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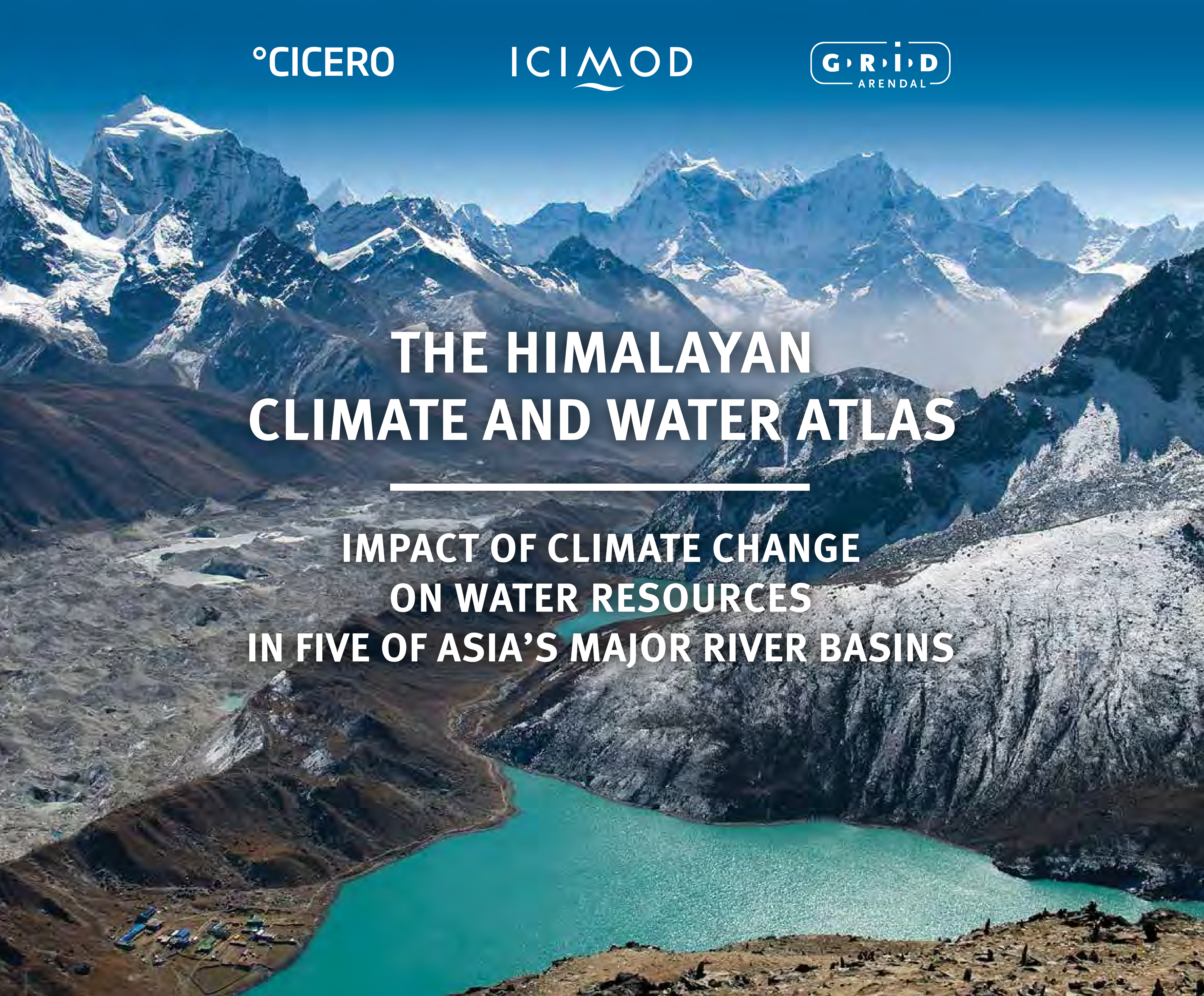

THE HIMALAYAN CLIMATE AND WATER ATLAS

IMPACT OF CLIMATE CHANGE ON WATER RESOURCES IN FIVE OF ASIA'S MAJOR RIVER BASINS

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This Atlas was developed as part of the Himalayan Climate Change Adaptation Programme (HICAP). HICAP is implemented jointly by the International Centre for Integrated Mountain Development (ICIMOD), GRID-Arendal and the Centre for International Climate and Environmental Research-Oslo (CICERO), in collaboration with local partners, and is funded by the governments of Norway and Sweden.

