# 3. Challenges of the Climate

The anticipated climate change is likely to alter precipitation patterns, glacial storage, and river runoff with respect to timing, volume, and variability from highland plateaux and upland watersheds, therefore it will influence runoff characteristics in the lowland plains as well (see figure 3). As important as global climate change seems to be, the increase in population and booming economy, in important lowland areas or downstream, will exert heavy pressure on the highland or upstream river basins for land, water, and other resources. These pressures will foster the construction of dams for irrigation and hydropower generation and conversion of land for cash crop plantation, which in turn will have an impact on the availability of water in the lowlands with the potential to raise political tensions between the highlands and lowlands. Highland populations are also likely to intensify land use which will need more water and lead to soil erosion and water degradation. The possible consequences will occur both at local and regional levels in the transition to economic globalization and in the context of climate change. How to manage the Asian water tower, therefore, is a regional challenge for Asia.

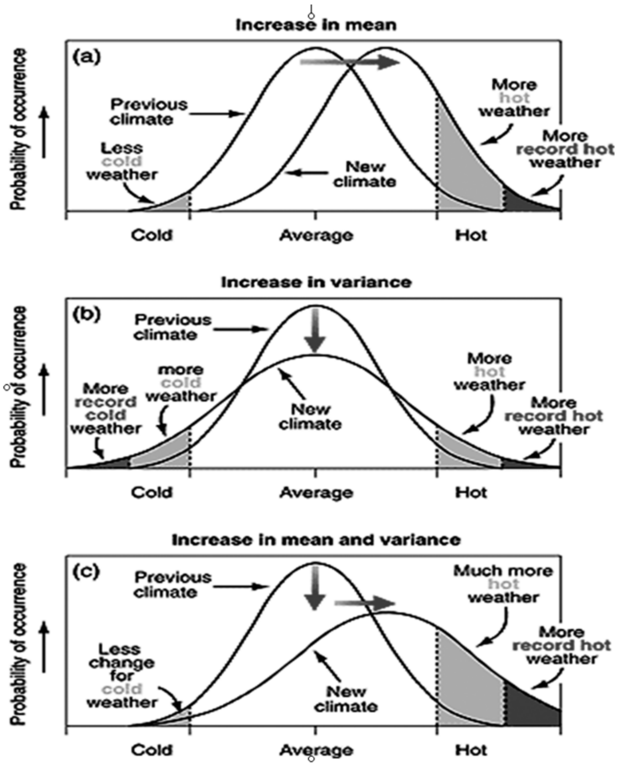

Figure 3: The climate can change in terms of both average and variability which will alter precipitation patterns and glacial storage and river runoff from mountain watersheds with respect to timing, volume, and variability.

### Intensely Warming Highlands

In the highlands, climatic conditions vary more sharply with elevation and over shorter distances than they do with latitude. Mean temperatures, for example, decline about 1$^{o}$C per 160m of elevation, compared with about 1$^{o}$C per 150 km by latitude (Hartman 1994). The effects of climate change, therefore, are expected to intensify at high elevations, and they are considered to be unique areas for detection of climate change and related impacts (Beniston 2003). The global average temperature increased by 0.74 °C (0.07 °C per decade) in the last 100 years (1906 to 2005). Warming over the last 50 years was almost twice (0.13 °C per decade) that for the last 100 years. Warming in the high plateau has been much higher than the global average warming rates, and warming of 0.25°C per decade took place between 1961 and 1990 (table 6), suggesting that the elevated land masses of the Asian water tower are extremely sensitive to climate change.

**Extreme events and fluctuation in precipitation-** Another feature of climate change is the increasing frequency and magnitude of extreme weather events such as intense rainfall, typhoons, and droughts, which have substantial impacts on local economies and human lives. There is also increasing unevenness of rainfall distribution in space; in most cases wet areas have become wetter and dry zones have become drier (see figure 4).

### Complex Responses

The broad predictions of global climate change, especially the emphasis on shifts in mean temperature, do not take into account important regional complexities on the mountain plateaux which are related to the influ-

**Table 6: Average annual increase in temperature at different altitudes for the plateau and surrounding areas 1961-1990 (°C/decade)**

| Altitude (m) | No. of stations | Spring | Summer | Autumn | Winter | Ann. av. Change |
|---|---|---|---|---|---|---|
| <500 | 34 | -0.18 | -0.07 | 0.08 | 0.16 | 0.00 |
| 500-1500 | 37 | -0.11 | -0.02 | 0.16 | 0.42 | 0.11 |
| 1500-2500 | 26 | -0.17 | 0.03 | 0.15 | 0.46 | 0.12 |
| 2500-3500 | 38 | -0.01 | 0.02 | 0.19 | 0.63 | 0.19 |
| >3500 | 30 | 0.12 | 0.14 | 0.28 | 0.46 | 0.25 |

