BioOne COMPLETE

WWF Initiatives to Study the Impact of Climate Change on Himalayan High-altitude Wetlands (HAWs)

Authors: Chatterjee, Archna, Blom, Esther, Gujja, Biksham, Jacimovic, Ruzica, Beevers, Lindsay, et al.

Source: Mountain Research and Development, 30(1) : 42-52

Published By: International Mountain Society

URL: https://doi.org/10.1659/MRD-JOURNAL-D-09-00091.1

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://complete.bioone.org/journals/Mountain-Research-and-Development on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Mountain Research and Development (MRD)
An international, peer-reviewed open access journal
published by the International Mountain Society (IMS)
www.mrd-journal.org

MountainPlatform

WWF Initiatives to Study the Impact of Climate Change on Himalayan High-altitude Wetlands (HAWs)

© 1986 Panda symbol WWF–Word Wide Fund For Nature (Formerly World Wildlife Fund)

® "WWF" is a Registered Trademark

Editor's note: As a response to the reality of the impacts of climate change both on ecosystems and local people in the broader Himalayan region, the World Wide Fund for Nature (WWF) and two technical partners, UNESCO–IHE Institute for Water Education and San Diego State University (SDSU), undertook scientific studies focusing on high-altitude wetlands. Around 200 papers were consulted by experts to write the review upon which the present article is based. A detailed report of the review is currently being produced; this article summarizes the key findings and recommendations.

Introduction: water, wetlands and the Qinghai-Tibetan plateau

Water towers is frequently used as a symbolic term for a mountain area that supplies disproportional runoff by comparison with the adjacent lowland catchment. *Headwaters* is another often-used term that actually refers to the source of the water, ie the place from which the water in the river or stream originates. The headwater areas of rivers are crucial source areas for water supplies and ensure sustainable development not only in mountain regions but also in downstream, water-limited lowlands.

The Himalayan region, including the Tibetan plateau, fulfills both roles and is thus significant in this region. Table 1 shows that the mountainous area of the Himalaya plays an essential role in providing water to downstream catchments. The Qinghai–Tibetan plateau is the most important source of water for Chinese rivers, being one of the wettest areas with the highest water generation in China.

Research has shown that water towers are more sensitive to climate change than other regions. Climate change is a main factor affecting the eco-environmental changes in headwater regions. Expected changes are related to the volume and timing of runoff, which affect the discharge of rivers. Among others, the regions affected include parts of northwestern India and areas south of the Hindu Kush. Air temperatures in the headwaters of the Qinghai–Tibetan Plateau have been continuously rising since 1954. Glacier retreat is significant and its implications for water resources could be serious because these glaciers feed the headwaters of the Indus, Ganges, and Brahmaputra rivers, which sustain one of the world's most populous regions.

High-altitude wetlands (HAWs)

Many wetlands are located in headwaters. They are considered to be of international importance because they provide water for many transboundary rivers. The total area of freshwater wetlands on the Qinghai–Tibetan plateau has been reported to be around 13.3×1010 m^2, excluding small patches of wetlands (Figure 1). The sources of the Yangtze River host the largest clusters of wetlands—3.29×1010 m^2 in area—while the Qilian Mountains contain the second largest group of wetlands in the source of the "Five Rivers"—1.5×1010 m^2 in area. The areas of wetlands on the Zoig Peat Plateau and surrounding mountains, the sources of the Yellow River, and the sources of the Upper Yaluzangbu River, are 1.26×1010, 0.63×1010 and 0.13×1010 m^2, respectively.

Due to the vast area that headwater wetlands occupy, they are of great environmental, ecological and socioeconomic importance; indeed, they provide crucial ecosystem goods and services. Wetland users are primarily poor communities or ethnic minority groups whose livelihoods greatly depend on wetland ecosystem goods and services. These need to be managed wisely, sustainably and judiciously.

There is no exact definition of high-altitude wetlands (HAWs) in available scientific literature. The following working definition is generally used:

Downloaded From: https://complete.bioone.org/journals/Mountain-Research-and-Development on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

TABLE 1 Role of the Himalayas in water yield for downstream catchments (Sources: Biggs and Beland 2009; Jacimovic et al 2009).

Region	Type of water tower	Description
Southwest Himalayas (Indus River)	Essential	Most of the discharge in the respective lowland basins originates from the mountains, which are therefore a major priority for conservation.
Central and northwest Himalayas	Occasional	Mountains may be essential for downstream discharge on the regional scale.
Eastern Himalayas (Chang Jiang/Yangtze River)	Supportive	Mountains contribute a high proportion of downstream discharge and provide a major potential for hydropower.

