Climate Change Impact and Vulnerability in the Eastern Himalayas – Technical Report 3

ICIMOD

FOR MOUNTAINS AND PEOPLE

Functions and Services of Wetlands in the Eastern Himalayas: Impacts of Climate Change

MacArthur Foundation

Preface

Mountains are among the most fragile environments on Earth. They are also rich repositories of biodiversity and water and providers of ecosystem goods and services on which downstream communities (both regional and global) rely. Mountains are home to some of the world's most threatened and endemic species, as well as to some of the poorest people, who are dependent on the biological resources. Realising the importance of mountains as ecosystems of crucial significance, the Convention on Biological Diversity specifically developed a Programme of Work on Mountain Biodiversity in 2004 aimed at reducing the loss of mountain biological diversity at global, regional, and national levels by 2010. Despite these activities, mountains are still facing enormous pressure from various drivers of global change, including climate change. Under the influence of climate change, mountains are likely to experience wide ranging effects on the environment, natural resources including biodiversity, and socioeconomic conditions.

Little is known in detail about the vulnerability of mountain ecosystems to climate change. Intuitively it seems plausible that these regions, where small changes in temperature can turn ice and snow to water, and where extreme slopes lead to rapid changes in climatic zones over small distances, will show marked impacts in terms of biodiversity, water availability, agriculture, and hazards, and that this will have an impact on general human well being. But the nature of the mountains, fragile and poorly accessible landscapes with sparsely scattered settlements and poor infrastructure, means that research and assessment are least just where they are needed most. And this is truest of all for the Hindu Kush-Himalayas, with the highest mountains in the world, situated in developing and least developed countries with few resources for meeting the challenges of developing the detailed scientific knowledge needed to assess the current situation and likely impacts of climate change.

The International Centre for Integrated Mountain Development (ICIMOD) undertook a series of research activities together with partners in the Eastern Himalayas from 2007 to 2008 to provide a preliminary assessment of the impacts and vulnerability of this region to climate change. Activities included rapid surveys at country level, thematic workshops, interaction with stakeholders at national and regional levels, and development of technical papers by individual experts in collaboration with institutions that synthesised the available information on the region. A summary of the findings of the rapid assessment was published in 2009, and is being followed with a series of publication comprising the main vulnerability synthesis report and technical papers on the thematic topics climate change projections, biodiversity, wetlands (this publication), water resources, hazards, and human wellbeing.

Clearly much more, and more precise, information will be needed to corroborate the present findings. Nevertheless, this series of publications highlights the vulnerability of the Eastern Himalayan ecosystems to climate change as a result of their ecological fragility and economic marginality. It is hoped that it will both inform conservation policy at national and regional levels, and stimulate the coordinated research that is urgently needed.

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Functions and Services of Wetlands in the Eastern Himalayas: Impacts of Climate Change

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The Eastern Himalayan Region

The Himalayan Mountains rise sharply in the eastern reaches from about 150 masl to over 8,000 masl to include the world's highest mountain peaks. In Southwest China, the altitude ranges from less than 700 masl on valley floors to 7,558 masl at the summit of the Gongga Shan. The main Himalayan mountain ranges in the north are oriented east-west forming a shallow arc, and then take an almost abrupt southward turn so that the ranges in the east are oriented in a north-south direction.

The Eastern Himalayan region is a distinctive biogeographic area and is included in the 'Himalaya' biodiversity hotspot (Mittermeier et al. 1998, 2004) The region includes central and eastern Nepal (east of 83°E Longitude), Bhutan, and the North Eastern states of India (Sikkim, Assam, Meghalaya, Arunachal Pradesh, Nagaland, Mizoram, Manipur, Tripura, and hilly areas of West Bengal). Two adjoining hotspot areas, Mountains of Southwest China (parts of Yunnan province) and Indo-Burma (parts of Chin and Kachin states of Myanmar) are also interlinked. Several major rivers rise in the Eastern Himalayas (Koshi, Teesta, Manas, Chindwin, and Irrawaddy) and many others pass through the valleys (e.g., the Brahmaputra and Salween). Rivers originating in the mountains of Southwest China or passing through the area include tributaries of the Yangtze River (the Jingshajiang, Yalongjiang, Daduhe, and Minjiang). The Mekong River (Lancangjiang) and the Nujiang also pass through Yunnan Province.

The region has a tropical to subtropical monsoon climate at lower elevations (below 1,000 m), which remain frost free throughout the year, but, with increasing elevation, the climate becomes temperate and alpine. Peaks above 5,000 m are generally covered with glaciers. The annual precipitation varies from more than 5,000 mm in the foothills to less than 500 mm at higher altitudes (above 3,000 m). Most of the precipitation occurs during the southwest monsoon (June to September). In Southwest China, the average annual rainfall exceeds 1,000 mm on southwestern slopes at higher altitudes, whereas the northwestern part lies in the rainshadow of the Tibetan Plateau and receives <400 mm annually.

Wetlands

'Wetland' is a term used to define a diversity of habitats in different climatic zones of the Earth. Ecologically, wetlands are transitional (ecotonal) systems between upland terrestrial and deep open water systems. They are characterised by aquatic vegetation (hydrophytes) (Mitsch and Gosselink 2007). It is difficult to demarcate clear boundaries between wetlands and adjacent deep-water systems, especially when water levels fluctuate greatly and frequently between extremes (seasonal wetlands). For the purpose of conservation, the 'Ramsar Convention on Wetlands of International Importance' (RCS 2006) adopted a definition of wetlands that covers all kinds of aquatic habitats (see Box 1). In order to assess possible impacts of climate change, this report has taken into consideration the rivers and lakes in the region.

Wetlands, their functions, goods, and services have not been studied in detail in the context of the possible impacts of climate change in developing countries in general. This lack of focus on wetlands per se, means that information on wetlands in the Himalayan region, in this case in the Eastern Himalayas is scattered and usually embedded in information about countries as a whole.

Some of the most important wetlands in the Eastern Himalayan region are listed in Table 1, showing some of the variety of wetland types.

Box 1: **Definition of wetlands (Ramsar Convention)**

"Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres."

Article 2.1 of the Convention further states that wetlands: "may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands."

Wetland types

Wetland characteristics vary greatly and most significantly in hydrological, chemical, biological, and sedimentation characteristics, in addition to shape, size, and location. All wetlands, both natural and human-made, are linked within a river basin through their hydrology (Figure 1). Migratory animals provide additional linkages between wetlands, even in different river basins.

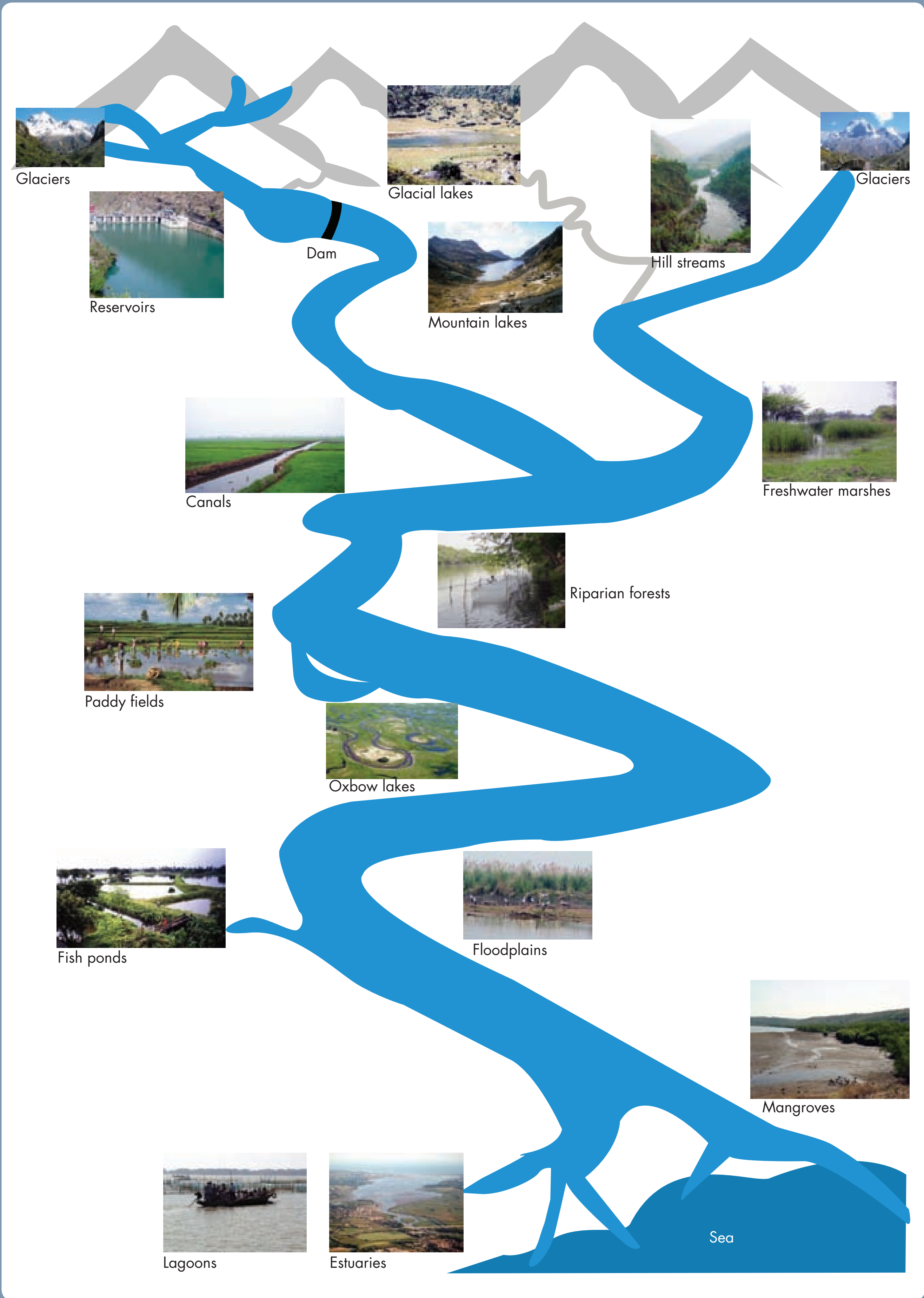
Several classification systems have been applied in different regions (Finlayson and van der Valk 1995). These schemes differ according to definitions of wetlands