*Source:*Liu and Hou, 1998

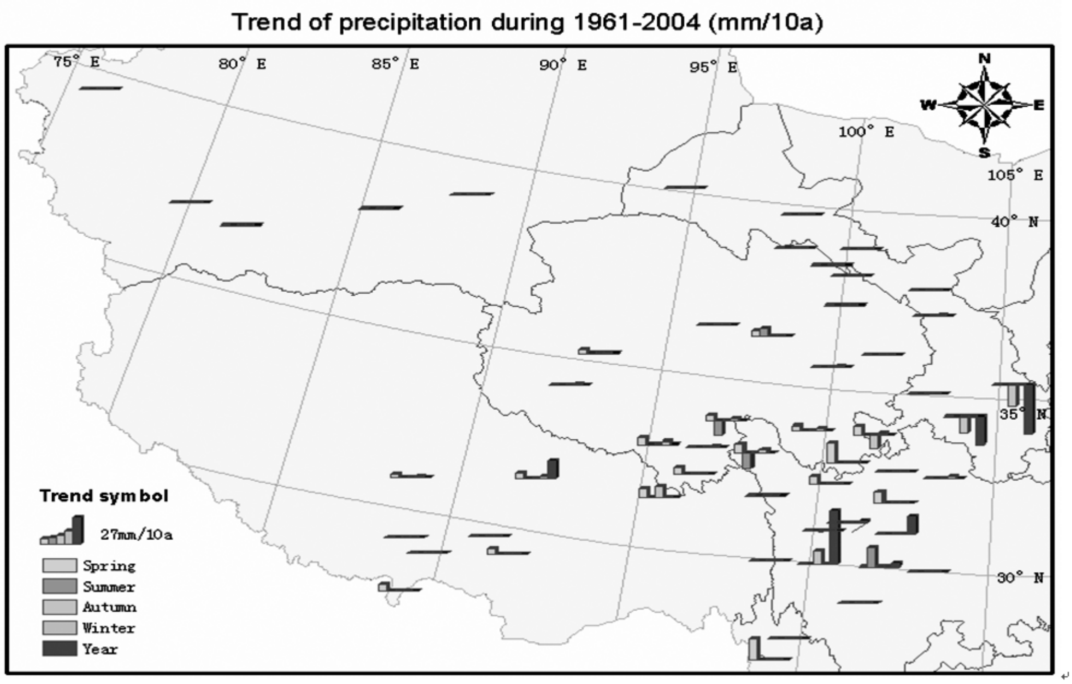

Figure 4: Precipitation trend from 1961-2004 on the Tibetan Plateau of China

ence of topography and elevation. If climate change mainly involves vertical shifts in precipitation and thermal conditions, ruggedness, elevation, and orientation also will modify the significance of regional and local climate changes. The highest mountains, or those facing or funnelling the prevailing winds, may retain substantial, if diminished, glacial cover, whereas lower or less favourably oriented watersheds may lose theirs. Furthermore, intensification of the Asian monsoon is predicted by most climate models. On a regional scale this could result in an increase in precipitation, although local effects are poorly understood. Moreover, climate change means not only warmer temperatures, but also changes in precipitation, evapotranspiration, soil and air moisture, runoff, and river flow as well as groundwater through water cycles. Climate change is expected to accelerate water cycles and thereby increase the available, renewable freshwater resources (Oki and Kanae 2006). Temperature changes have a predominantly regional character, whereas precipitation changes are more locally determined and very difficult to analyse and to predict, especially in mountain areas and river basins (Jian et al. 2006).

Complexities arise, especially from interactions among different cold climate elements – freeze-thaw and periglacial processes, snowfall, valley wind systems, avalanches, glacial processes, and seasonal or spatial balance between frozen and liquid precipitation, albedo, and evaporation. Not only are they likely to change with general climate shifts, but also interactions among them can buffer, exaggerate, or redirect the impacts of change in any one element. The most rapid and varied interactions occur through the 'vertical cascade' between different topoclimates – zones stacked vertically and on slopes of differing orientation – notably transport of moisture, runoff, sediment, and dissolved solids downslope. The occurrence and impacts of major hazards, such as avalanches, debris flows, landslides, and flash floods, also have a bearing on downslope, down-glacier, and downstream cascades. Whereas snow avalanches and glacial lake outburst floods (GLOFs) predominate at very high elevations (> 3000m), landslides, debris flows, and landslide dam outburst floods (LDOFs or 'bishyari') are more common in the middle mountains (1000-3000m). Riverine floods are the principal hazards in the lower valleys and plains. The causes of these floods are related to climatic conditions (Chalise and Khanal 2001, Dixit 2003, Xu and Rana 2005).

Equally critical are issues related to the structure, processes, and resilience of ecosystems or biosphere and human adaptations to them; bearing in mind that ecosystems and humans are possibly already stressed by adaptation to topoclimatic diversity. Global warming is predicted to affect vegetation productivity as well as decomposition (Cornelissen et al, 2007). Dramatic increase of woody plant biomass occurs in response to warming of highland cold biomes. Increased productivity will probably increase litter production, accelerated rate of litter decomposition due to warmer highland will feedback to climate through carbon cycle. Therefore climate change may turn the highland cold biomes, including living vegetation, plant litter and stored peat land, from large carbon sinks into sources. Recent study (Cornelissen et al, 2007) the feedback of decomposition to climate warming is complex by both a positive and a negative response. The positive feedback will result from direct temperature effects on decomposition rate, warming will increase the leaf litter carbon released into the atmosphere. There is also, however, a negative feedback that results from the warming-induced woody vegetation shift to higher altitude, which shows slower decomposing shrub leaf litter; this reduces the amount of carbon release to the atmosphere, and nutrients released in the soil to support plant production.In general, local impacts of the climate do not follow single or simple paths, whether in terms of plant ecology, stream hydrology, erosion and sedimentation, extreme events, or human activities.