High-altitude wetland (HAW) is a generic term used to describe areas of swamp, marsh, meadow, fen, peatland or water located at an altitude above 3000 m, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or saline. In general, HAWs are areas located at altitudes between the continuous natural forest border and the permanent snowline.

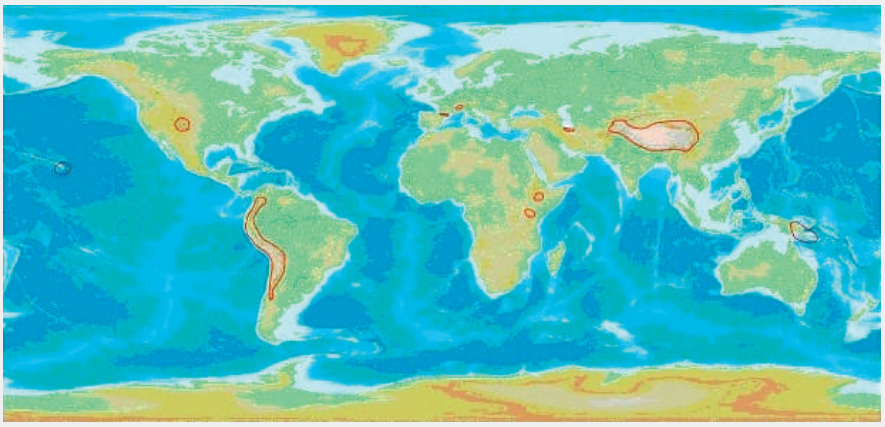
The main characteristic of HAWs is the existence of a permafrost (seasonal or diurnal) layer and a cold climate. Due to the low air temperature and increased radiation, the vegetation cover is usually simple in terms of its composition—predominantly grassland and shrubs—of which many species represent endemics and rarities for the region.

Environmental factors

The Himalayas and the Qinghai–Tibetan plateau are influenced by the East and Southwest Asian Monsoon during the summer and the Westerly during the winter. HAWs in the Himalayas and on the Qinghai–Tibetan Plateau are characterized by the following environmental factors:

- Cold, dry alpine climate;
- Freezing period extending from September to April;
- Extreme temperature variation within 24 hours;
- Annual mean temperature from −5 to −2°C, with little seasonal variation and without an absolutely frost-free season, which results in the formation of an extensive permafrost layer;
- Strong sun radiation;
- Mean annual precipitation from 300–600 mm, falling mainly as snow or heavy rain;
- More than 80% of all annual precipitation during the growing (warm) season;
- A relatively arid cold season climate;
- Evaporation varying between 1200 and 1500 mm; and
- Relative humidity varying between 50 and 60%.

FIGURE 1 High-altitude wetlands (HAWs): distribution worldwide as reported in the scientific literature. The circled areas mark regions where HAWs have been reported. (Map courtesy of UNESCO–IHE)



The natural environment in the region is very harsh; therefore, the ecosystems that developed and adapted there are fragile. Precipitation and air temperature are the two most important abiotic factors in HAW ecosystems. The presence of a permafrost layer plays a very important role in the growth and development of high-cold vegetation because it provides water for plants at the beginning of the growing season, when precipitation is still low. It also plays an important role in the water retention capacity of the soil.

Seasonal snow accumulation is the important freshwater resource in the dry areas in northwestern China: the average amount of snow accumulation (water equivalent) in winter is up to 3.61 × 1010m^3. The

http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00091.1
Downloaded From: https://complete.bioone.org/journals/Mountain-Research-and-Development on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

TABLE 2 Effect of climate change on different land types, land cover, and water bodies (Sources: Qian et al 2006; Wang et al 2006; Wang G et al 2008; Wang H et al 2008; Wang et al 2009).