Table 1: **Some wetlands of international importance (Ramsar sites) in the Eastern Himalayan region**

Site name	Country	Habitat types	Elevation range (masl)	Total site area (ha)
Bitahai wetland	China	Alpine wetland with swamps, lake, peatlands, and surrounding forest	3,000-4,260	1,985
Napahai wetland	China	Seasonal karst marsh composed of meadow, open water, peatlands, and surrounding forest	>3260	2,083
Loktak lake	India	Freshwater lake and associated swamplands supplied by several streams	750	26,600
Deepor Beel	India	A permanent freshwater lake in a former channel of the Brahmaputra River	53 (av)	4,000
Rudrasagar lake	India	A lowland sedimentation reservoir in the northeast hills, fed by three perennial streams discharging into the River Gomti.	7-16	240
Gokyo and associated lakes	Nepal	A complex of glaciers, glacial lakes, and alpine pastures	4710-4950	43
Gosaikunda and associated lakes	Nepal	Shrubland interspersed by rocky slopes and alpine pasture, with a complex of more than 15 lakes and ponds	4054-4620	14
Koshi Tappu	Nepal	Section of the Koshi River and its floodplain of extensive mudflats, reed beds, and freshwater marshes	75-81	17,500
Beeshazar and associated lakes	Nepal	Oxbow lake system, forested wetlands	286	3,200
Jagadishpur Reservoir	Nepal	A reservoir constructed for irrigation purposes fed by the Banganga river	197	225

Source: The Ramsar Sites Information Service www.ramsar.wetlands.org (as of 2007)

Figure 1: **Wetlands are integral components of river basins. Spatially they occupy positions all along the river courses from headwaters to deltas.**



Box 2: **Ramsar classification system for inland and human-made wetland types**
(Source: RCS 2006)

Inland wetlands

L	Permanent inland deltas
M	Permanent rivers/streams/creeks; includes waterfalls
N	Seasonal/intermittent/irregular rivers/streams/creeks
O	Permanent freshwater lakes (over 8 ha); includes large oxbow lakes
P	Seasonal/intermittent freshwater lakes (over 8 ha); includes floodplain lakes
Q	Permanent saline/brackish/alkaline lakes
R	Seasonal/intermittent saline/brackish/alkaline lakes and flats
Sp	Permanent saline/brackish/alkaline marshes/pools
Ss	Seasonal/intermittent saline/brackish/alkaline marshes/pools
Tp	Permanent freshwater marshes/pools; ponds (below 8 ha), marshes and swamps on inorganic soils; with emergent vegetation water-logged for at least most of the growing season
Ts	Seasonal/intermittent freshwater marshes/pools on inorganic soils; includes sloughs, potholes, seasonally flooded meadows, sedge marshes
U	Non-forested peatlands; includes shrub or open bogs, swamps, fens
Va	Alpine wetlands; includes alpine meadows, temporary waters from snowmelt
Vt	Tundra wetlands; includes tundra pools, temporary waters from snowmelt
W	Shrub-dominated wetlands; shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils
Xf	Freshwater, tree-dominated wetlands; includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils
Xp	Forested peatlands; peatswamp forests
Y	Freshwater springs; oases
Zg	Geothermal wetlands
Zk(b)	Karst and other subterranean hydrological systems; inland

Note: 'floodplain' is a broad term used to refer to one or more wetland types, which may include examples from the R, Ss, Ts, W, Xf, Xp, or other wetland types. Some examples of floodplain wetlands are seasonally inundated grassland (including natural wet meadows), shrublands, woodland, and forests. Floodplain wetlands are not listed as a specific wetland type herein.

Human-made wetlands

1	Aquaculture (e.g., fish/shrimp) ponds
2	Ponds; includes farm ponds, stock ponds, small tanks; (generally below 8 ha)
3	Irrigated land; includes irrigation channels and rice fields
4	Seasonally flooded agricultural land (including intensively managed or grazed wet meadow or pasture)
5	Salt exploitation sites; salt pans, salines, etc
6	Water storage areas; reservoirs/barrages/dams/impoundments (generally over 8 ha)
7	Excavations; gravel/brick/clay pits; borrow pits, mining pools
8	Wastewater treatment areas; sewage farms, settling ponds, oxidation basins, etc
9	Canals and drainage channels, ditches
Zk(c)	Karst and other subterranean hydrological systems; human-made

and types in various geographical regions. The Ramsar Convention initially adopted a simple classification that recognised 22 wetland types. This system was revised later to recognise more categories. Categories of inland wetlands recognised by the Ramsar Convention are given in Box 2. Several countries and organisations still continue to use a variety of categorisations and nomenclature which differ from those given by the Convention.

Wetland functions and values: goods and services of wetland ecosystems

Wetland functions are a result of interactions between the physical, chemical, and biological components of wetlands; for example, production of organic matter by plants through photosynthesis and cycling of various elements through uptake, transformation, and release after decomposition.

'Value' is an anthropocentric term: humans attach 'value' to several ecosystem functions. Primary or secondary production functions are valuable because they give products used as food, fibre, fodder, timber, and fuel. The Ramsar Convention refers to these ecosystem functions and values as "products, functions and attributes" whereas the Millennium Ecosystem Assessment (MEA) calls them "the benefits people obtain from ecosystems" or "ecosystem services" (MEA 2005a) and groups them into four types: (a) provisioning services such as food and water; (b) regulating services such as regulation of floods, drought, land degradation, and disease; (c) supporting services such as soil formation and nutrient cycling; and (d) cultural services such as recreational, spiritual, religious, and other non-material benefits. (Table 2) (Gopal 1995; Mitsch and Gosselink 2007).

Hydrological functions and associated services

Usually wetlands are low lying within a given landscape and receive water from surrounding areas at higher elevations, retaining it for a time before releasing it gradually in a desynchronised manner. Retention of water for a sufficient period allows for its percolation to the aquifer, rendering wetlands valuable for flood control (or mitigation) and groundwater recharge. Recharge of groundwater depends also upon the substrata and soil characteristics of the wetland. The volume of water

Table 2: **Ecosystem services provided by wetlands**

Services	Examples
Provisioning	
Food	Fish, wild game, fruit, and grain
Freshwatera	Storage and retention of water for domestic, industrial, and agricultural use
Fibre and fuel	Production of logs, fuelwood, peat, and fodder
Biochemical	Extraction of medicines and other materials from biota
Genetic materials	Genes for resistance to plant pathogens, ornamental species, and so on
Regulating	
Climate regulation	Source of and sink for greenhouse gases; influence on local and regional temperature, precipitation, and other climatic processes
Water regulation (hydrological flows)	Groundwater recharge and discharge
Water purification and waste treatment	Retention, recovery, and removal of excess nutrients and other pollutants
Erosion regulation	Retention of soils and sediments
Natural hazard regulation	Flood control and storm protection
Pollination	Habitat for pollinators
Cultural	
Spiritual and inspirational aspects of wetlands	Source of inspiration; many religions attach spiritual and religious value to wetlands
Recreational	Opportunities for recreational activities
Aesthetic	Many people find beauty or aesthetic value in wetland ecosystems
Educational	Opportunities for formal and informal education and training
Supporting	
Soil formation	Sediment retention and accumulation of organic matter
Nutrient cycling	Storage, recycling, processing, and acquisition of nutrients

Source: Millennium Ecosystem Assessment 2005b retained depends upon the area and depth of the wetland and the space occupied by the vegetation it contains. Thus wetlands provide one of the most important services – the provisioning of water itself.