Much of the cryosphere is sensitive to sustained changes in atmospheric temperature. Already many Himalayan glaciers are shrinking, some extremely rapidly in the global context. The widespread consensus is that climate change is the main factor in this. Apparently, conversely, in the high Karakoram-Himalayas, the rate of loss of ice cover has been declining in the last half of the twentieth century, and evidence is emerging that some glaciers are expanding; but this is also due to changing climatic patterns and unexpected regional consequences of 'warming' (Archer and Fowler 2004, Hewitt 2005). In the Tien Shan, predominantly summer-fed, continental-type glaciers are situated within 100km of predominantly winter-fed, more maritime ones. Although most glaciers in both classes are shrinking, there are significant differences in the rates and forms of response to warming (Bolch 2006). Although studies show marked variations in the local impacts of climate change, such as orographic precipitation in different valleys and at different elevations within the same mountain range, most of the region remains unstudied in terms of a baseline for assessment or prediction of these complexities.

Figure 5 illustrates the linkage between atmosphere and other systems such as the cryosphere, hydrosphere, biosphere, and anthrosphere. The change in atmosphere, which is largely driven by human activities in the biogeophysical environment, has direct impacts on the cryosphere at high altitude and both directly and indirectly impacts the biosphere and human society through hydrological processes in mountain ecosystems. Such impacts are manifested by glacial retreat and melting permafrost, increasing natural hazards, change in stream and river flows, and biological responses such as shift of vegetation, migration of species, and phenelogical change. The downstream impacts will include rises in sea level due to large glaciers melting in the polar region and medium and small glaciers melting in mountain regions such as the Tibetan Plateau. Human health in marginal mountain ecosystems will deteriorate as a result of climate change and its related environmental impacts.

The consequence, rate, and magnitude of impacts vary in different zones. Key impacts of climate-induced changes in the highlands of Asia include vegetation shift, frequent wildfires, changes in freshwater supplies, and problems to human health caused by environmental dysfunction. Table 7 depicts the potential impacts of climate changes on water resources, agriculture, biodiversity, and human health in different critical zones from the highlands to the uplands, from the lowland to coastal and urban areas. The general circulation model (GCM) shows that the highlands have experienced a decrease in freshwater runoff in most arid and semi-arid drylands and an increase in the eastern Himalayas; an increase in wildfire frequency and increase in have been experienced in most highlands of Asia (Sholze et al. 2006). Furthermore, increasing human activities in the highlands through land-use and land-cover change, infrastructural development, and tourism have exacerbated the vicious cycle of climate change.

## The Constraints of Limited Investigations

The relationship between climate change and the cryosphere on the Tibetan Plateau is not sufficiently understood to drive detailed policy responses, even though such a relationship has been confirmed by scientists in general and farmers and herders over widespread areas have been experiencing warmer winters and longer growing seasons. While in-depth studies of glaciers, snow packs, and permafrost have been carried out in some areas, they have been scattered widely in space and time. No detailed investigations of snow and ice processes or their relevance to the climate have taken place in most areas of the Himalayas and other high ranges. For most areas, there are no baseline studies, particularly for areas higher than 3000 masl, and there has been little long-term monitoring of the interconnections between climatic variables, perennial snow and ice, runoff, and hydrology in the context of the extraordinary heterogeneity of mountain topography (Liu and Chen 2000, Rees and Collins 2006, Messerli et al. 2004). Most models and predictions for high-altitude areas (above 3000 masl) are dependent upon extrapolation from climate and stream-gauging stations at comparatively low altitudes and upon assumptions based on other, better studied, parts of the world (Rees and Collins 2004). The importance of the most widespread cryogenic processes – avalanches, debris flows, rock glaciers, alpine permafrost, and surging glaciers – has been recognised and their incidence recorded for certain areas; and yet almost no basic scientific investigations of these cryogenic processes have taken place

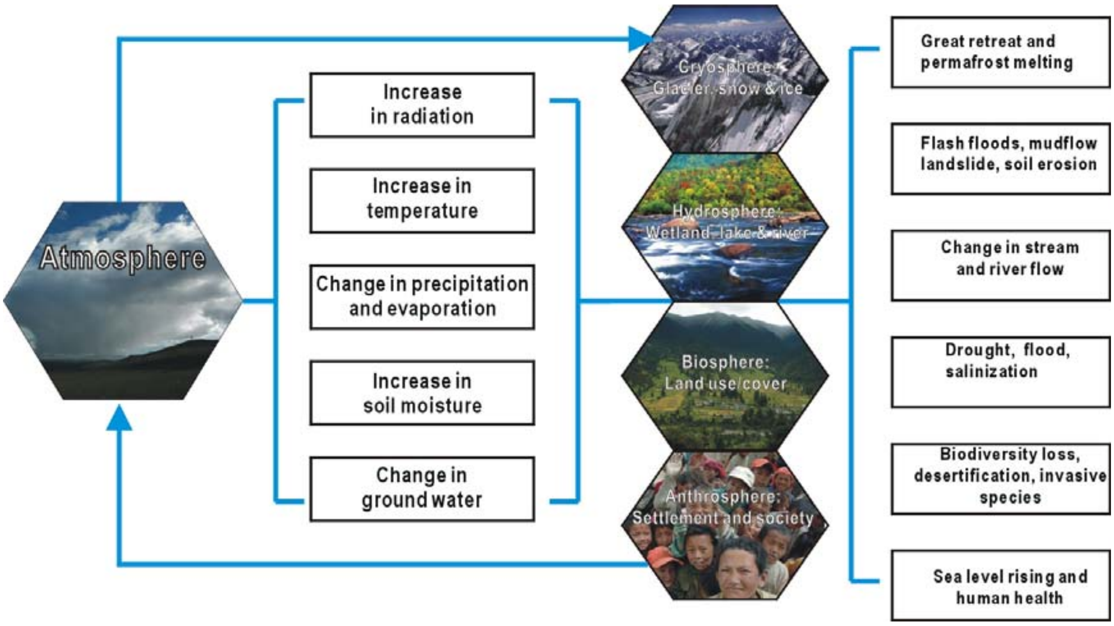

Figure 5: Climate Change and Cascade Amplification of Impacts on in Highland Asia