Authors (timeframe)	Mean permafrost temperature increase (°C/10 yrs)	Area decrease (km^2)					Depth lost (m)		Thickness lost (m)	
		Lakes	Glacier	Permanent snow	Wetland	Swamp-land	Rivers	Lakes	Glaciers	Permanent snow
Wang et al 2006 (1986–2000)	0.2	35.99	107.78	167.38	–	43%	0.3	0.8	3.0	3.0
									13.5% turned into bare rock (1986 to 2000)	
Wang G et al 2008 (1986–2000)	0.2	–	–	–	–	–	–	–	–	–
Wang H et al 2008 (last 40 yrs)	–	0.54% (1970–1980s)	–	–	70.4%	75.0%	–	–	–	–
		9.25% (1980–1990s)			1980–2004	1980–2004				
Wang et al 2009 (last 30 yrs)	–	–	–	–	24%	–	–	–	–	–
Qian et al 2006 (1986–2000)	–	7.5% at Yangtze River source	17.24% at Yellow River source	–	5.15% in last 15 years	24.36% in last 15 years	–	–	–	–
			1.7% at Yangtze River source							

abundant light and relatively humid climate during the growing season lead to high productivity and an increase in organic carbon in the soil. Therefore, wetlands in this region are considered as carbon sinks.

The role of high-altitude wetlands (HAWs)

High-altitude wetlands play key roles in the hydrology and ecology of several major rivers in Asia. Wetlands function as simple reservoirs or aquifers, storing water during wet periods and releasing it throughout drier periods, either through runoff, subsurface drainage, or evapotranspiration. Since climate controls many ecosystem attributes and functions, changes in temperature and precipitation in future will alter the hydrological processes of wetlands with potentially significant consequences for downstream water resources.

In addition to their hydrological function, wetlands are of cultural and ecological importance. Himalayan high-altitude wetlands regulate microclimates and have immense livelihood, cultural, and spiritual significance for local communities (Box 1; Figure 2). All the major rivers in Southeast Asia—the Ganga (or Ganges), Indus, Brahmaputra, Irrawaddy, Salween, Mekong, Amu Darya, Hilmand, Yangtze, and Yellow rivers—originate in high-altitude lakes and wetlands in the Himalayas and the Qinghai–Tibetan plateau. Yet despite their importance, high-altitude wetlands and the catchments draining into them are under increasing threat from anthropogenic climate change, land use, upstream flow modification, and unsustainable exploitation; and there is a risk that these threats could lead to negative knock-on effects along the river systems that they supply.

WWF studies

In order to protect high-altitude wetland ecosystems that benefit

http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00091.1
Downloaded From: https://complete.bioone.org/journals/Mountain-Research-and-Development on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

FIGURE 2 Community horse race for team building in Longbaotan, China. Such major community activities are an important means of building local support and doing teamwork with the indigenous communities, for conservation efforts initiated by WWF. (Photo by Kelsang Norbu, WWF–China)



people's livelihoods in this region, as well as the millions of people who depend on freshwater downstream, WWF's Regional Initiative, Saving Wetlands Sky High, is working in 5 countries in the region: India, Nepal, Bhutan, Pakistan, and China. The Initiative is using a multistakeholder and multiscalar approach.

Responding to the reality of climate change impacts in this region, both on ecosystems and the people, WWF along with its technical partners—UNESCO–IHE

BOX 1: The Longbaotan Wetland: a nature reserve undergoing high dynamics

The Longbaotan Wetland is situated at the source of the Yangtze River in the southern part of Qinghai Province in China; it lies within the Longbao National Nature Reserve in Yushu Tibetan Autonomous Prefecture. The nature reserve is flanked by steep mountains on either side which extend like parallel lines, forming a 10-km-long and 3-km-wide ravine with traces of lakes on its surface.

Longbaotan and its surrounding pastures are important grazing sites for the livestock belonging to Tibetan herders in the area. About two decades ago, nomadic herders would move from place to place in a seasonal pattern to find grazing land. However, now herders have settled down in one place and are no longer nomadic. Recently, approximately 200 households settled down around the Longbaotan Wetland, using its meadows as their main grazing land.

The wetland is also religiously significant to the communities living around it. Each year a large number of Tibetans walk around it on a pilgrimage. They believe that the herbs found around the wetland cure diseases and that its water, from glacial melt, is provided by Buddha, offering a bath that purifies not only the body but also the soul.

http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00091.1
Downloaded From: https://complete.bioone.org/journals/Mountain-Research-and-Development on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Institute for Water Education and San Diego State University (SDSU)—undertook two studies. The first study aimed to understand the level of scientific information already available on high-altitude wetland systems worldwide, analyze it to discern the trends and patterns, and identify data gaps. The second study focused specifically on the hydrologic response of high-altitude wetlands to climate change. In addition to the two scientific studies, WWF also used the Climate Witness approach to record perceptions among local communities of the changes they have witnessed in various aspects of their environment and livelihoods.