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This Atlas is based on four years of scientific research by HICAP across the HKH region. Most of the work presented in this Atlas results from this research. Any other scientific data given in this book is referenced accordingly. Non-referenced data can be assumed to be derived from the HICAP studies results.

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Preface

The Hindu Kush Himalayas (HKH) is a crucially important region for South Asia and China. These mountains are the 'Water Towers of Asia', providing water to 1.3 billion people. However, the warming trend in the HKH is higher than the global average – a cause for grave concern. There is no other place in the world where so many people are being affected by climate change so rapidly.

The Government of Norway has long recognized the need to support and strengthen knowledge about climate change and its likely impacts in the region, as well as focusing on adaptation and transboundary cooperation. At the sixteenth Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Cancun, Mexico in 2010, we announced multi-year support to the Himalayan Climate Change Adaptation Programme (HICAP). HICAP is an inter-disciplinary programme that seeks to understand climate change and its impact on people in the region, and provide adaptation options and solutions to policy makers, practitioners and local communities. It is led by the International Centre for Integrated Mountain Development (ICIMOD), GRID-Arendal, and the Centre for International Climate and Environmental Research-Oslo (CICERO). One of the main goals of HICAP has been to enhance regional knowledge and understanding of climate change and its impact on the region's precious water resources – now and into the future.

We are proud to see that new knowledge on this topic has been generated and visualized through this Himalayan Climate and Water Atlas, in which high quality scientific knowledge has been made available in simple graphics and language for policy makers and the general public. The findings presented in the Atlas provide the first comprehensive, regional understanding of past climate trends, as well as possible future projections up until 2050. These will be invaluable in informing governments of the adaptation measures that need to be taken in the region to address new climate realities.

Mountains and their importance as water towers for the world should be higher on the global climate change agenda. We are confident that the Himalayan Climate and Water Atlas will help raise the visibility of mountains in the global climate change discourse.

Børge Brende
Minister of Foreign Affairs, Norway

Foreword

Freshwater is the most important resource for mankind and is essential for human health, prosperity and security. In South Asia and China, about 1.5 billion people depend either directly or in-directly on water flowing down from the Hindu Kush Himalayas.

Globally, water resources are facing increasing pressure from climate change and other global drivers. The extent to which changes in climate will affect these 'Water Towers of Asia' has been a question of key importance for scientists and governments in the region. Despite being one of the most populous, disaster-prone and vulnerable regions in the world, our knowledge of the region's climate is limited and scattered.

One of the main goals of the Himalayan Climate Change Adaptation Programme (HICAP) has been to increase our understanding of the region's climate and its impact on water resources, and make this knowledge relevant to local actors and decision makers for adaptation planning. This Atlas is an important part of this goal. Through the use of various maps and infographics, this Atlas describes recent changes in climate and hydrology and possible future impacts in five of the most important river basins of the Hindu-Kush Himalayas – the Indus, Brahmaputra, Ganges, Salween and Mekong.

The findings underline that the region's climate has been changing fast and will continue to do so in the future. Temperatures have risen faster than the global average, and further warming can be expected even under a low emissions scenario, especially at higher altitudes and during the winter season. Glaciers in the region will lose considerable mass in the 21st century. Precipitation across the region could change by up to 25%, increasing in some areas whilst decreasing in others. For middle hill and mountain communities that lie far above streams and rivers, water availability may change drastically.

Although the total amount of water flowing within some of Asia's biggest rivers such as the Ganges, Brahmaputra and Indus is not expected to decrease until 2050, we can expect higher variability and more floods and droughts. Extreme rainfall events are projected to become more intense, increasing the risk of catastrophic flooding events.