## Table 7: Possible Impacts from Climate Change on Asian Society

| Critical zones | Water | Agriculture | Biodiversity | Health |
|---|---|---|---|---|
| High plateaux | Warmer winters and more rainfall; snow avalanches, melting glaciers, and potential glacial lake outburst floods; increase in water levels in highland lakes in the short run and decreases in the long run | Early spring might cause more overgrazing, degradation of rangeland, desertification, snow storms, and invasive species. | Species richness decrease, woody vegetation moves upward, increase in the number of endangered alpine species , weedy species may spread over; ecosystem will deteriorate due to increasing rodent population | Cholera and diarrhoea increase.<br>Increase in new diseases such as Avian flu due to interaction of wildlife, livestock, and human beings. |
| Upland watersheds | Flash floods, landslides, debris flows, and landslide dam outburst floods occurring more frequently; increase in runoff during monsoon, low flow will decrease during the dry season, increase in soil erosion and sediment transport downstream; silt in the runoff will contaminate water supplies and clog hydroelectricity plants | Higher carbon dioxide levels and water temperatures may increase grain yields, irregular monsoon patterns will delay rice planting and harvests although rice yields may increase during good years. | Wildfires and pests increase, woody vegetation increases, wildlife moves upwards to high altitudes, changes in composition of biodiversity due to different performances of species to climate change | Cholera and diarrhoea increase; Schistosomiasis will move into higher wetlands and lakes. Malaria and dengue fever become more widespread in the uplands. |
| Lowland plains | Changing rainfall patterns, decrease in freshwater supplies (runoff) , severe droughts, decrease in ground water levels | Rice yields will decline as temperatures increase. Farms will be vulnerable to increasing pests and natural disasters | Biome change from forest to non-forest, increase in loss of agricultural diversity and invasive species both in water bodies and the ecosystem generally | Heat waves will kill more people in the lowland plains, poor sanitation together with environmental poisoning will cause an increase in health issues. |
| Coastal areas | Stronger cyclones, intrusion of saltwater into water supplies, decrease in groundwater, urban floods; sea levels could rise by up to one metre | Salination of farmlands, warmer water will threaten fish farms | Aquatic biodiversity decreases due to salination, warmer water, and water pollution. | Heat-related illnesses as well as dengue fever, cholera, and water- and sewage- related diseases will increase along with respiratory problems related to urban pollution and increasing migration. |

in the region, although they involve significant hazards, the patterns and intensities of which will be affected by climate fluctuations that may increase or decrease risk in given areas.

Thus, the immense diversity within the region should be recognised: diversity of climates and topoclimates, hydrology and ecology, and, above all, of human cultures and activities. Before effective responses can be made, much work has to be carried out to identify and predict the possible impacts of climate change filtered through such diverse contexts. In particular, there has been little engagement with local populations so far to learn from their knowledge and experience in adapting to unique and changeable environments and to address their concerns and needs (Xu and Rana 2005).

## Melting and Retreating Glaciers

Many Himalayan glaciers are retreating faster than the world average (Dyurgerov and Meier 2005) and thinning at the rate of 0.3-1 m/year. For example, the rate of retreat for the Gangotri Glacier over the last three decades has been more than three times the rate during the preceding 200 years (Xu et al. 2007). Most glaciers studied in Nepal are undergoing rapid deglaciation: the reported rate of glacial retreat ranges from several metres to 20 m/year ( Fujita et al. 2001, Fujita et al. 1997, Kadota et al. 1997). In the past half century, 82. 2% of glaciers in west China have retreated (Liu et al. 2006). While temperature increases, in the earlier stages thinning prevails and meltwater increases, whereas in the latter stages, the glacier shrinks, meltwater decreases, and some glaciers will disappear. There are wide disparities in the sensitivity and response of glaciers to climate warming, depending on the size and type of glacier. Large glaciers finally attain a new glacial mass balance at lower levels (see figure 6).

Different types of glaciers have different response patterns to increasing temperatures. Glaciers in China can be categorized into 3 types; i.e., the maritime (temperate), sub-continental (sub-polar), and extreme continental (polar) type; and they cover 22, 46, and 32% of the total existing glacial area (59,406 km$^2$) respectively. Since the Maxima of the Little Ice Age (the 17th century), air temperature has risen at a rate of 1. 3°C on average and the glacial area decrease corresponds to 20% of the present total glacial area in western China (Shi and Liu 2000). Shi and Liu (2000) further predict shrinkage of 12, 28, and 45% by the 2030s, 2070s, and 2100s respectively (see table 8).