In conjunction with water retention, wetlands trap silt and other suspended particulate matter; and this is facilitated by the reduction in flow velocity caused by resistance from vegetation. Sediment deposition is important because it helps to improve water quality and the sediments are an important resource (gravel, sand, or fertile soil).

Whereas freshwater is categorised as a provisioning service within the MEA, it is regarded as a regulating service by various sectors.

Biological functions and associated services

Thousands of species of plants, animals, and microorganisms survive and grow only in wetlands, and many other species depend on the wetlands for short periods of their life cycle. Wetlands provide habitats for many endemic, rare, endangered, or threatened organisms.

Ecological processes such as primary production, food chain interaction, and decomposition involving microorganisms and invertebrates produce services for humans such as food, fodder, fibre, fuel, medicinally useful organisms, and genetic material of economic significance.

Biogeochemical processes involving the uptake, storage, and transformation of nutrients and other chemical substances facilitate regulating services; viz., regulation and improvement of water quality as well as treatment of waste. Heavy metals and toxic substances are sequestered in anaerobic soils, clays, and humus, and, hence, wetlands are sometimes called the 'kidneys' of nature.

Wetlands play a major role in regulating the global carbon cycle through both carbon sequestration and methane emission; thus making a significant input to the global climate.

Many wetland plants have extensive root and rhizome systems which help to bind the soil and protect it against erosion. Dense stands of vegetation can even dissipate erosive forces of waves and storms. Formation of peat and trapping sediment provide both regulating (erosion control) and supporting (soil formation) services.

Sociocultural services

Besides providing quantifiable and consumable goods, wetlands have non-consumptive values which cannot be evaluated readily in economic terms. Wetlands provide aesthetic settings for activities such as swimming, fishing, canoeing, bird-watching, or just relaxing and marvelling at nature's beauty: their landscapes inspire poets and artists and are natural laboratories for education and research.

Functions and services of different wetland types

Wetland functions depend upon the characteristics of their ecosystems and the nature and degree of human intervention; hence the differentiation in the nature and magnitude of services provided by them. Every wetland does not perform all possible functions, and therefore, might not have the same value as others. No wetland can provide all the services described above. For example, lakes, reservoirs, and ponds have a marginal capacity to treat wastewater, whereas rivers, marshes, and swamps assimilate vast amounts of waste. Big rivers, deep lakes, and wetlands without macrophytes have very little primary production and consequently little secondary production and potential for groundwater recharge. The flood plains and shallow marshes or woody swamps have high production rates. The potential for carbon sequestration and methane production varies greatly according to the type of vegetation and other biophysical and climatic conditions (Sahagian and Melack 1998).

Natural and anthropogenic impacts

All natural and anthropogenic activities impinge upon the wetlands directly or indirectly because all wetlands are connected with their watersheds and embedded in the air sheds. Many of the wetlands in the Himalayas function as rangelands when not flooded, generally in winter and early summer. Transport of sediment, nutrients, and organic matter by water flowing from the watersheds affects water quality. Autogenic processes alter hydrological regimes and bring change to wetland characteristics.

Anthropogenic activities threaten the wetlands most. Hydrological regimes are altered directly by diversion and withdrawal of water as well as discharge of wastewater: direct disposal of waste degrades water quality. Land-use changes and habitat alteration through human activities and overexploitation of natural resources have direct impacts on wetlands. Deliberate or inadvertent introduction of exotic invasive species of plants or animals is often responsible for significant changes. Indirect anthropogenic impacts from farming, deforestation, grazing, mining, and others occur in the catchments. Such activities alter the amounts and quality of runoff from the catchments into the wetlands.

Climate Change

The primary driver of global climate change is the increasing concentration of carbon dioxide (CO_2) in the atmosphere, as well as other greenhouse gases (GHGs), among which methane and nitrous oxide are more prominent. Recent estimates indicate that the global mean CO_2 concentrations have increased to about 370 ppm and are projected to rise to between 490 and 1,260 ppm by 2100 (IPCC 2000). Climate change, often confused with global warming, has two main components: an increase in the global mean temperature of the earth's surface and an increased variability in precipitation regimes with greater frequency of extreme events.

Climate change in the Eastern Himalayas

There are no long-term climate data available for the Himalayan region (and Tibetan plateau). Long-term climatological observations began in 1973 in eastern Nepal at Lhajung (near Dingboche village, 4,420 masl); another observatory, the Pyramid, was established in 1990 by the Italian Project Ev-K2-CNR in Khumbu Himal (eastern Nepal) (Tartari et al. 1998a).

Shrestha et al. (1999) report that during the period from 1970 to 1994 , the mean annual temperature in Nepal increased at a higher rate in the uplands (> 4,000 m) than at lower elevations (<1,000 m): with a rise of more than 0.06°C per year over the long-term mean in the uplands and by 0.03°C per year in the lowlands. This may be explained by a feedback mechanism in which the rise in temperature accelerates glacial melting and the glacial retreat causes greater increase in temperature because of a reduced albedo effect (Meehl 1994). There are no estimates for CO_2 concentrations specifically for the eastern Himalayan region, but small variations, if any, from the global averages are unlikely to have a significant effect on temperature regimes.

Modelling climate change scenarios

In this study, HadRM2 and PRECIS models were used to project seasonal and annual temperatures and precipitation. HadRM2 was used for the period from 2040-2060 (centred around 2050) with the baseline taken as 1981-2000 (centred around 1990), thus the change was assessed over 60 years (1990 to 2050). PRECIS was used for the period from 2071-2099 (centred around 2085) with the baseline taken as 1960-1990 (centred around 1975); thus the change was assessed over 110 years. For the present study we considered two emission scenarios, B2 and A2 (IPCC 2000).

HadRM2 simulation over the Eastern Himalayan region predicts that the highest mean temperature increase by the middle of the 21st century will be 3.2°C during December, January, and February (DJF) and September, October, and November (SON); the lowest increase will be 2°C during March, April, and May (MAM); and there will be a 2.9°C increase in the annual mean temperature. Similarly, B2 scenarios from PRECIS simulation over the same region predict the highest mean temperature increase to be 3.6°C during DJF, the lowest increase to be 2.5°C during SON; and that there will be a 2.9°C increase in annual mean temperature. PRECIS projection for the A2 scenario is generally higher, predicting the highest mean temperature increase by the end of the 21st century to be 5.3°C during DJF, the lowest increase to be 3.8°C during SON and June, July, and August (JJA), and an annual mean temperature increase of 4.3°C.

HadRM2 predicts a seven per cent increase in monsoon precipitation from the current simulation over the Eastern Himalayan region by the middle of the 21st century; and the PRECIS model predicts a 17% increase (B2 scenario) or 28% increase (A2 scenario) in monsoon precipitation by the end of the 21st century. The projections of temperatures and precipitation in the Eastern Himalayas are summarised in Table 3. According to the trends for 1971-2000, the total precipitation is expected to go up, whereas the total number of rainy days is expected to decline (Chaulagain 2006). Seasonal variability is projected to increase with likely intensification of monsoon precipitation at lower elevations. It is projected that the northeast monsoon (winter rain) will bring more precipitation than the southwest monsoon (summer rain) and the intensity of

Table 3: **Projections of temperatures and precipitation in the eastern-Himalayas**

Temperature (°C)

	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)	Annual
HadRM2	3.2	2.0	3.0	3.2	2.9
PRECIS (B2)	3.6	2.6	2.8	2.5	2.9
PRECIS (A2)	5.3	3.8	3.8	4.3	4.3

Precipitation (%)

	Winter (DJF)	Pre-monsoon (MAM)	Monsoon (JJAS)	Post-monsoon (ON)	Annual
HadRM2	57	46	7	15	18
PRECIS (B2)	23	8	17	12	13
PRECIS (A2)	35	46	28	18	34

extreme events is likely to increase. Further, changes in the time of arrival and withdrawal of the southwest monsoon are likely to occur (expected to arrive earlier), causing uncertainty and spatio-temporal variability.

Wetlands in the Eastern Himalayas

Wetlands influence the climate as integral parts of river basins through their impact on the hydrological cycles at both global and regional scales (Mitsch and Gosselink 2007), and through regulating the atmospheric chemistry to a disproportionate extent in terms of their area. Some wetlands sequester large amounts of carbon (mostly as peat but also in biomass) over very long periods (from centuries to millennia), whereas others produce significant amounts of methane and nitrous oxide. Thus, wetlands can both mitigate climate change and act as its drivers.