The UNESCO-IHE study

The first review study conducted by UNESCO–IHE was structured to answer the following questions for each type of HAW:

1. What types of HAW have been reported in the scientific literature? What are the characteristics of these HAW?
2. What are the environmental factors that influence development of HAW?
3. What are their hydrological and hydraulic functions?
4. What ecosystem goods and services do they provide?
5. What are the possible threats to HAW ecosystems?
6. What are the effects of climate change on these ecosystems?
7. What knowledge gaps are related to these ecosystems?

The present article tries to summarize the key aspects of this review study. Most of the information presented here has been collated from this review.

The SDSU study

The second study by the San Diego State University has three components:

1. A review of hydrological functions of high-altitude wetlands with an emphasis on how they influence river flows;
2. A review of likely climate change impacts on high-altitude wetlands in the Himalaya, based on scenarios formulated by the Intergovernmental Panel of Climate Change (IPCC);
3. An analysis of how climate change will modify hydrological processes in one sample wetland, selected from the WWF project sites. In addition, an attempt will be made to identify and acquire from relevant institutions previously collected river flow data downstream of the sample wetland and to examine possible links between wetland and downstream hydrology.

This is work in progress, expected to be completed by September 2010.

Present status of information on HAWs in the Himalayan region

Wetlands are distributed throughout Tibet, Qinghai, and the west of Sichuan, where there are low air temperatures and little precipitation but sufficient sunshine. In Qinghai Province alone, the total area under wetlands is about 7 million ha, including about 4.4 million ha of salt lakes and 2.7 million ha of herb bogs. These wetlands are mostly inland or plateau wetlands. They are often located in river basin headwaters and represent diverse habitats such as lakes, springs, swamps, marshes, rivers, and alpine meadows, which support equally diverse ecosystem elements. These systems play an important role in capturing and retaining snow, ice melt and rainfall, and are capable of releasing water progressively. The total area of marsh and peat in Qinghai and Xizang provinces in 1999 was estimated at 4,420,635 ha.

The literature indicates that the most frequently studied types of wetland in areas above 3000 m in the Himalayas and Qinghai–Tibetan Plateau are lakes and ponds, meadows, marshes, swamps, bogs, and fens.

Meadows

Meadows are one of the most studied ecosystems among HAWs in the Himalayas and the Qinghai–Tibetan Plateau. The alpine meadow ecosystem is also the most widespread ecosystem on the Qinghai–Tibetan Plateau, covering some 450,000 km^2. *Kobresia* is one of the main vegetation types. Himalaya and Tibetan meadows are rich in biodiversity. For instance, the Qinghai–Tibetan Plateau is a unique and fragile ecosystem with more than 13,000 vascular plant species and about 1100 species of terrestrial vertebrates. Alpine meadows in the Himalayas and Qinghai–Tibetan Plateau have the following characteristics:

1. They are located at altitudes above 3000 m, between forest border and permanent snowline (ie roughly between 3000 and 5200 m, rarely higher);
2. They remain frozen for 6 to 11 months each year;
3. They have great water retention capability due to the existence of a permafrost layer and therefore are usually the source of rivers;
4. They feature no woody vegetation, only herbaceous meadows and dwarf shrubs. The biodiversity is generally very low but unique and endemic. A decrease in species richness with increasing elevation and decreasing temperature results in simple composition of shrubs and grasslands, with endemic and subendemic plants; and
5. They are fed by precipitation, snowmelt water, glacier meltwater or permafrost melt.

Meadows are usually located in the river source areas. It is acknowledged that these ecosystems are important for surface water provision for the major international rivers that originate on the Qinghai–Tibetan plateau, and that these ecosystems provide a

http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00091.1
Downloaded From: https://complete.bioone.org/journals/Mountain-Research-and-Development on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

FIGURE 3 High-altitude lake and wetland in Ladakh. (Photo by Pankaj Chandan, WWF–India)



habitat for many medicinal plants that are being increasingly used for commercial purposes. In addition, due to their scenic beauty, these areas are often locations for tourism development. Therefore, there is no doubt that alpine meadows provide many ecosystem goods and services, not only locally but also on the national and international scales. However, alpine meadows are facing severe degradation due to climate change (rising temperature), which leads to:

- Permafrost degradation, which results in reduced soil moisture content during the growing season;
- Glacier melt and snowmelt, which alter water inflow patterns; and
- Vegetation cover change, due to reduced soil moisture content.