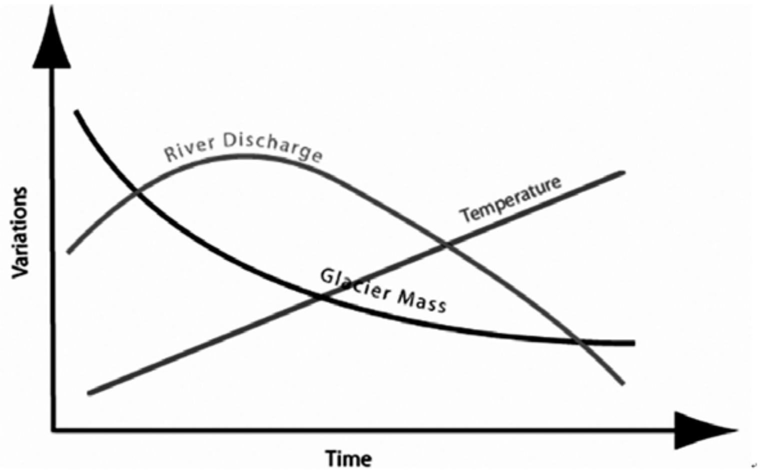

Figure 6: Theoretical model of the increase in river discharge first, followed by a decrease afterwards while the glacier retreats

**Table 8: Estimated glacial retreat trend in the Tibetan Plateau in the 21st century**

| GLACIER TYPE | REGION | 2030S | | 2070S | | 2100S | |
|---|---|---|---|---|---|---|---|
| | | Temperature rise/K | glacial retreat (area and volume [%]) | Temperature rise/K | Glacial retreat (area and volume (%) | Temperature rise/K | Glacial retreat (area and volume [%]) |
| Maritime | Southeast plateau | +0.4 | -14 | +1.2 | -43 | +2.1 | -75 |
| Sub-continental | Northeast and southern plateau | +0.9 | -15 | +2.0 | -32 | 3.0 | -48 |
| Extremely continental | Western plateau | +1.2 | -6 | +2.7 | -13 | +4 | -20 |
| Average | | +0.8 | -12 | 2.0 | -28 | 3.0 | -45 |

Source: Shi and Liu 2000

## Impacts on Water Resources

Climate change presents very serious risks to freshwater resources. The rise in temperature has been much faster than the global average in the highlands. Besides glacial retreat, impacts of climate change include disappearance of small wetlands; and this includes lakes which are part of the Asian water tower. Glacial melt provides freshwater, vital for the ecosystem and society, particularly in arid areas of west China and during critical periods from the dry season to monsoon. The supply of freshwater, or meltwater from snow and ice, in large river basins is projected to increase over the following decades as perennial snow and ice decrease. Later, however, most scenarios suggest a decrease, even of catastrophic proportions, by the 2050s. Climate change may result in increasing temperatures, decreasing snow packs, and earlier snowmelt, and that will certainly reduce the flow of water in the rivers originating from the highlands, particularly in the dry season. Wang et al (2006) concludes the connections between decreasing water discharge and global El Niño/ Southern Oscillation (ENSO) events in Yellow River of China. Shi (2001) predicts that small glaciers (less than 2km$^2$) will be more sensitive to climate warming, meltwater will reach its peak value at present, and will decrease or even disappear by 2050. Medium-sized glaciers of 5-30 km$^2$ will reach their meltwater peak value by 2050. The larger glaciers (areas exceeding 100 km$^2$) will retreat slowly. Glacial meltwater accounts, at present, for 50~80% of the discharge from the Yarkant, Yurunkax, and Aksu rivers and upstream of the Tarim (42% in the Tarim). It is predicted that glacial meltwater will continue to increase before 2050, the increased volume may be 25~50% more than that at the beginning of this century (Yan et al. 2007). In the short run, animal husbandry and agriculture could benefit from rises in temperature rise and increases in meltwater discharge if good water management practices and proper irrigation facilities are introduced, particularly in dryland and arid areas. Effective and efficient water management technology has still to be introduced and institutionalized in order to cope with long-term decreases in water supplies. In the eastern Himalayas, however, or the southeastern Tibetan Plateau where there is heavy precipitation and the temperature of the ice is higher than in other areas, the temperature rise will accelerate the ablation and retreat of glaciers, perhaps causing frequent flood and debris flow disasters in fragile mountain watersheds.

## Water-induced Natural Hazards

Shifts in rainfall patterns and increase in extreme weather events, floods, and droughts: natural hazards are omnipresent in highland Asia due to its unique lithosphere and the interaction of the monsoon climate and mountain environment. Natural hazards include flash and riverine floods, droughts, landslides and debris flows, snow avalanches, and even wildfires when there is insufficient rainfall. Wide fluctuations in the melting of snow and ice can result in excessive or insufficient water supplies: heavy snowfalls can block roads or overload structures. Snowfall on steep slopes and associated conditions give rise to avalanches: advancing or retreating glaciers can interfere with communications or cause dangerous impoundments. The action of frost and melting of permafrost pose ecological and technological dangers. The most destructive hazards, and those that can have impacts far beyond their mountain sources, tend to be the direct consequences of changes in the cryosphere. They include ponding of water by or around glaciers and subsequent glacial lake outburst floods (GLOFs), and can involve much more water than the amount generated by climatic events alone. Fluctuations in glaciers, especially retreat and thinning, destabilise surrounding slopes, and may give rise to catastrophic landslides (Ballantyne and Benn 1994, Dadson and Church 2005) damming streams and sometimes leading to outbreak floods. Excessive melting often in combination with heavy rains may trigger flash floods or debris flows. In the Karakoram, there is growing evidence that catastrophic rockslides have a substantial influence on glaciers and may have triggered glacial surges (Hewitt 2005). Glacial surges are a particular hazard in the Karakoram and Pamir mountains. Severe cold and high winds threaten wild life, domestic animals, and humans.