Although the effects of increased concentrations of CO_2 and higher temperatures on wetlands are poorly understood, increasing variability in precipitation regimes, melting snow and glaciers, as well as rising sea levels, will have an impact on the biodiversity and functions and ecosystem services of wetlands through alteration of hydrological regimes (Gitay et al. 2001; van Dam et al. 2002; MEA 2005b).

The Eastern Himalayan region is fairly rich in both the extent and diversity of wetlands. Wetlands occur at all altitudes – from the foothills at 150 m to glaciers on peaks above 6,000 m. Tectonic forces and glacial activity have created many shallow, mostly small, lakes throughout the Himalayas. Several lakes are formed in valleys blocked by moraine or landslides. The rivers form narrow channels as they descend over steep slopes and pass through deep gorges: at lower elevations, passing through wide valleys, they meander and form vast flood plains and oxbow lakes.

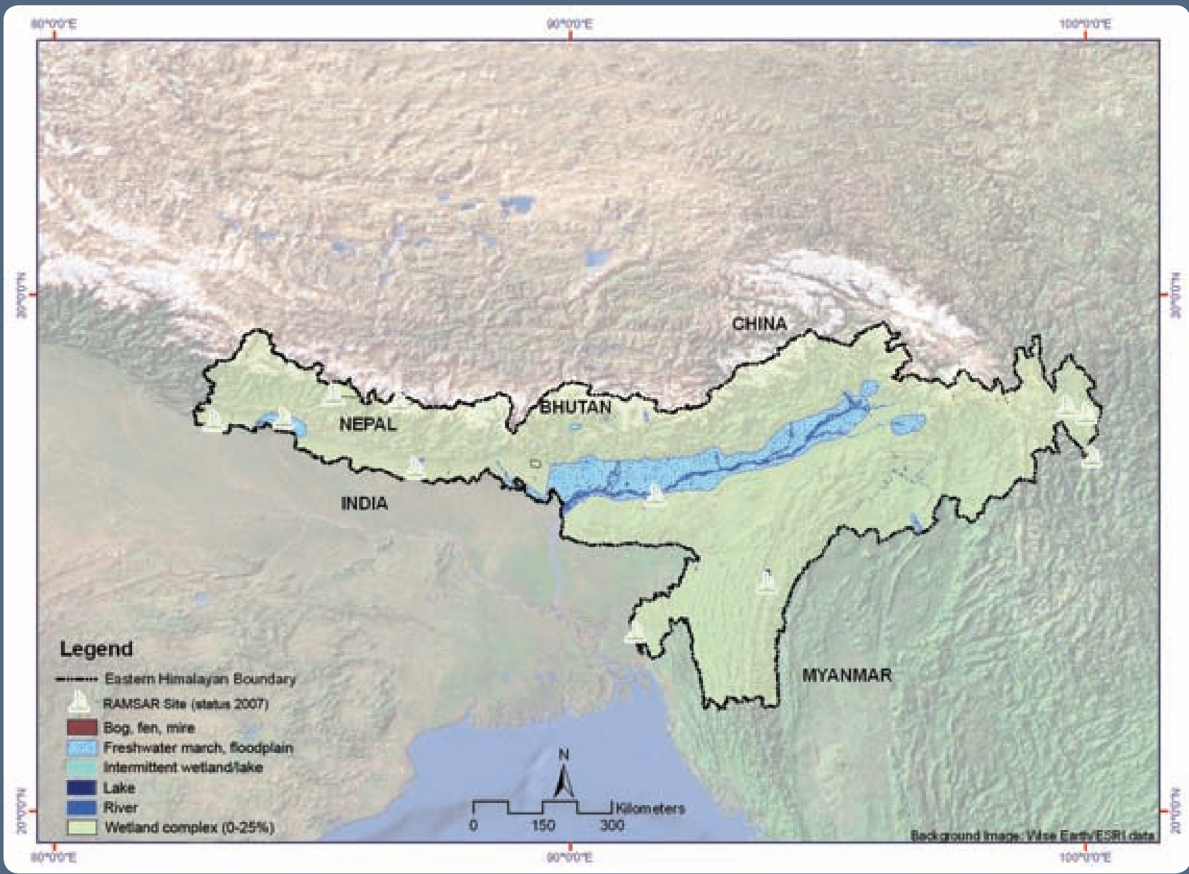
Distribution of wetlands

Despite several efforts at national, regional, and global levels, wetland inventories for the region remain incomplete and do not provide adequate information about area, hydrology, and other characteristics (Finlayson and Spiers 1999). Often, too, wetland habitats are defined differently from country to country making global standardisation difficult. Although attempts have been made to include the Eastern Himalayan wetlands in national wetland inventories (Scott 1989; MOEF 1990; Lu 1990; WWF-India 1993, Bhandari 1998; Davies et al.2004), surveys are difficult because of the mountainous terrain and regional discrepancies in wetland classification. An Asian wetland inventory based on inputs from different countries was prepared about 20 years ago. It used simple categorisation and focused mainly on sites that are important for waterfowl (Scott 1989). This inventory was revised partly for India, Nepal, China, and, recently, Myanmar (Burma); and lately, efforts have been made to prepare an inventory using remote sensing data and GIS techniques (Garg et al. 1998; Vijayan et al. 2004). Recently the Asian Wetland Inventory methodology developed by Wetlands International was adapted specifically for use in preparing an inventory of greater Himalayan wetlands (ICIMOD 2009), supported by an interactive GIS-based dynamic web-system for entry and analysis (the Greater Himalayan Wetlands Information System. In future, it is hoped that this will provide a framework for developing a detailed, comprehensive, and consistent inventory of the Himalayan wetlands, but this type of data was not available for the present study.

Another effort to assess the extent of wetlands on a global scale used data from all published sources to create a Global Lake and Wetland Database (GLWD) (Lehner and Doll 2004). It distinguishes between lakes and wetlands, and only maps lakes larger than 10 ha. An analysis of these maps shows that there are only four lakes larger than 50 sq.km in area in the region, and only 210 between 10 ha (0.1 sq.km) and 50 sq.km. Most lakes in the Eastern Himalayas are very small (<1 ha) and remain unmapped. Lehner and Doll (2004) estimated the maximum area under all kinds of wetlands by superimposing published maps from different sources. These maps treat the entire Brahmaputra river valley as wetland (flood plains) (Figure 2).

'Wetlands' in the Eastern Himalayan context are mostly freshwater lakes and rivers. Glacial lakes are the most common wetlands at elevations above 4,500 m. Moraine-dammed lakes are widespread in Nepal (Yamada 1993); and they grow in size, both area and depth, often at a very rapid rate with the retreat of glaciers (Kattelmann 2003). Herbaceous marshes and tree- and/or shrub-dominated swamps associated with lakes or rivers are common although there are relatively few peatlands; man-made reservoirs are a recent development. Paddy fields and aquacultural ponds are common in areas at lower elevations (<1,500 m). The distribution, area, and types of wetlands within the Eastern Himalayan region are described country-wise below.

Figure 2: **Wetlands of international importance in the Eastern Himalayan region (Ramsar sites)**



Nepal

There is one comprehensive inventory of wetlands in Nepal (Bhandari 1998), but it covers only the Terai region in southern Nepal where the elevation ranges from 60 to 330 m. Descriptions of 163 wetlands are given and the existence (with a map) of another 79 wetlands at higher elevations in the rest of Nepal is mentioned. A remote sensing and map survey carried out at ICIMOD (Mool et al. 2002) recorded the distribution of 2,323 glacial lakes in areas above 3,000 m, including 182 lakes larger, than eight hectares in area. Lake Rara (1,036 ha) located at 3,000 m is the largest, and Lake Shey Phoksundo (452 ha) the second largest lake. Lake Tilicho (approximately 400 ha) is among the highest (4,919 masl). Another inventory of glacial lakes in the Khumbu Himal region (Sagarmatha National Park) lists 90 lakes within an area of 650 sq.km. at altitudes between 4,500 and 5,645 m (Tartari et al. 1998b;c), the majority of them being <1 ha. There are numerous smaller ponds and fish ponds scattered throughout the hills of Nepal as well as a few geothermal springs (Sharma 1997). Nepal has designated nine wetlands under the Ramsar Convention, four of which are in the eastern Himalayan region.

Bhutan

There is little information about the wetlands of Bhutan (Scott 1989) and Bhutan is not a party to the Ramsar Convention. The major river systems are the Torsa (Amo Chu), Raidak (Wong Chu), Sankosh (Mo Chu), and Manas (Gongri).These rivers flow southwards in deep and steep-sided valleys before entering the broad alluvial plains of West Bengal and Assam. Only in the inner valleys, such as Thimphu, Punakha, and Bumthang, are there flat valley bottoms. Extensive bogs and marshes once existed in these broad valleys, but now they have been drained for agricultural purposes and significant marshes remain only in remote areas such as the Phobjikha and Khalong Chu. Phobjikha is an important wetland for winter roosting of black necked crane.