In addition, these ecosystems also suffer from human interference, such as agriculture and tourism development, and increased grazing activity. This results in degraded water resources in these areas, often with transboundary effects.

Unfortunately, not many baseline studies have been done until now. In order to understand these ecosystems better, as well as to predict future disturbance effects, such studies are urgently needed. The literature review has revealed that, in terms of vegetation cover and change as well as greenhouse gas emissions, sufficient data can be found. However, for hydrology, hydrological functions, and water resources, detailed data were not found. Therefore, it is reasonable to assume that these data are missing and that an effort has to be made to collect and systematize it. Nonetheless, it is possible that the above data are available in Chinese; therefore, close cooperation is recommended with Chinese and Japanese scientific institutes.

Lakes and ponds

These ecosystems are usually located in river source areas. It is generally recognized that high-altitude lakes are very important for water availability in downstream rivers. These lakes are mostly fed by precipitation, glacier meltwater, permafrost meltwater, snowmelt water, and icefield meltwater. Most high-altitude lakes are nutrient poor, with poor ecosystem productivity.

The general characteristics of high-altitude lakes can be defined as:

http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00091.1
Downloaded From: https://complete.bioone.org/journals/Mountain-Research-and-Development on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

FIGURE 4 An endangered black-necked crane (*Grus nigricollis*) tending its eggs on the shore of a Ladakh high-altitude lake. (Photo by Pankaj Chandan, WWF–India)



1. Strong temperature variation during the day;
2. The salinity in lakes and ponds varies from freshwater to salt lakes and ponds, and is mostly related to bedrock type and soil composition, outlet existence, and evaporation;
3. Cold and relatively nutrient poor;
4. High intensity solar radiation;
5. Ponds and lakes can have vertical mixing of the water column.

These lakes can be saline or freshwater. In addition, due to their scenic beauty (Figure 3), these areas are often locations for tourism development. Like alpine meadows, high-altitude lakes undoubtedly provide many ecosystem goods and services, not only locally but on national and international scales as well.

High-altitude lakes are facing severe degradation due to climate change (temperature rising) which leads to:

- Permafrost degradation, resulting in declining lake water level;
- Glacier disappearance, which alters water inflow patterns and can reduce water level in the lake; and
- Desertification and soil erosion, which may increase the sedimentation rate in lakes.

In addition, these ecosystems also suffer from human interference such as agriculture and grazing activity. This results in degradation of water resources, often with international effects.

Unfortunately, many baseline data are missing. In order to understand these ecosystems better, as well as to predict future disturbance effects, baseline studies are urgently needed. Close cooperation with institutions that have been involved in high-altitude lakes research is strongly recommended. Among others, these include: Ramsar, the International Centre for Integrated Mountain Development (ICIMOD), the Pallanza Institute in Italy, and the Geo-environmental Monitoring Institute of Tibet Autonomous Region.

Peatlands (swamps, marshes, bogs, and fens)

Peat is a spongy type deposit which consists of organic matter with varying degrees of decomposition. The main component in peat is plant organic matter, which accounts for more than 30% of the total content of peat in general. Numerous studies have shown that the accumulation and distribution of peat depends on several factors, such as climate, geography, landform, hydrology, and vegetation. Among these factors, climate is considered to be the most dominant. At high altitudes, lower temperatures not only make evaporation and transpiration processes slower, favoring water retention and moss formation: they also decrease the decomposition process, which favors the accumulation of organic matter and peat formation. Many types of wetlands belong to peatlands, eg swamps, marshes, bogs, and fens (or grasslands). All of these wetlands have one characteristic in common, which is that the peat is widespread and well developed within the wetland.

In general, swamps and marshes are located in the headwater regions of river basins, in flat bottom land, usually in the vicinity of lakes and ponds. Another common characteristic is that these ecosystems are biodiversity hotspots. Zoige Marsh is one biodiversity hotspot in China; it harbors many endemic and endangered species, including *Grus nigricollis*, the only plateau crane (Figure 4). Numerous species are endemic to Zoige Marsh, such as *Caltha scaposa*, *Kobresia tibetica Maxim*, *Carex muliensis*, and *Blysmus sinocompressu*s. Many species are becoming rare and endangered. For instance, *Sinocarum coloratum*, *Scrophularia chinensis*, *Scrophularia*

Downloaded From: https://complete.bioone.org/journals/Mountain-Research-and-Development on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

chinensis and *Rheum palmatum* have been listed as endangered species by the Environmental Protection Agency of China. Zoige Marsh is very rich in animal resources. There are 38 mammal species belonging to 15 families of 5 orders, and 137 bird species belonging to 28 families in 13 orders.