Complexities arise, especially from interactions among different elements of the cold climate – freeze-thaw and peri-glacial processes, snowfall, valley wind systems, avalanches, glacial processes, and seasonal or spatial balances between frozen and liquid precipitation. Not only are they likely to change with general climate shifts, but also interactions among them can buffer, exaggerate, or redirect the impacts of change in any one element. The most rapid and varied interactions occur through the 'vertical cascade' between different topoclimates – zones stacked vertically and on slopes of differing orientation – notably transport of moisture, runoff, sediment, and dissolved solids downslope. The occurrence and impacts of major hazards, such as avalanches, debris flows, landslides, and flash floods, also have a bearing, as mentioned previously, on downslope, down-glacier, and downstream cascades. Whereas snow avalanches and glacial lake outburst floods (GLOFs) predominate at very high elevations (>3000masl), landslides, debris flows, and landslide dam outburst floods (LDOFs or 'bishyari') are more common in the middle mountains (300-3000masl). Riverine floods are the principal hazards in the lower valleys and lowland plains. The causes of these floods are related to climatic conditions (Chalise and Khanal 2001, Dixit 2003, Xu and Rana 2005). In the eastern and central Himalayas, glacial melt associated with climate change has led to the formation of glacial lakes in open areas behind exposed end moraines, causing great concern. Many of these high-altitude lakes are potentially dangerous. The moraine dams are comparatively weak and can breach suddenly, leading to the sudden discharge of huge volumes of water and debris. The resulting GLOFs can cause catastrophic flooding downstream, with serious damage to life, property, forests, farms, and infrastructure. Twenty-five GLOFs have been recorded in the last 70 years in Nepal, including five in the sixties and four in the eighties (Mool 2001, NEA 2004, Yamada 1998). Highland Asia has a history of disasters triggered by some or all of the cryogenic processes discussed. The main point is that climate change can alter their frequencies, distribution, mix, and magnitudes – both favourably and adversely. Because of limited investigation into these processes and their relationships to climate, our understanding of how climate change will affect them (and in different sub-regions) is also limited. We, thus, need to be cautious about making predictions, especially alarmist ones, while emphasising that there is cause for concern.

## Impacts on the Natural Ecosystem

Climate change may affect the natural ecosystem or biosphere in a variety of ways, from species' composition to vegetation distribution, from carbon and nutrient cycling to water evapotranspiration, and from pollination to phenology. There are widespread reports by Tibetan nomads that spring is coming more than a week earlier than expected and grazing seasons are longer than usual. The possibility of alterations in overall albedo, water balance, and surface energy balance on alpine grasslands with increasing degradation and desertification in the arid areas is causing concern. Signs of the effects of climate change on the grasslands have been documented from the northeast Tibetan Plateau where experimental warming caused a 26~36% decrease in species richness (Klein et al, 2004), and *Kobresia* sedge and alpine turf communities are changing to semi-arid alpine steppe, known in Chinese as 'black bleaching' in addition to overgrazing (Ma and Wang 1999, Miller 2000). Qinghai Province in China alone has approximately 20,000 sq.km. of degraded rangeland. Upward movements of the tree line and encroachment of woody vegetation on to alpine meadows are reported widely. In the eastern Himalayas, the tree line is rising at a rate of 5-10 m per decade (Moseley 2006). Although it is difficult to attribute this to climate change alone as human activities could also be a factor, rapid changes in alpine communities (both structure and species' composition) are expected as the climate changes. As temperatures rise and glaciers retreat, species shift their ranges to follow their principal habitats and climatic optima. The ability of species to respond to a changing climate varies, however. Shifts in species' ranges during past major global climate changes indicate that all species have climatic limitations beyond which they cannot survive.

There is significant uncertainty about the effects of global warming on vegetation and animal productivity in large dryland ecosystems. Although high altitude drylands might enjoy increases in net primary productivity (NPP) locally, the greatest confidence is in predicting implications for production of vegetation, with lesser confidence in implications for vegetation composition, animal production, and options for adaptation (Campbell and Stafford Smith 2000). Satellite observations suggest that some rangelands might be suffering from processes of degradation due to warmer, windier, and drier trends (Dirnbock et al. 2003). Degraded rangeland already accounts for over 40% of dryland on the Tibetan Plateau (Zhong et al. 2003,Gao et al. 2005); and it is expanding at a rate of 3 to 5% each year (Ma and Wang 1999). The culprits are climate warming and overgrazing, as well as the mutual influence of human activities and climate change. Increase in evaporation, reduction in snow cover, and fluctuations in precipitation are key factors contributing to the degradation of dryland ecosystems. In addition, degradation of grassland by overgrazing could increase the evapotranspiration level, thereby promoting climate warming and the degradation process (Du et al. 2004).

Impacts of climate change on montane forest ecosystems include shifts in forest boundaries by latitude and the movement of tree lines to higher elevations; changes in species' composition and vegetation types; and an increase in net primary productivity (NPP) (Ramakrishna et al. 2003). In the eastern Himalayas, forest vegetation will expand significantly; forest productivity will increase from 1-10%; and it is expected that forest fires and pests such as the North American pinewood nematode (*Bursaphelenchus xylophilus*) will increase as dryness and warmth increase (Rebetez and Dobbertin 2004). The overall impact of climate change on the forest ecosystems can be negative (Siddiqui et al. 1999).

