountain villages and an assured market for wood or wood products, in what may be called a 'Wood for Food' programme (Chalise and Joshy, 1983), could greatly help increase the forest cover in the mountains of the HKH.

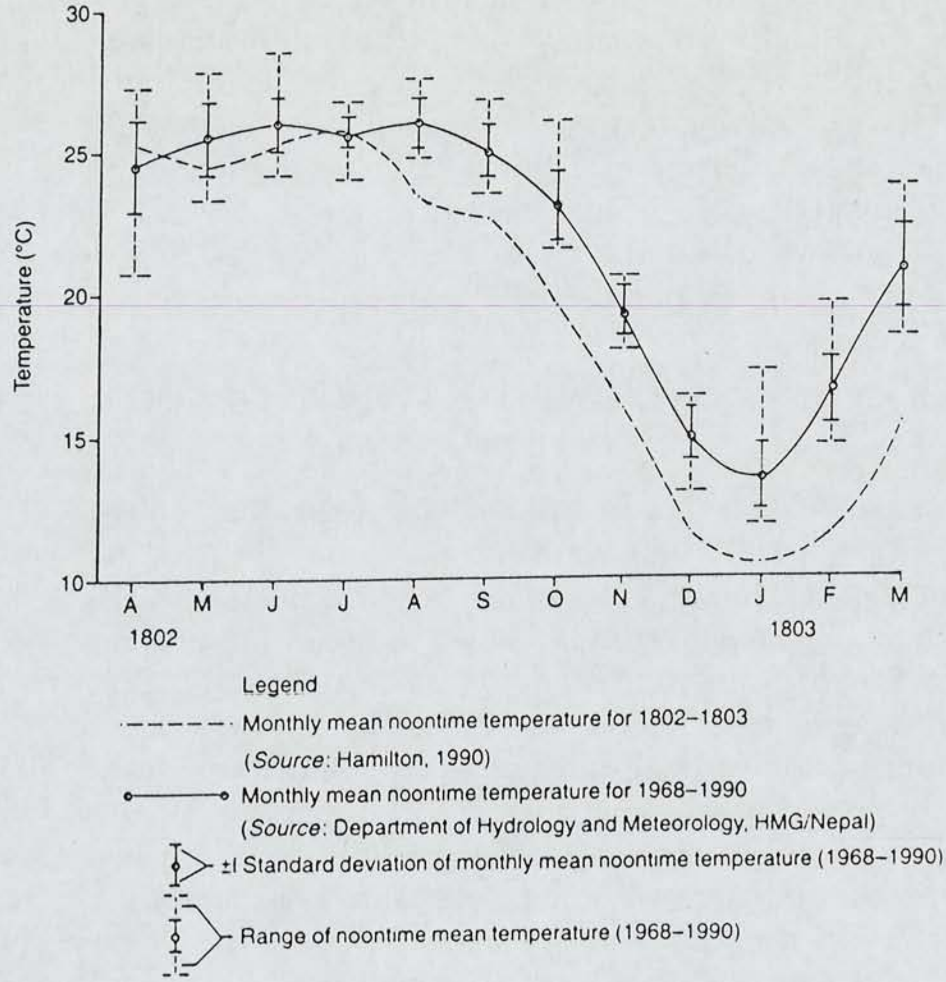

Figure 24.2 Noontime temperature distribution in Kathmandu (1802–3 and 1968–90). *Source*: S.R. Chalise 1993.

showing no significant trend. Although this preliminary analysis shows that the mean monthly noontime temperature has been increasing in recent years in Kathmandu, it needs further examination of factors, such as the impact of urbanization, which could influence such warming before definite conclusions are made in terms of its possible linkage with global warming.

Glacier fluctuations

Glacier studies in the Hindu Kush-Himalayas have received a lot of attention, particularly by scientists from outside the region. Most of the studies indicate that the glaciers are generally retreating. Mayewski and Jeschke (1979) have made local and regional syntheses of 112 records of such fluctuations in the HKH and their study shows that the glaciers in this region have been in a general state of retreat since AD 1850. Similar reports of glacier retreat and accelerated ablation are available from Nepal (Miller, 1989; Miller and Marston, 1989; T. Yamada, personal communication, 1991), although

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economic, scientific/technical, and political. So far, the poverty that exists in the countries of the region appears to be the main reason for not utilizing this huge potential, but external input of capital will not be difficult if the projects are viable. Such examples already exist in many countries of the region. Thus the scientific and the political seem to pose more important problems than the availability of capital.