We are entering a more uncertain water future, and the impacts of change depend on the vulnerability and measures taken to secure water availability for all. The research presented in this Atlas can help inform and prepare decision-makers and governments. Our key message is that governments and people within the region need to be flexible in order to deal with increased variability and to meet the challenges posed by either too little, or too much, water.

David Molden, ICIMOD

Kristin Halvorsen, CICERO

Peter Harris, GRID-Arendal

Key messages

Temperatures across the mountainous Hindu Kush Himalayan region will increase by about 1–2°C (in places by up to 4–5°C) by 2050.

Studies conducted so far indicate that the mountainous Hindu Kush Himalayas (HKH) are warming significantly faster than the global average. By 2050, temperatures across the five basins studied are projected to increase by about 1–2°C on average, with winters seeing greater warming than summers in most places, and temperature extremes also becoming more frequent. Mountainous and high altitude areas are particularly affected, with warming reaching 4–5°C in some places, with some variation observed across the region.

Precipitation across the Hindu Kush Himalayan region will change by 5% on average and up to 25% by 2050.

Precipitation is projected to change, but with no uniform trend across the region. Summer precipitation in the Ganges, upper Salween and upper Mekong basins is projected to increase, while the trends are mixed in the Brahmaputra and Indus basins. Although highly uncertain, increases of 5% on average across the HKH, and up to 25% in some areas, are projected. Winter precipitation is projected to increase in the Upper Salween and Mekong basins, while for the other three basins there will be mixed trends, with most areas receiving less precipitation.

The monsoon is expected to become longer and more erratic.

Overall, precipitation in the HKH is likely to increase slightly in the 21st century with the monsoon season expected to lengthen, starting earlier and ending later, and with more erratic precipitation within the season posing more water resource challenges to communities and disaster risk managers.

Extreme rainfall events are becoming less frequent, but more intense and are likely to keep increasing in intensity.

Over the past decades, the amount of rainfall in the HKH has not shown a significant trend overall, although spatial and temporal variations have been observed. Increased monsoon precipitation is being observed over the high mountain belt of the Himalayas, particularly in the east, while the greatest decrease in monsoon rainfall has been observed in the south within the Ganges and Indus basins. There also appears to be a decreasing trend in the number of extreme rainfall events, although their intensity is increasing. More water is falling during each event. In the future, extremes in precipitation are likely to keep increasing in intensity (both negative and positive), exposing already-vulnerable populations to further risk of floods and droughts.

Glaciers will continue to suffer substantial mass loss, the main loss being in the Indus basin.

Substantial glacial mass and area losses are projected in the coming decades for most parts of the HKH.[1] The highest relative loss is projected for glaciers within the Mekong river basin (–39 to –68%), and the lowest in the Indus river basin (–20 to –28%).[2] However, the highest quantity of ice will be lost from the Indus because of its large glaciated area. Warmer temperatures will also cause more precipitation to fall as rain than snow, resulting in melting ice not being replenished.

Through to 2050, no decreases in annual volumes of water are projected.

Overall, runoff within the river basins will not decrease until at least 2050. An increase is even projected for the upper Ganges (1 to 27%), Brahmaputra (0 to 13%) and Mekong (2 to 20%) basins. Increasing precipitation is the main driver of this change, first combined with increased glacial melt, and eventually compensating for decreased contributions of glacial and snow melt. Runoff projections are mixed for the upper Indus (–5 to +12%) and upper Salween (–3 to +19%) basins. The projections also suggest that overall, significant seasonal shifts in flow will not occur by 2050. However, changes in spatial distribution may be significant, leading to high impacts in certain locations.

More floods and droughts are expected.

Despite overall greater river flow projected within the basins of the HKH, higher variability in river flows and more water in pre-monsoon months are expected, which will lead to a higher incidence of unexpected floods and droughts. This will greatly impact on the livelihood security and agriculture of river-dependent people.

Communities living immediately downstream from glaciers are most vulnerable to glacial changes.

Mountain people are particularly affected by changes in glaciers through reduced reliability of local water resources and increased occurrence of hazards including glacial lake outburst floods.