Rajbanshi and Csavas (1982) listed sixty lakes, covering a total area of about 4 250 ha, occurring at altitudes above 3,500 m. Mool et al. (2001) reported the occurrence of 2,674 glacial lakes covering an area of about 10,700 ha (107 sq.km). Three main groups of glacial lakes can be identified: a group of several lakes, the largest about 300 ha in area at 27°57′N, 89°24′E in the northwestern part of Jigme Dorji Wildlife Sanctuary;

a group of eleven small lakes (all <100 ha) at 4,000-4,500 m in western Bhutan (27°30'N, 89°08'E); and a group of six small lakes at similar altitudes in the east (27°34'N, 89°30'E). A few lakes and oxbows are found below 2,000 m.

India

Inventories of wetlands in India cover different habitats and provide different estimates. According to the directory of the Ministry of Environment and Forests (MOEF), there are 2,167 natural and 65,254 man-made wetlands covering 1.45 million and 2.59 million ha respectively (MOEF 1990). The Asian Wetland Directory listed only 93 wetlands (Scott 1989); this was revised by World Wildlife Fund (WWF-India) expanding the list to 190 (WWF-India 1993). A nation-wide survey based on remote-sensing images was undertaken by the Space Application Centre, Ahmedabad (Garg et al. 1998); it published state-wise estimates of the number and area of wetlands categorised into lakes and ponds, oxbow lakes, waterlogged (seasonal), swamps and marshes, and reservoirs and tanks. Another remote-sensing survey undertaken by the Salim Ali Centre for Ornithology and Natural History (SACONH) was used to prepare a wetland atlas (Vijayan et al. 2004); this data was used for the Eastern Himalayan region analysis. Distribution of wetland types in the Eastern Himalayan States is given in Tables 4 and 5 (North-East India and West Bengal).

Sikkim has more than 192 wetlands of which 7 have been identified as important for conservation (Roy and Thapa 1998). Assam, traversed by the River Brahmaputra and its numerous tributaries, has extensive flood plains with a complex variety of wetland types such as forested swamps; herbaceous marshes (Gopal and Krishnamurthy 1993); and 1,400 lakes and oxbows, locally known as 'beel' (Sugunan and Bhattacharya 2000). Meghalaya has no lake although several reservoirs have been constructed that form a significant component of natural wetlands consisting of seasonally waterlogged areas and swamp or marshland.

In the three northern districts of West Bengal, the number and area of wetlands decrease with increasing elevation (Table 5). In Coochbehar, oxbows are dominant and there are many lakes, whereas in Jalpaiguri seasonally waterlogged wetlands are as important as oxbows and they together cover about 80% of the total wetland area. Oxbow lakes and seasonal wetlands are also the dominant types in the hills of Darjeeling.

Mizoram has the smallest number and area (1.5 sq.km) of wetlands of all the eastern states, and they are seasonally waterlogged. Nagaland has the largest wetland coverage of seasonally waterlogged and marshy habitats, whereas the lakes and oxbows are very small and cover very little area. Manipur has several shallow, floodplain lakes, locally known as 'phat.' Loktak lake, a Ramsar site, is the largest (286 sq.km) and contributes most of the total wetland area. Tripura has numerous, small seasonally waterlogged wetlands but lakes and

Table 5: **Estimates of wetland areas in three hill districts of West Bengal**

	Darjeeling		Jalpaiguri		Coochbehar	
Wetland type	Area	No.	Area	No	Area	No
Lakes / ponds	0.04	1	1.01	18	5.46	32
Oxbow lakes	0.77	11	4.22	63	42.55	280
Waterlogged (seasonal)	1.24	19	4.30	58	0.95	15
Swamp/marsh	0.05	1	0.36	2	0.05	1
Reservoirs	0.27	5	0.42	2	0.03	1
Tanks		7	0.54	9		6
Total	**2.37**	**44**	**10.85**	**15.2**	**49.01**	**335**

Source: Garg et al. 1998

Table 4: **Wetland distribution and area (sq.km) in the North East Indian states**

	Tripura		Meghalaya		Assam		Arunachal		Nagaland*	Manipur		Mizoram*
Wetland Type	Area	No	Area	No	Area	No	Area	No	Area	Area	No	Area
Lakes/ponds	25.04	74			154.94	690	30.99	380	0.07	433.58	21	0.29
Oxbow lakes	3.60	84	0.42	5	154.60	861	2.45	6	0.53	0.35	2	
Waterlogged (seasonal)	15.73	226	7.9	58	234.31	1,125	451.87	396	4.39	94.66	130	1.16
Swamp/marsh			2.25	9	434.33	712	77.93	24	3.82			
Reservoirs	53.22	5	9.82	12	26.62	10				1.00	2	
Tanks	1.36	19	1.82	14	7.49	115			0.36			0.05
Total	**98.95**	**408**	**22.21**	**98**	**1,012.29**	**3,513**	**563.24**	**806**	**9.16**	**529.59**	**155**	**1.50**

* Total number of mapable wetlands in Nagaland 143, and Mizoram 24. Wetland type data not available.
Source: Garg et al. 1998

reservoirs cover about 80% of the total wetland area. Seasonally waterlogged wetlands dominate Arunachal Pradesh which has several small lakes (Gopal et al. 2008a).

India is a party to the Ramsar Convention and so far has designated 25 wetlands as Ramsar sites.

Myanmar (Chin and Kachin states)

Myanmar has many lakes and wetlands associated with its major river systems – Irrawaddy-Chindwin, Sittaung, and Salween, as well as three major lakes. Two tributaries of the Irrawaddy rise in the Himalayan mountain ranges bordering India and China. The Chindwin river is the largest tributary and joins it from the western side. The Salween river rises in the eastern highlands of Tibet Autonomous Region, China and flows beyond the boundaries of the Eastern Himalayas. The Sittaung flows between the two river basins and rises at lower latitude than the other tributaries.

Recently an inventory of Myanmar's wetlands was prepared after fresh surveys and by using information from the Asian Wetland Directory (Davies et al. 2004). It recognises six wetland regions; four associated with rivers and two with coastal complexes. The 99 wetlands listed are mostly river floodplain systems which include lakes, ponds, and man-made systems (reservoirs and paddy fields). There is no information on glacial lakes although, apparently, there are glacial lakes which are a perennial source of water for the Irrawaddy river.

China (Himalayan region)

The Himalayan region of China covers an area of 38,325 sq.km and forms the southern part of the Tibet Autonomous Region (TAR) of China bordering India, Nepal, and Bhutan. The altitude averages >4,500 m. The region includes the headwaters of several major rivers flowing through Nepal such as the Pumqu (Arun), Poiqu (Bhote-Sun Koshi), Rongxer (Tama Koshi), Jilongcangbu (Trishuli), Zangbuqin (Budhi Gandaki), and Majiacangbu (Humla Karnali). A recent study (Wu et al. 2005) recorded 824 glacial lakes with a total area of 85.2 sq.km.

Yunnan Province in southwest China has many natural wetlands in the form of lakes, marshes, seasonal wetlands, and rivers as well as many man-made wetlands such as reservoirs and ponds. There are also areas of high-altitude peatland. The lakes cover approximately 1,164 sq.km of which 966 sq.km is contributed by 37 lakes with an area of more than one square kilometre each. The rivers cover approximately 1,202 sq.km and the marshes another 39 sq.km. Some glacial lakes at higher altitudes 5000 m are sources of major rivers such as the Yangtse. China has designated 36 wetlands under the Ramsar Convention.

Functions and values of Eastern Himalayan wetlands

The functions and values of wetlands have been discussed above. The importance of individual wetlands in the Eastern Himalayas depends upon their location and characteristics and the sociocultural and economic status of the human communities around them. The numerous glacial lakes at high altitude are an abundant source of water as well as of the headwaters of many rivers. The snow and glacial melt from these lakes provide the low season flows (presummer season) in the rivers for downstream users far beyond the boundaries of the Eastern Himalayas. The wetlands, the rivers to be specific, in the Himalayan region are valued for their hydropower potential (Agrawal et al. 2003).

Many glacial lakes and their associated marshes and other high-altitude wetlands are important habitats for many species of wildlife such as cold-water fish and migratory waterfowl. These wetlands are under very little anthropogenic pressure relative to other wetland areas, but, many of them (e.g., Lake Tsomgo and Lake Guru Dongmar in Sikkim) are considered sacred by local communities (Gopal et al. 2008a).