Due to the abundance of vegetation, the swamps and marshes are often exposed to overgrazing, which is the main economic activity of local people. Climate change is recognized as the main threat to swamp ecosystems on the Qinghai–Tibetan plateau. Ruoergai Bog, the largest plateau bog in China, is located in the eastern part of the Qinghai–Tibet plateau at an altitude of over 3390 m. Herbaceous plants dominated by *Kobresia tibetica* cover the entire bog at present and have also been the source of organic matter for peat. There are only a few conifers in the surrounding mountains. The peat area covers up to 6400 km^2 and its thickness ranges from several meters to over 10 meters. Microbial activity is likely to be the dominant process in this bog.

Many detailed quantitative baseline studies are missing for high-altitude bogs. Long-term observations of hydrological processes in high-altitude bogs are generally lacking worldwide.

Climate change and the hydrologic response of high-altitude wetlands

The general conclusion of the SDSU study is that wetlands will likely change as climate continues to change and glaciers continue to melt.

Wetlands are often thought to increase dry season flow and decrease flood peaks. Contrary to expectation, most studies surveyed found that wetlands *decreased* dry season discharge downstream due to high evaporation rates from open water surfaces. A majority of studies found that wetlands mitigate flood peaks by increasing the storage capacity of the landscape.

Several global circulation models (GCMs) predict that both temperature and precipitation will increase in the Himalayas through 2100. Direct warming of lake water alters circulation patterns in lakes, with consequent impacts on wetland biogeochemistry and ecosystem functioning. Several studies in the Himalayas have documented rapid expansion of high-altitude lakes at the base of glaciers due to enhanced melting rates. The effect of increased glacial melt has not been documented for larger lakes such as the Ramsar sites in the Ladakh region of India. There may be a shift towards more rain and less snowfall, with consequently higher floods. Dry season discharge in the Himalaya could actually increase under a warmer climate, as most snowfall occurs during the winter months when streamflow is low. Evapotranspiration from both watersheds and wetlands is projected to increase, which could decrease streamflow, particularly in the wet season. Wetlands will potentially experience shifts in storage levels and evapotranspiration, which will likely change the timing and magnitude of discharge downstream. In the Himalayas, a great deal of uncertainty surrounds the quantification of the hydrological response of high-altitude wetlands to projected climate change scenarios.

Owing to the influence of climate change, obvious changes have occurred in the permafrost on the Qinghai–Tibet Plateau. The permafrost area has significantly decreased. The normal growth and reproduction of vegetation has been seriously affected because the degradation of the permafrost results in soil moisture decreasing in the root zone, surface soil desiccation, swamps drying up, and changes in soil structure and composition. If these disturbances occur in areas of rivers, lakes, glaciers, and permanent snow cover, they will directly lead to water source dysfunctionality. Table 2 shows the effect of climate change on different land types, land cover, and water bodies.

Land desertification is developing rapidly. Desertified land in the source region of the Yellow River is expanding at an annual rate of 1.83%. Most authors agree that this negatively influences and reduces the availability of water resources. However, no detailed studies that would explain the mechanism of this problem were found.

One hydrological model used to estimate the effects of climate change predicted a summer temperature increase of 4.5°C and a winter temperature increase of 4.8°C for 2071–2100. It also estimated that precipitation will increase by 15.7% in summer and 19.7% in winter. Based on these results, it was concluded that the effects of climate change on streamflow are significant. The following phenomena are observed:

- The part of the precipitation that falls as snow is reduced from 60% to 48%.
- Due to the increase in overall precipitation, the annual runoff from snowmelt remains nearly the same. However the peak snowfalls appear approximately one month earlier and discharge is more distributed in time.
- Although the extent of glaciers has been assumed to decrease by 50%, total glacial runoff has been reduced by only 22%, and the temporal pattern remains unchanged. The difference between the extent of glacier decrease and glacier runoff can be explained by increased albedo temperatures, which intensify water evaporation.
- Rainfall runoff has increased significantly by 53%, and rain peak discharge remains concentrated in June–July–August.
- Total streamflow has increased by 7%.

http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00091.1
Downloaded From: https://complete.bioone.org/journals/Mountain-Research-and-Development on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

FIGURE 5 A group of local people discussing conservation issues on the banks of Chandratal Lake, Himachal Pradesh, India. (Photo courtesy of WWF–India)



Lakes, permafrost and wetlands play a great role in regulating lateral flow of rivers. The increased air temperature results in earlier melting of the frozen soil and increased soil evaporation. This results in a decline in the groundwater table and water levels of the lakes, which reduces water supply of baseflows from groundwater and lake water. The water resources in the region declined between 1956 and 2004 due to the above changes. In addition, in some parts of the Yellow River, sources were converted from grassland to cropland, which adds to the problem.