# 4.The Societal Challenge

## Land-use and Land-Cover Change: the Impact on Water

Over 80% of the population in the Asian mountain region depend either on full- or part- time farming for their livelihoods (Thulachan 2001). With population increases and economic growth, more and more people search for land for subsistence production and income generation. The pace, magnitude, and spatial reach of land-cover and land-use changes in the Asian Continent have increased over the last half century as a result of land reclamation, for example, for rubber plantation in Yunnan previously and in northern Laos at present, the Green Revolution in India, and fibre production (e.g., cotton in Xinjiang). Deforestation occurred mainly during the 'Great Leap Forward' in 1958 and forest tenure transition in the early 1980s in west China, in the large tropical forests of Myanmar, and in mainland Southeast Asia in past decades. Large forest areas have been converted into croplands, particularly in Ganges, Yangtze, Mekong, Indus, Brahmaputra and Yellow river basins (see table 9).

Degradation of grassland (e.g., changes in quality and class of grasslands and desertification) on the Tibetan Plateau is attributed to overgrazing. Official statistics report that livestock numbers on the plateau are now three times higher than in the 1950s. Overgrazing has adverse impacts on vegetation, on soil system properties, as well as on green water storage in the ecosystem. The relative contributions of climate change and overgrazing to degradation are hard to quantify. Some studies report, however, that recent grassland management policies – which have encouraged growth in herd sizes and reduced mobility in grazing systems - have contributed to overstocking and overgrazing. Paths and rates of land-use change are often driven by the local political economy, mostly by state policies and the market economy. Land-use and land-cover changes affect fauna and flora; contribute to local, regional, and global climate changes; and are the primary source of soil, water, and land degradation (Pielke 2005, Sthiannopkao et al. 2007). Land-use decisions, thus, are also water decisions (Falkenmark 1999). Altering ecosystem services from the Asian water tower—i.e., the provisions people obtain from ecosystems (e.g., food and water), regulating services (e. g., predator-prey relationships and flood and disease control), cultural services (e.g., spiritual and recreational benefits), and support services (e.g., pollination, nutrient cycling, and productivity)—that maintain the conditions for life on Earth affects the ability of biological systems to support human needs in Asia. While climate warming reduces the storage of fresh water in glaciers, land use and land cover have contributed greatly to wetland loss in west China. China has lost 127 cubic km of water storage capacity as a result of wetland loss in the western plateau in the past 50 years (Wang et al, 2006a) (see table 10).

**Table 9: Land-use or -cover in 8 Key River Basins**

| River | Forest | Grassland & bush | Wetlands | Cropland | Irrigated cropland | Dryland | Loss of original forest cover |
|---|---|---|---|---|---|---|---|
| Indus | 0.4 | 46.4 | 4.2 | 30.0 | 24.1 | 63.1 | 90.1 |
| Ganges | 4.2 | 13.4 | 17.7 | 72.4 | 22.7 | 58.0 | 84.5 |
| Brahmaputra | 18.5 | 44.7 | 20.7 | 29.4 | 3.7 | 0.0 | 73.3 |
| Irrawaddy | 56.2 | 9.7 | 6.3 | 30.5 | 3.4 | 4.4 | 60.9 |
| Salween | 43.4 | 48.3 | 9.5 | 5.5 | 0.4 | 0.1 | 72.3 |
| Mekong | 41.5 | 17.2 | 8.7 | 37.8 | 2.9 | 0.8 | 69.2 |
| Yangtze | 6.3 | 28.2 | 3.0 | 47.6 | 7.1 | 2.0 | 84.9 |
| Yellow River | 1.5 | 60.0 | 1.1 | 29.5 | 7.2 | 79.4 | 78.0 |

Source: IUCN, IWMI, Ramsar Convention Bureau and WRI 2002

**Table 10: Loss of glaciers and wetlands in the Chinese highlands**

| ITEM | ORIGINAL AREA ($X10^3KM^2$) | AREA LOSS ($X10^3KM^2$) | ICE LOSS ($KM^3$) | WATER LOSS ($KM^3$) |
|---|---|---|---|---|
| Glaciers | 64.7 | 5.3 | 587 | 505 |
| Lakes & rivers | 45.0 | 5.0 | _ | 15 |
| Swamps | 48.0 | 3.5 | _ | 14 |
| **Subtotal** | 152.4 | 13.8 | 587 | 534 |

Source: Wang et al. 2006a

Besides climate factors, the quality and flow of water resources are determined by the management of land resources. Two types of land-use activities that have a fundamental impact on livelihoods and, thus, on the issues outlined above will be addressed: a) land use dependent on drainage and flood protection, or, for example, dependent on limitations imposed by water on societal and biomass production. This type of land use is called ‘water-dependent’ land use. The second type, b) land use which has an impact on rainwater partitioning through soil and vegetation or impacts related to the function of water as a carrier of solutes and silt in the landscape. This type of land use is called ‘water-impacting’ land use. Managing land-use practices is inextricably linked with water resources. Land use/cover is intrinsically linked with the hydrological cycle and changes in land use and their impacts on the hydrological cycle have been studied in depth for decades. The best results are obtained by managing both land and water resources simultaneously within a landscape framework or at river basin level. Good land-use practices can contribute significantly to a) hydrological benefits - controlling the timing and volume of water flows and the quality of water; b) reducing sedimentation - avoiding damage to downstream reservoirs and waterways and hence their uses (hydroelectric power generation, irrigation, recreation, fisheries, domestic water supplies) arising from sedimentation; and c) disaster risk reduction – controlling and preventing debris flow and landslides. FAO (2002) concluded that land-use impacts on hydrological parameters and sediment transport are inversely related to the spatial scale on which the impacts can be observed. In contrast, impacts of land-use changes on water quality parameters may be relevant on the meso- and macroscales. It is important to note that the impact of these land-use and -cover changes are variable in terms of time scale. While the quality of water in rivers and lakes can be restored in quite short time, the biodiversity destroyed will take several thousands of years to recover to its original condition. Any planting of trees or current changes in land use and cover that involve the natural growth of flora or the natural multiplication of fauna take time and are an investment in the future. The positive benefits of any intervention of this kind will only become effective in years to come. If rapid impacts are required, other means need to be envisaged.