At middle and lower altitudes throughout the Eastern Himalayan region, wetlands are valued mostly for their provisioning services – fish for human consumption and forage for wildlife and domestic animals. Extensive fisheries are supported by the numerous rivers and streams. Large populations of local people depend on these wetlands (Barik and Katiha 2003). Paddy and deep-water rice are important products from wetlands in Manipur, Tripura, and Assam. These wetlands are the only habitats for a diverse range of plants and animals including many endemic, rare, and endangered species such as the one-horned rhino (*Rhino unicornis*) in Kaziranga (Assam), and brow antler deer (*Cervus elde elde*) in Keibul Lamjao (Manipur). The rivers in Myanmar are extremely rich in fish species (Groombridge and Jenkins 1998).

The biogeochemical functions and related regulating services of these wetlands have not been estimated or investigated. The high productivity of marshes and swamps and the rapid stream flows, however, are clear indicators that these wetlands transform large quantities of nutrients and function as important treatment systems for domestic waste discharged into the rivers without treatment.

Some wetlands at higher altitudes in Nepal and Yunnan Province of China, and a few at lower elevations (e.g., Lake Khecheopalri in Sikkim), have played a significant role in carbon sequestration in the form of thick peat deposits in the past; and they continue to do so (Jain et al. 2004).

Practically all wetlands in the region, particularly those close to human habitats, provide social and cultural services as local communities depend on them not only for water and natural resources but also for social, cultural, religious, and recreational activities. Most high-altitude lakes are regarded as sacred by Buddhists and Hindus.

Impacts of Climate Change on Wetlands

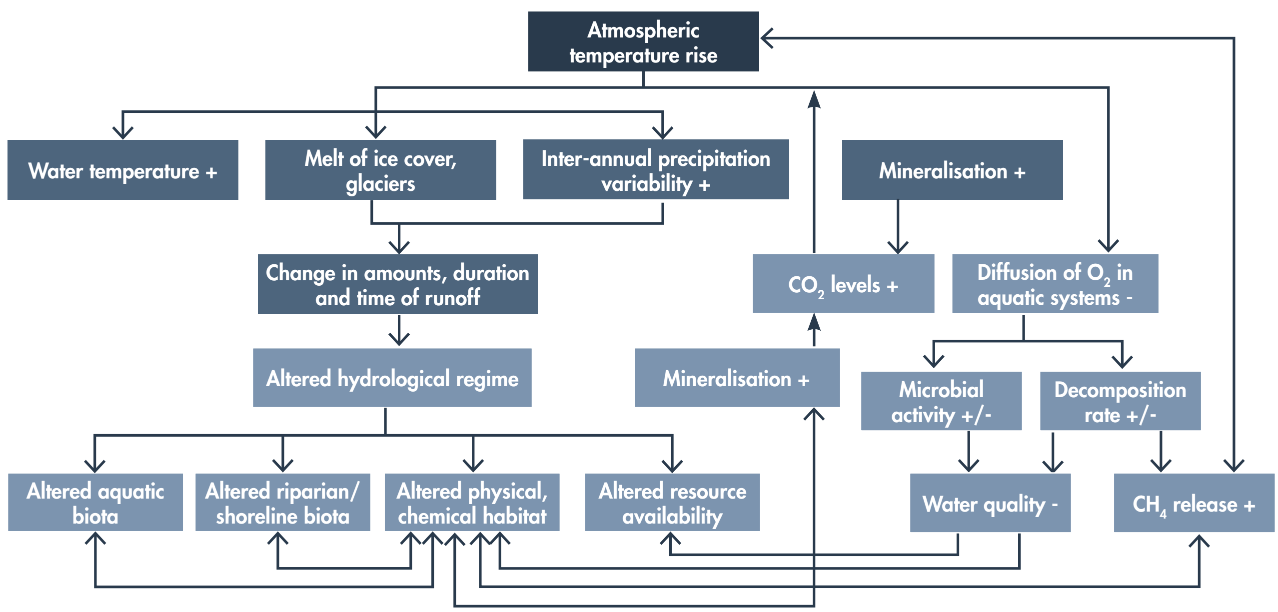
Discussions on the impacts of climate change on wetlands can be found in the assessment reports of the IPCC (Gitay et al. 2001; Fischlin et al. 2007; van Dam et al. 2002; Sharma et al. 2002; Sharma 2003). These reports focus on wetlands at higher altitudes (>4000 m) (peat bogs and other temperate wetlands) and on coastal wetlands, especially mangroves, in relation to rising sea levels and coral reefs. Assessments of impacts of climate change on freshwater wetlands in developing countries, in general, and the Himalayan region in particular are limited. The following account is based largely on extrapolation of information from temperate regions.
Climate change impacts on wetlands can be considered at two levels: First, the impacts of forcing factors and their interactions with wetland processes and, second, the overall impacts on different kinds of ecosystem goods and services.

Impacts range from the direct effects of increasing concentrations of CO_2 and the resultant rise in temperature, to the indirect effects caused by alterations in the hydrology caused by melting glaciers and ice cover and changes in precipitation regimes. Some selected pathways of these changes are shown in Figure 3. An important consideration in the Eastern Himalayan region is the difference in impacts along the altitudinal gradient and their cascading influence at successively lower elevations. Very little is known about the altitudinal differences in climate change except for a trend towards increasing temperatures at higher altituudes.

Rise in CO_2 concentration

Of all the GHGs, CO_2 is of direct importance to plants. An increase in CO_2 concentration enhances the rate of photosynthesis unless there are other limiting factors.

Figure 3: **Possible impacts of climate change on inland wetlands and other aquatic ecosystems**



(+ increase, – decrease)

For example, rice productivity in cool climates increases with greater concentrations of CO_2 but the temperature becomes limiting to grain maturation beyond a threshold temperature (varying according to rice species) (Lin et al.; 2005; Jagdish et al. 2007; Prasad et al. 2006). In natural wetlands, studies have shown that elevated CO_2 concentrations promote carbon fixation in C_3 plants such as emergent macrophytes, although the response of *Sphagnum sp*. and other plants occurring in bogs is not clearly known (Gitay et al. 2001). Plant communities of the Eastern Himalayan wetlands range from alpine to tropical and are likely to respond differently. This has implications for the carbon sequestration potential of the wetlands in the region.

In the case of phytoplankton in rivers and lakes, increased CO_2 levels may enhance photosynthesis at higher elevations, but at lower elevations the increased temperature may reduce solubility and is unlikely to affect photosynthesis

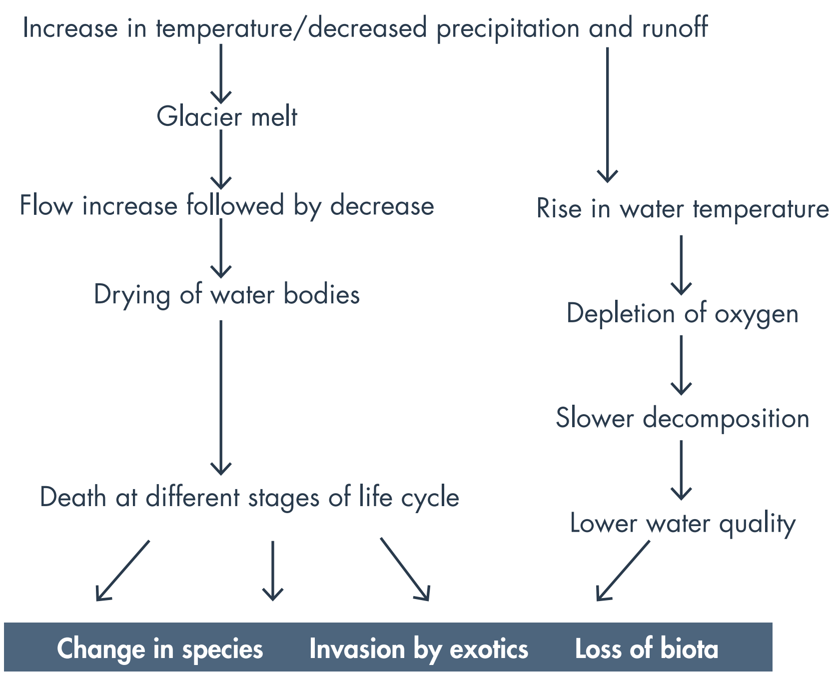
Rise in temperature

The impacts of increasing temperature have received considerable attention in the countries of the Himalayan region because of the influence on glacial melt and retreat. Himalayan glaciers are thought to be retreating at rates of more than 10 m per year. The termini of many glaciers in high-altitude valleys of Bhutan, China, and Nepal are reported to have shifted 100 m in the last 50 years (Yamada 1993; Kattelmann 2003; Agrawal et al. 2003). Areas of research include the Dudh Koshi sub-basin in the Everest region of Nepal (Lake Imja Tsho) and the Pho Chu basin of Bhutan, where the glacial lakes have increased substantially over a relatively short period of time. Examples of retreating glaciers and the resulting enlargement of glacial lakes are given in the literature.