The basic constraint from the scientific or technical point of view is the lack of long-term historical data bases on relevant biogeophysical parameters for a proper understanding and modelling of the hydrological systems of these mountain basins, big or small, which are so different from each other in terms of geology, topography, altitude, vegetation, and land-use. Even smaller basins have not been systematically and adequately studied to understand the inter-relationships between precipitation, erosion, land-use changes, sedimentation, and streamflow. Hence the impacts of natural and anthropogenic processes are difficult to model or predict, and have given rise to much debate and uncertainty (Kattelmann, 1987). This problem is further complicated because the hydrology of high mountain areas is itself not very well developed and the peculiar combination of the extremely high altitudes, steep slopes, and intense seasonal monsoonal rainfall, limits and even precludes the application of hydrological techniques, principles, and models developed in temperate regions of Europe and America. These problems are the primary concerns of the proposed project, namely, Regional Network of Experimental Watersheds for Hydrological Studies (RENEWHS), which is being launched by UNESCO and ICIMOD jointly in close co-operation with the countries of the region (UNESCO/ICIMOD, 1990 and 1992).

The complexity of the problems associated with the development of water resources in the region could be further complicated by the potential impacts of enhanced monsoon rainfall and increase in rainfall intensity due to global warming. The implications of such an increase in the amount and intensity of rainfall, which are virtually impossible to quantify, on the highly energized, geologically active high mountain environments of the HKH are evident but uncertain. Similarly, the possible impact of shrinking areas under seasonal snow, ice, and permafrost could seriously alter the hydrologic characteristics of the river systems in the region.

Considering the serious inadequacy of present knowledge on mountain hydrology, future changes in the hydrologic regimes of the rivers because of climate change will add further to the uncertainty and risks in harnessing water resources in the region. Technical designs for large dams exceeding fifty years' duration will need to consider these uncertainties. The region faces a dilemma as to whether to ignore these warnings or face the prospect of bearing additional costs, and whether or not such costs are affordable. Either way mountain environments could be adversely affected.

There is the possibility of developing other renewable resources, particularly solar and wind, in the region. They are virtually untapped so far.

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difficulties have seriously hindered a better understanding of climates in the Himalayas (Barry, 1981; Mani, 1981; Das, 1983; Chalise, 1986).

LOCAL CLIMATES

As the Himalayas rise suddenly from the plains in a series of folds, they are the causes of several complexities in the climate of the region. A greater number of sub-climates and small-scale subdivisions exist in the region due to dramatic changes in orientation, altitude, and size of the mountains, slopes, valleys, and plateaux (Domroes, 1979). According to Flohn (1970), multiplicity of diverse local climates in these high mountains is caused by the interaction of different atmospheric processes – local heat budget, thermal circulation of varying magnitude, and convection and advection as a result of the synoptic processes occurring in the lower and upper troposphere.

An interesting feature of such local climates is that the valley bottoms in the HKH are generally characterized by dry, and the adjoining slopes and peaks by wet, climatic conditions. Flohn (1970) attributes this to a thermal circulation pattern, 'with valley breezes blowing up-valley throughout the day', through the influence of the Tibetan Plateau which acts as a heat source. This dry valley phenomenon is considered to be a unique feature of the Himalayas and particularly associated with the larger valley systems.

Strong winds are also characteristic features of the Himalayan valleys in Nepal (Hagen, 1980: 57) as evidenced by the deformed trees in the Kali Gandaki valley (Ohata and Higuchi, 1978). Possibilities of utilizing such winds for power generation in some potential sites in Nepal have drawn some attention, but systematic assessments are difficult as relevant data are not normally available (Chalise and Shrestha, 1982).

Another common feature is the wetness of the windward side and the dryness of the leeward side in these mountains. This is true at the local scale as well as at the macro scale. For example, Lumle (1,642 m) lying south of Annapurna range in the Nepal Himalayas receives about 5,000 mm of rain per annum, whereas Jomsom (2,750 m) lying north of it receives only about 250 mm per annum.

Despite the broad influence of monsoon in the summer and western disturbances in the winter on the precipitation pattern in the region, local variation in rainfall is significant. Orography influences the rainfall pattern very strongly at the local scale and contrasts in rainfall amount even in adjacent watersheds are quite common.

Studies of diurnal rainfall in Nepal (Dhar and Mandal, 1986) and India showed that its variation is small at places where precipitation is mainly the result of depression and cyclonic storms, as both phenomena act irrespective of the time of the day. The variation could however be significant where precipitation is caused by strong insolation. This can be seen outside the monsoon months, especially during the pre-monsoon period, where isolated