## Increasing Demand for Water and Pollution from Agriculture

All countries within continent of Asia have economies which are based on agriculture which depends heavily on water resources for irrigation. The use of water by the people of Asia is far below the world average. Water withdrawal for irrigation has, unavoidably, a big impact on river flow. Falkenmark (1999) gives an example from Central Asia where intensified irrigation and increased extraction of water from the rivers have not only led to decreased flows in these rivers, but have also increased salinity in the lakes downstream. The most famous example of this is the Aral Sea where the two tributaries, Amu Darya and Syr Darya, are used intensively for cotton, fodder, and rice production. Another example comes from the Tarim Basin, on the other side of Tian Shan Mountain. Large wetland areas have been converted to agriculture here through a resettlement programme and agricultural development in the upper basin has led to decreased flows downstream the Tarim River Basin, threatening both the ecosystem and people. Based on an analysis of water distribution and allocation during a period from 1956 and 2000, Chen et al. (2003) show that glacial meltwater from the headwaters increased about 10.9% after the 1990s, but the water supply from the upper catchment (the Aqsu, Yarkand, and Hetian) downstream has decreased significantly by 18.83%. Increasing use of water in the upper catchment for agriculture and the decreased river flow downstream have caused soil salinisation, pollution, depletion of groundwater, and destruction of the ecosystem in the areas downstream. Desertification becomes inevitable. Nitrate and phosphorus concentrations in surface and groundwater continue to be a matter of concern throughout the region. Water quality has been seriously affected by agriculture, mainly by the application of chemical fertilizers and pesticides as seen in the Yangtze, Tarim, and Yellow River areas. Increasing accumulation of phosphorus in soil threatens rivers, lakes and coastal oceans with eutrophication (Bennett et al, 2001), which has been constantly moving upwards to high elevations. In the case of a middle mountain catchment in Nepal also, high nitrate and phosphate loadings have been observed (Merz et al. 2004). Most lakes in China both on the plateaux and in the lowland plains had to be treated for eutrophication, example of, Dianchi in Kunming and Taihu downstream from the Yangtze Delta. Agricultural mismanagement is seen also as a major cause of soil degradation. This not only includes soil erosion, but also salinisation and decline in soil fertility. Cultivation of cash crops (off-season vegetables, tobacco, and cut flowers in Yunnan) upstream was not only shown to increase sediment yield but also to pollute the water.

In order to feed about 3 billion people, almost half of the world’s population, agriculture consumes the lion’s share of total water supplies in the region. Water use is expected to increase rapidly together with population growth, particularly in South Asia (figure 7).

As an attempt to lessen the dependence on the monsoons for agriculture, the Indian government has proposed a river-linking project to divert water from the northeast (including from the Brahmaputra and Ganges) to the west and central parts of country. In general water use in Southeast Asia is slightly better than in South Asia because of Southeast Asia’s efficiency and diversification of water use.

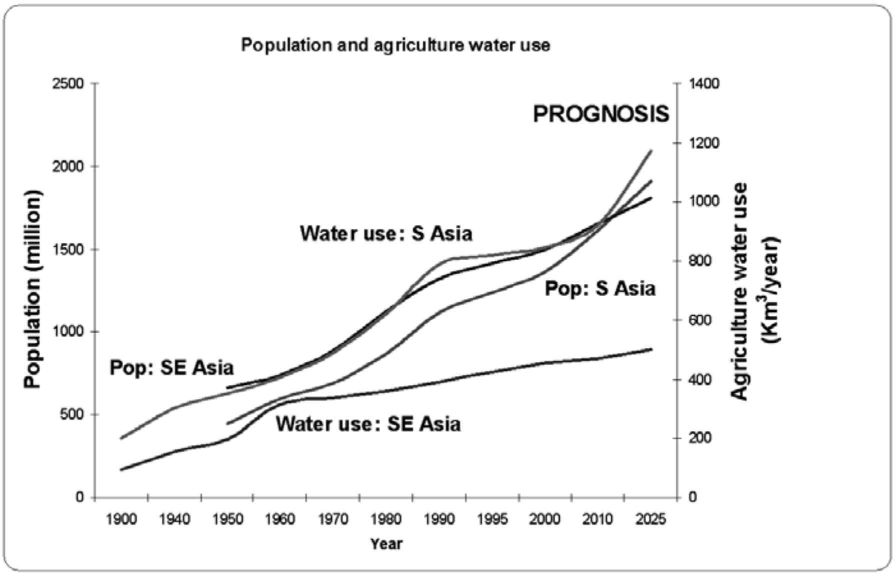

Figure 7: Increase in population and the use of water for agriculture in South and Southeast Asia (Source: Xu and Eriksson 2007)