The contribution of various water sources to river flow will change.

In response to changing precipitation and temperature patterns, the relative contribution of different sources of water – glacial melt, snow melt, rainfall, and baseflow – to river flow will change, with consequences for water management practices.

Changes in temperature and precipitation will have serious and far-reaching consequences for climate-dependent sectors, such as agriculture, water resources and health.

Agriculture is by far the most important source of livelihood for rural communities, and is tightly linked to both the availability of water and temperature.

Policy recommendations

1. Implement flexible and diverse solutions to address the high level of uncertainty.

Solutions and adaptation measures will have to take into account the overall expected changes as well as the spatial variations and uncertainties in changes. For example, farming systems urgently need restructuring towards higher flexibility so that they can withstand the increased flood risk, lower water availability and other impacts of climate change. As migration, mainly of men, is increasing, it is necessary to develop more gender-sensitive farming approaches while strengthening education and building effective networks for knowledge sharing.

2. Implement structural and non-structural measures to adequately prepare for and manage extreme events.

While the number of extreme events is projected to decrease, the intensity of precipitation events is likely to increase and result in more severe damage to lives and property. Structural measures (such as flood prevention structures) and non-structural measures (such as the implementation and enforcement of building codes, land use planning laws or early-warning systems) are needed to reduce exposure, vulnerability and risks for populations, as well as to adequately manage disaster events if they occur.

3. Strengthen modelling approaches to further reduce uncertainty and undertake research to fill critical gaps.

Climate models are not able to sufficiently capture the sharp horizontal and vertical gradients of biophysical processes in the region. Efforts to improve the models through increasing spatial resolution as well as incorporating more mountain-specific physical processes in the models are essential. Further research is required to understand the factors that impact on the functioning of springs (a major source of water in the mid-hills) and to implement measures to improve the functioning of springs.

4. Improve regional coordination and sharing of data.

Much of the uncertainties in the scientific results stem from the fact that climate monitoring in the HKH region is inadequate, particularly in high altitude areas. There is a strong need for a coordinated regional effort to improve hydrometeorological monitoring in the region and data sharing within institutions. Innovative ways of combining in-situ measurements, remote sensing based measurements and modelling approaches should be undertaken to fill the data gaps.