Several patterns of climate change can be observed on the Qinghai–Tibetan plateau:

- *Pattern 1: Air temperature shows no change while rainfall increases*
  This pattern is observed in Changdu County in eastern Tibet.
- *Pattern 2: Air temperature shows no change while rainfall decreases*
  This pattern is observed in Bomi County in the Great Canyon Region along the Brahmaputra River.
- *Pattern 3: Both air temperature and rainfall increase*
  This pattern is observed in Lhasa City and in the Brahmaputra River valley.
- *Pattern 4: Air temperature increases while rainfall decreases*
  This pattern is observed in Nielamu County in the southern hillside region of the Himalayas.

Conclusions and recommendations

Based on the above results, it can be concluded that no general pattern of climate change on the Qinghai–Tibetan plateau can be established due to temporal and spatial variations. Projecting spatial and temporal estimates of future flow rates into wetlands, the response of wetland water levels to changing inflows, and the ecological consequences of the changes in the wetlands are essential for communities, conservationists, and water resource managers. These have also been identified as the major knowledge gap areas in the review. Modeling studies on selected high-altitude wetlands to determine their hydrologic response to climate change have begun and are expected to yield important trends that could help put HAWs and the services they provide on the agenda of policymakers.

Some of the recommendations emerging from these studies are:

1. **Given the key hydrological role played by HAWs in headwaters and their importance in carbon**

http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00091.1
Downloaded From: https://complete.bioone.org/journals/Mountain-Research-and-Development on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

sequestration, conservation and management of these ecosystems could be a sound approach within the wider Adaptation Strategy for these vulnerable regions.

2. **HAWs are important for keeping rivers flowing.** Although detailed scientific data were not found on this point, most authors have emphasized the importance of HAW ecosystems for provision of water for the downstream areas of river basins, more so under climate change scenarios.
3. **Comprehensive and detailed quantitative baseline studies are needed for each HAW type.** Without such basic studies it will not be possible to estimate the value of HAWs and their ecosystem goods and services, nor the disturbance effects on HAWs. Among other things, there is an urgent need to obtain the following information:

- *Basic detailed quantitative hydrological studies*: It is important to understand hydrological processes in HAW ecosystems in order to estimate the freshwater provision function of these ecosystems, as well as possible effects of climate change. Among other things, the most important priority is to understand the water retention rate of HAWs and the factors that influence this rate.
- *Comprehensive detailed database of HAW biodiversity*: This represents one of the basic requirements for information about HAW ecosystems. It is important to record biodiversity for each HAW type in order to be able to develop sustainable conservation management plans as well as to estimate the loss of biodiversity due to different disturbances in future.
- *Detailed studies on ecosystem goods and services of HAWs*: These studies are important to estimate the value of HAWs and their influence on downstream areas of the catchments. Understanding the role of HAWs in freshwater provision for downstream areas is a priority. It is often reported that HAWs, especially in the Andes and Qinghai–Tibetan Plateau, provide freshwater for numerous downstream users and often for big cities and large irrigation schemes as well. However, very little information was found about factors that influence this freshwater provision. The reaction of HAW systems to disturbances in the future is, at this point, very difficult to estimate.

4. **Lack of scientific data will not impede the continuation of conservation efforts.** Along with global warming, human activities in HAW areas cause major damage to these ecosystems. Therefore, further efforts will be directed at preventing and restricting these activities in HAW areas.
5. **Closer cooperation with different national and international institutions, universities, and NGOs is strongly recommended to strengthen the scientific base.** It is noticeable that monitoring data at high altitudes are either missing or not available in English but in Chinese. Therefore, it is recommended to strengthen cooperation with different Chinese governmental and educational institutions involved in data collection or HAW monitoring programs. In addition, close cooperation with different international institutions at different levels, such as the Millennium Ecosystem Assessment, Ramsar, ICIMOD, IUCN–The Conservation Union, and Wetlands International is also recommended in order to develop and maintain a comprehensive HAW database.