Although the snowmelt in the Eastern Himalayas contributes less to the total runoff than snowmelt in the Western Himalayas, seasonal changes are expected in the timing and distribution of surface runoff; and this could increase during autumn, and occur earlier and faster during spring.

It is believed that temperature increases will affect practically all biological activity, although studies in temperate regions and in Africa give conflicting results. Studies carried out in northern latitudes of Europe and North America suggest major changes may occur in species' composition, seasonality, and production of plankton communities; an increase in nuisance blue green algae blooms; and interactions in the food web. Studies along an altitudinal gradient in Sweden show that net production increases considerably with a rise in air temperature. These changes have a direct bearing on water quality and other characteristics of wetlands. Observations from the tropics (Lake Tanganyika) show a lowering of photosynthesis and decline in fish production with rise in temperature over time.

Figure 4: **Generalised effects of temperature rise on wetlands**



An increase in temperature will result in a rise in snowline and, therefore, species' distribution is expected to shift to higher elevations. The atmospheric temperature generally drops by 1.5°C for every 300 m in elevation and, therefore, with an average 1°C rise in temperature, most species are likely to extend their distribution upwards by 300 m. Exotic invasive species, such as water hyacinth, have already been extending their range into the hills and may spread to higher elevations.

Effect on water quality

Another impact of rising temperatures will be an increase in water temperature and, as a result, less dissolved oxygen (Figure 4). This could affect a number of animals – both invertebrates and vertebrates. Many invertebrates in their larval stages have narrow temperature ranges for development and a rise of 1°C may affect their life cycles. Rising temperatures will alter the ice-free period and bring about a longer growing season. Changes in the patterns of thermal mixing in lakes and an increase of anaerobic conditions for benthic organisms – including microbes – could occur. The unique thermal properties of water (maximum density at 4°C and freezing at 0°C) mean that, with a 1°C rise in temperature, the lakes may not freeze or may freeze at a different time and their mixing behaviour will change. The consequences of these changes for food-chain interactions, community structure, nutrient dynamics, and water quality are difficult to predict in the absence of appropriate studies. Low-elevation wetlands with higher water temperatures will be affected to a lesser extent and there will be no change in the mixing pattern.

Indirect effects

The composition of wetland plant, animal, and microbial communities and practically all wetland ecosystem processes is determined primarily by the hydrological regime. Even small changes in any one component of hydrology can affect one or more phases of the life cycle of wetland organisms. Therefore wetlands are extremely vulnerable to hydrological changes – not only in quantity and quality but also in the frequency, duration, and timing of water availability. Changes in water quality often act synergistically, although the interactions are complex. Alterations in hydrological regimes caused by melting glaciers and changes in precipitation regimes will have the most significant and pronounced impacts on wetlands.

Upstream-downstream linkages

Of greatest significance in mountain regions like the Eastern Himalayas is the fact that the impacts of climate change will cascade down from higher elevations to lower elevations in the foothills, even if the actual climate change is of a different order of magnitude along the altitudinal gradient. This cascading effect will be caused by the hydrological connectivity between upstream (uphill) and downstream (downhill) wetlands. The wetlands in the valleys and other areas at lower elevations will bear the brunt of changes taking place above. The change in the amount, timing, and duration of water availability, the changes in extreme events, and the intensity and timing of monsoon precipitation will affect the wetlands most at lower elevations. There is very little information available as yet, however, on the current state of these wetlands and, hence, it is difficult to predict the course and direction of change with change in climate.

Feedback effects – changes in GHG emissions

As noted earlier, wetlands are both a source and a sink of greenhouse gases and the balance is affected by changes in hydrology. Changes in production of organic matter; its accumulation or mineralisation; and microbial activities caused by changes in water level will determine the amount of methane emission. Whereas wetlands may help sequester more carbon and thereby mitigate impacts of climate change, they may also become a source of increased methane emission and hence trigger further changes in the climate.

Impacts on Ecosystem Goods and Services

The magnitude of impacts of climate change on inland wetlands in the Eastern Himalayas is difficult to assess because of the lack of a proper inventory and differences in characterisation of different wetlands. As mentioned earlier, not all wetlands provide the same ecosystem services and not all will be affected to the same extent by climate change. The nature of impacts will be similar to those elsewhere (Gitay et al. 2001; van Dam et al. 2002; Fischlin et al. 2007). Impacts specific to the region are highlighted below.

Provisioning services

At higher elevations (above 3,000 m) wetlands are comprised almost exclusively of glacial lakes which remain frozen for six to 11 months each year, and direct anthropogenic influence on these wetlands is almost non-existent: their only ecosystem service is providing water to the valleys and to lower elevations. Most glacial lakes form the direct source of rivers that downstream become the major rivers of the region. Information on the biodiversity of these glacial lakes is not well documented. The increase in temperature and differential warming between seasons will lead to an increase in snow-free periods, and also affect the patterns of thermal mixing in the lakes. The increase in lake area and depth will also have consequences on their functioning and increase the possibility of floods (e.g., glacial lake outburst floods) downstream. Our understanding of the structure and functioning of these glacial lakes, however, is very limited.

A direct consequence of accelerated melting of glaciers and reduced snow cover could be increased summer flows in some rivers for several years – in some cases perhaps up to 2100, after which the flow will decrease and rivers dry up as the glaciers disappear. A recent study in Nepal predicted that the total availability of water in the country will increase from the current 176.1 km3/yr to 178.4 km3/yr in 2030 and then decrease to 128.4 km3/yr in 2100 (Chaulagain 2006). This will have significant impacts on the wetlands at low elevations and in the plains as they depend on runoff from upstream areas. There are also concerns about the possible impact of increased variability in flow on hydropower generation in the region (Agrawal et al. 2003; Alam and Regmi 2004).

Changes in stream flow and increased water temperatures could affect insects and other invertebrates living in streams and rivers with repercussions up the food chain for fish, amphibians, and waterfowl. Warming water is likely to cause local extinctions of cold- and cool-water species and changes in precipitation patterns could affect reproduction patterns of fish such as Schizothorax and Tor spp.

Changes in wetlands between ~3000 and ~5000 m could result in loss of unique, endemic biodiversity; and this includes rare, endangered, and threatened species as well as migratory waterfowl from northern latitudes which use them as breeding grounds.

At lower elevations, wetlands will be most hard hit by hydrological changes such as the frequency and intensity of extreme events. These wetlands are rich in biodiversity of all organisms, but especially of fish and waterfowl. Plant resources include a wide variety of grasses, herbs, and medicinal plants. Besides fisheries, many wetlands are managed extensively for paddy cultivation. The dense populations in Eastern Himalayan countries, and local communities especially, depend for their subsistence on the natural resources provided by lakes, streams, and flood plains. Wetlands are a source of fish and fodder as well as of sediments transported by streams.

Many studies from north Asia and Japan have shown that in those countries increased carbon dioxide levels and longer growing periods are likely to augment rice yields. In south and southeast Asia, however, rice crops could be reduced as they are vulnerable to increased minimum temperatures; grain maturation has a threshold temperature of 26°C and yield decreases by about 10% for every one degree increase above this threshold during the post-flowering period. Therefore, within the Himalayan region, rice yields may be affected in different ways in different altitudinal zones.

Wetlands provide habitat and food to a wide diversity of wildlife and this will be affected by changes in hydrological regimes. Climate change will affect habitat characteristics through changes in water regimes, vegetation types, and possibly sediment characteristics, influencing migration patterns of birds and fish. Loss or degradation of wetland habitats will threaten many vulnerable and endangered species.

Regulating services

Regulating services would be most affected by climate change. The capacity of wetlands to regulate floods and droughts is limited by morphological and hydrological characteristics. Increased runoff from melting glaciers would increase erosion and augment sediment transport downstream. Deposition of sediments in lake basins and flood plains will reduce floodwater retention. Reduction of water supply in the long term (around the year 2100) will affect the drought-regulating function: changes in plant communities will contribute to this.

Wetland regulation of water quality is significant, particularly in the context of increasing human influence (terraced agriculture, human settlements, and industrial activity). Declining levels of dissolved oxygen with an increase in water temperature and changes in mixing patterns in deep-water wetlands will result in degradation of water quality. The ability of microorganisms and benthic invertebrate communities to degrade organic matter could decline significantly.

The effects of temperature and increased CO_2 concentrations on ecosystem processes, such as primary and secondary production, decomposition, and nutrient dynamics, or on the growth of various species in inland water bodies, have not been investigated. Yet, climate change will have implications for climate-regulating services of wetlands. Natural or anthropogenic increase in organic matter in water bodies with lowered oxygen levels will promote methane production and affect water quality.