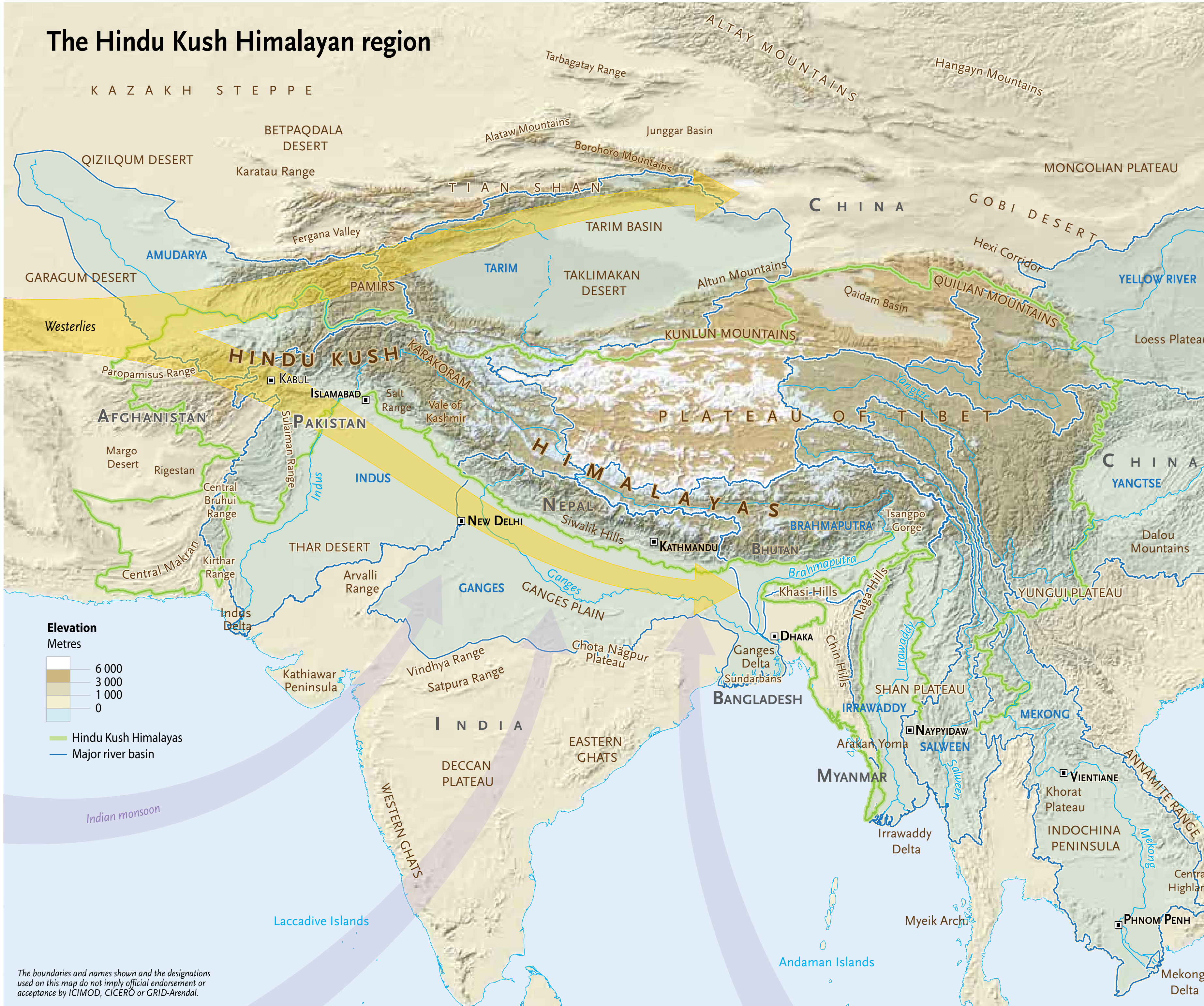
5. Adopt a river basin approach to protect Himalayan ecosystems to harness the potential of water resources.

Although the total amount of water resources in the HKH may stay roughly the same as present day, they will need to be managed more effectively as demand will undoubtedly increase in the future to meet increasing energy and water-intensive food production needs. Within the region, there exists a high dependency of downstream communities and countries on upstream ecosystem services, particularly for water in the dry-season,[3] and the benefits of sustainable watershed management transcend national boundaries. At the same time, integrated planning and management between sectors, such as water, energy, land, forest, ecosystems and agriculture, is needed to enhance resource use efficiency and reduce environmental impacts.

6. Put mountains on the global climate change agenda.

Globally, mountains provide 60–80% of the world's fresh water. The HKH mountains, home to some of the largest rivers in the world, directly provide water and other services to over 1.3 billion people living within the region and downstream. While water is recognized as one the central issues in the global climate change discourse, the interlinkage between water and mountains is yet to be established as a global priority agenda. Therefore, putting mountains on the global agenda would be in the interest of not only mountain communities, but also the global community.