WWF's current HAW agenda

Through the review studies presented in this paper, WWF has attempted to bring together existing information on these lesser understood ecosystems, while also highlighting critical knowledge gaps in one of the most vulnerable ecosystems. Expanding scientific research and the knowledge base on high-altitude wetlands and their interplay with climate and other drivers of change is an urgent need for the conservation, management, and delivery of ecosystem goods and services, as well as to guide policies and programs at national and regional levels.

A regional collaborative research program focusing on HAWs is critical and should be taken up as a priority. WWF can play a facilitating role for organizations and research institutes to come together and work on this important gap area (Figure 5). The research agenda for HAWs is broad, and as results become available it should be possible to manage these systems better. HAWs are our water banks for the future, so the sooner we understand their intricate processes, the better off we will be. Investment in research on these ecosystems is thus critical.

One of the aims of the coming years for the WWF initiative is to put the value of high-altitude wetlands as water towers on the agenda of policymakers and bring them to the attention of the wider public. Valuing the services of HAWs, including their role in adaptation to climate change, is an important aspect of this work. It can be achieved by identifying and applying the lessons from the various field programs as well as by reaching out to various stakeholders, among which are governments and sectors that depend on these ecosystems.

REFERENCES

Biggs TW*, *Beland M. 2009. *Hydrologic Functions and the Effects of Climate Change on Himalayan Wetlands*. Unpublished manuscript. Available from the author of the present paper.

Jacimovic R, et al. 2009. *Hydrological and Ecological Value of Water Towers and Their Role in Adapting Climate Change*. Zeist, The Netherlands:

http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00091.1
Downloaded From: https://complete.bioone.org/journals/Mountain-Research-and-Development on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use

WWF Netherlands and Institute for Water Education (UNESCO-IHE).
Qian J, ***Wang G***, ***Ding Y***, ***Liu S***. 2006. The land ecological evalutional patterns in the source areas of the Yangtze and Yellow rivers in the past 15 years, China. *Environmental Monitoring and Assessment* 116:137–156.
Wang G, ***Li S***, ***Hu H***, ***Li Y***. 2009. Water regime shifts in the active soil layer of the Qinghai–Tibet et Plateau permafrost region, under different levels of vegetation. *Geoderma* 149: 280–289.
Wang G, ***Li Y***, ***Wang Y***, ***Wu Q***. 2008. Effects of permafrost thawing on vegetation and soil carbon pool losses on the Qinghai–Tibet Plateau, China. *Geoderma* 143:143–152.
Wang G, ***Wang Y***, ***Jumpei K***. 2006. Land-cover changes and its impacts on ecological variables in the headwaters area of the Yangtze River, China. *Environmental Monitoring and Assessment* 120 (1–3):361–385.
Wang H, ***Zhou XL***, ***Wan CG***, ***Fu H***, ***Zhang F***, ***Ren JZ***. 2008. Eco-environmental degradation in the northeastern margin of the Qinghai–Tibetan Plateau and comprehensive ecological protection planning. *Environmental Geology* 55:1135–1147.

AUTHORS

Archna Chatterjee
AChatterjee@wwfindia.net
Compiler of the present article and corresponding author, Head,
Regional Program on Himalayan Glaciers, Rivers and High-altitude Wetlands, WWF–India, 172-B, Lodi Estate,
New Delhi–110003, India.
Tel: +91-11-43516202
www.wwfindia.org

Review and inputs from:
Esther Blom
Head, Freshwater, WWF Netherlands, Zeist, The Netherlands.
www.wnf.nl

Biksham Gujja
Advisor, WWF International, Gland, Switzerland.
www.wwf.org

Technical Study partners:
Ruzica Jacimovic, Lindsay Beevers, Jay O'Keeffe
Hydrological and ecological value of water towers and their role in adapting to climate change: A review. UNESCO–IHE Institute for Water Education, Delft, The Netherlands.
Michael Beland, Trent Biggs
Hydrological functions and the effects of climate change on high-altitude wetlands. Department of Geography, San Diego State University (SDSU), San Diego, CA, USA.

Open access article: please credit the authors and the full source.

Downloaded From: https://complete.bioone.org/journals/Mountain-Research-and-Development on 28 Mar 2024
Terms of Use: https://complete.bioone.org/terms-of-use