Supporting and cultural services

Wetlands in the Eastern Himalayan region are interconnected through a dense network of streams and rivers. Transportation of sediments and nutrients from the mountains supports populations in the valleys and also those in the plains of India and Bangladesh where soil fertility depends upon the wetlands in the mountains.

Most mountain wetlands have great spiritual and cultural values as they are considered sacred and are sites of cultural tourism. Evaluating these values in economic terms is difficult and has rarely been attempted. One study using a travel-cost method (Jain et al. 2000) demonstrated the economic value of Lake Khecheopalri for ecotourism. High-altitude lakes are of particular significance in this respect (Gopal et al. 2008a). Changes in characteristics may affect their significance.

Feedback impacts of wetlands on climate change

Although the role of carbon sequestration by wetland plants is not clear, climate change will trigger increased emission of GHGs from many wetlands as can be surmised from studies carried out both at high latitudes as well as in temperate regions in boreal and permafrost areas. Methane emissions occur during the summer thaw in permafrost regions (Rinne et al. 2007). Longer and warmer growing seasons are projected to result in desiccation of peat and production of CO_2. Hirota et al. (2004) found methane emission to be as high as in other boreal and alpine wetlands – increasing in summer as surface biomass increased and varying with different plant species.

In north temperate zones, lakes contribute significantly to methane emissions (Michmerhuizen and Striegl 1996; Walter et al. 2007): lakes with smaller surface areas emit proportionately more methane during spring melt, apparently because of larger shorelines where littoral vegetation adds large amounts of organic matter to the sediments (Michmerhuizen and Striegl 1996).

Glacial lakes may accumulate organic matter along their margins or in the sediments, and melting away of ice will result in production and ebullition of methane. Lakes at lower elevations may become a source of methane as they will accumulate organic sediments as lower solubility of oxygen at increased temperature will lead to anaerobic conditions occurring more readily. There are no estimates of potential organic carbon sequestered in the glacial lakes of the Eastern Himalayas, however.

Contribution of climate change vs other anthropogenic stressors

In the Eastern Himalayan region, the nature and magnitude of anthropogenic impacts on rivers, lakes, and other wetland ecosystems is well documented. Growing populations and urban expansion; discharge of domestic wastewater into surface water bodies without or with only partial treatment; expansion of agriculture on to steep and unstable mountain slopes; and deforestation and overgrazing causing rapid soil erosion and increasing sediment loads in the rivers all lead to impacts on wetlands. The construction of Ithai barrage has affected the ecosystem of Loktak lake and particularly the habitat of brow antler deer (Trisal and Manihar 2004). Weeds, such as water hyacinth and *Ipomoea fistulosa*, have spread in recent years in many parts of Nepal. Hill streams are being tapped at increasing pace for hydropower (Thomsen 2004; NHPC 2008). Anthropogenic activities have altered hydrological regimes and degraded water quality already. Changes expected to occur over a century under different scenarios of climate change could actually occur within a few years because of human activity. Thus, impacts of human activities and climate change will be synergistic: climate change will exacerbate the effects of human-induced stressors such as land-use and land-cover changes. Management strategies must consider them together.

Alterations in water-resource management practices will influence the wetlands, and changes in economic development will affect wetlands to a greater degree than will climate change (Vorosmarty et al. 2000; Gopal et al. 2008b; Polunin et al. 2008). Already it is being argued that water-storage capacities have to be increased in the Himalayan region to mitigate the impacts of increasing incidence and intensity of extreme events, especially floods, and to meet hydropower requirements in periods of uncertainty (Agrawal et al. 2003).

Research Gaps and Needs

Our current knowledge of climate change and its impacts in the Eastern Himalayan region is poor. Although retreating glaciers have received global attention, data are scarce. There are few long-term records of past climate change as several areas throughout the Himalayas, particularly in North East India and at high elevations, have very few meteorological stations. A network of automated weather stations is required to cover the entire altitudinal range and valleys. Further, long-term data on greenhouse gases, an inventory of their sources and rates of emission, and their transport across the Himalayan ranges are essential.

Wetlands are one of the most poorly understood ecosystems, despite recognition of the importance of their goods and services. A list or map of their distribution and size is of no help in assessing their functions or ecosystem services and, consequently, the likely impacts of climate change. There is an urgent need for detailed inventories that include basic information on their hydrological, physical, chemical, and biological characteristics as well as human interactions (use and impacts) with each system. Wetlands should be classified according to their functional attributes and their ecosystem services prioritised.

Priority areas for research in relation to wetlands

The priority areas for research are grouped in the following under short-and long-term goals.

Short-term studies (3-5 years)

- A detailed inventory of wetlands with quantitative data on their ecological characteristics. The following parameters should be included: geomorphology, wetland boundaries and basin shape, hydrology, vegetation type, primary production, soil nutrient status, transport of organic matter and sediments into or out of wetlands, temperature regimes, and salinity (Sahagian and Melack 1998).

  Hydrological data should focus on water depth, changes in water level, inflow-outflow levels, duration and season of water availability, and timing and duration of ice-free periods in glacial and other high altitude lakes. Data on groundwater recharge and evapotranspiration losses are also required.

  The study should include composition of plant communities, their productivity and nutrient status, the fate of organic matter production, and the rates of carbon sequestration in sediments, as well as planktonic and benthic diversity and their role in carbon and nutrient transfer along the food chain.

- Study on the responses of both plant and animal species to components of climate change such as elevated CO_2 concentration, temperature, and hydrological parameters. A rapid assessment of environmental flow requirements is required.

Long-term studies (> 5 years)

- Environmental flow requirements of various organisms, including rare, endemic and threatened (RET) species, in different stretches of rivers and in other wetlands
- Effects of enhanced CO_2 concentration on primary production, decomposition, N metabolism, and transpiration in major plant communities (species)
- Detailed limnological studies on the structure and functioning of glacial lakes
- Effects of temperature on primary and secondary production, decomposition, nutrient dynamics, and growth of aquatic species
- Effects of enhanced CO_2 levels on methane emission
- Effects of temperature on growth, carbon sequestration, and methane emission in different wetland types;
- Monitoring of distribution ranges of plant and animal species

Coping Practices and Adaptation Strategies

The most important consequences of climate change will be increased variability and uncertainty in the availability of water resources, coupled with altered frequency and intensity of extreme events (floods and droughts). In the Eastern Himalayan region, these extreme events may also be in the form of glacial lake outburst floods (GLOFs); which have already occurred in the recent past. People will have to cope with both uncertainty and wide variability. In the past, people have suffered large losses of life and property. Human ability to cope with situations arising from such hazards, and also to prevent and avoid them, and establish adequate warning systems, needs improving.

Another important adaptation is to meet the challenge of water resources for which there will be increased demand and competition. A key strategy for ensuring the future of wetlands and their services is to maintain the quantity and quality of their natural water regimes, including the frequency and timing of flows. This infers developing and implementing an ecosystem-based integrated water resource management policy. Tradeoffs between competing water uses may be necessary, but decisions about water management must consider protection of the wetlands as the decision could tip the balance towards accelerating or mitigating climate change, and wrong action could lead to rapid degradation of water quality, whereas timely intervention could help improve it at low cost in an energy efficient manner. Unfortunately, there is as yet little sign of an ecosystem approach being used to integrated water resource management. Climate change is likely to worsen the situation unless immediate steps are taken to manage water resources properly.

In addition to climate change, the Millennium Ecosystem Assessment (MEA 2005b) recognises habitat change, invasive species, overexploitation of resources, and pollution as major drivers of change for both freshwater and mountain ecosystems. These drivers are causing serious problems already – in fact they threaten ecological integrity in freshwater ecosystems. Adaptation strategies must consider these drivers along with climate change: no driver or stressor should be viewed or managed separately in isolation from others.

Adaptation strategies for integrated water resource management require reducing water requirements by different sectors by adopting appropriate tools and techniques and economic instruments; recycling of wastewater should be emphasised. Water-saving techniques will be required for agriculture, industry, and the domestic sector to ensure that the needs of wetlands are met. At the same time, wetland management should adapt to the conditions of a changing climate so that wetland ecosystem services are less affected. Currently, our understanding of approaches and methods of wetland management is extremely poor, particularly in the Eastern Himalayan region. Hence, the importance of education and awareness, as well as capacity building at all levels should be recognised; currently, these are at their lowest ebb in the context of wetlands.

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Acronyms and Abbreviations

CO_2	carbon dioxide
GHG	greenhouse gas
GIS	geographic information system
GLOF	glacial lake outburst flood
GLWD	Global Lake and Wetland Database
ICIMOD	International Centre for Integrated Mountain Development
MEA	Millennium Ecosystem Assessment

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The International Centre for Integrated Mountain Development, ICIMOD, is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush-Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalisation and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

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