WATER AND CLIMATE IN THE HKH



The Hindu Kush Himalayan region
KAZAKH STEPPE
BETPAQDALA DESERT
QIZILQUM DESERT
Karatau Range
Tarbagatay Range
ALTAY MOUNTAINS
Hangayn Mountains
Alataw Mountains
Junggar Basin
Borohoro Mountains
TIAN SHAN
MONGOLIAN PLATEAU
CHINA
GOBI DESERT
TARIM BASIN
Fergana Valley
AMUDARYA
GARAGUM DESERT
PAMIRS
TARIM
TAKLIMAKAN DESERT
Altun Mountains
Hexi Corridor
QUILIAN MOUNTAINS
Qaidam Basin
YELLOW RIVER
Westerlies
HINDU KUSH
KUNLUN MOUNTAINS
Loess Plateau
KARAKORAM
Paropamisus Range
KABUL
ISLAMABAD
Salt Range
Vale of Kashmir
Yangtze
AFGHANISTAN
PAKISTAN
PLATEAU OF TIBET
Margo Desert
Rigestan
Sulaiman Range
HIMALAYAS
CHINA
YANGTSE
INDUS
Indus
Central Bruhui Range
NEPAL
Tsangpo Gorge
BRAHMAPUTRA
NEW DELHI
Siwalik Hills
KATHMANDU
BHUTAN
Dalou Mountains
THAR DESERT
Central Makran
Kirthar Range
Brahmaputra
Arvalli Range
GANGES
Ganges
GANGES PLAIN
Khasi Hills
Naga Hills
YUNGUI PLATEAU
Indus Delta
Elevation
Metres
6 000
3 000
1 000
0
Hindu Kush Himalayas
Major river basin
DHAKA
Chota Nagpur Plateau
Vindhya Range
Satpura Range
Kathiawar Peninsula
Ganges Delta
Sundarbans
Chin Hills
Irrawaddy
SHAN PLATEAU
BANGLADESH
IRRAWADDY
MEKONG
INDIA
EASTERN GHATS
NAYPYIDAW
Arakan Yoma
SALWEEN
Salween
DECCAN PLATEAU
MYANMAR
VIENTIANE
ANNAMITE RANGE
Khorat Plateau
WESTERN GHATS
Indian monsoon
Irrawaddy Delta
INDOCHINA PENINSULA
Mekong
Central Highlands
Laccadive Islands
Myeik Arch.
PHNOM PENH
Andaman Islands
Mekong Delta
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by ICIMOD, CICERO or GRID-Arendal.

Introduction

The Hindu Kush Himalayas (HKH) are the freshwater towers of South Asia and parts of Southeast Asia. Water originating from their snow, glaciers and rainfall feed the ten largest river systems in Asia. Together these rivers support the drinking water, irrigation, energy, industry and sanitation needs of 1.3 billion people living in the mountains and downstream.[4]

This valuable resource is under increasing threat. Along with a rapidly increasing population which is placing greater demands on water resources, climate change is affecting water availability throughout the HKH and beyond. The Hindu Kush Himalayas are warming about three times faster than the global average.[5] Glacier behaviour across the region varies greatly, but most glaciers are retreating.[6] Many human activities, most notably agriculture, are timed with the seasonal flows of water and predictable cycles of rain. However, as the region warms, the hydrological (water) cycle becomes more unpredictable, at times with too much or too little water. The effects on people, communities and ecosystems can be devastating with the most visible impacts including catastrophic floods, landslides and droughts.

Exacerbating the situation is the fact that this region contains some of the poorest populations in the world. Their ability to adapt to changes in climate and water availability is severely limited. Women, children and the elderly – already marginalized social groups – are particularly vulnerable.

Knowledge is an essential ingredient in building more resilient communities and populations. We need to understand the nature of the changes occurring in order to develop the tools to adapt to these changes. While many uncertainties remain regarding our understanding of the impacts of climate change on the water resources of the HKH, this Atlas and the research behind it enhances our understanding of both past, present and possible future changes to climate and water resources across this important region.

This Atlas is based on data from five of the ten main river basins in the Hindu Kush Himalayan region: the Brahmaputra, Ganges, Indus, Mekong and Salween. The data and maps presenting historical analyses of climate trends at the regional and basin scales, as well as future projections of water availability, are the result of HICAP research. Further details on the methods and data sets used are included towards the end of this Atlas, under **'Additional Information'**.

The Atlas is primarily intended for policy makers, practitioners and implementers, scientists and the donor community working on water-related issues in the region. It is also relevant to the broader public within and beyond the region.

This Atlas is organized according to the following:

'Key messages' delivers the main scientific findings on climate change and its impact on water resources derived from this report. This is followed by **'Policy recommendations'**, which presents a set of key policy recommendations, the implementation of which will allow governments and communities in the region to both prepare for, and adapt to, the changes to come.

'Water and climate in the HKH' highlights the complexity of the HKH region from a physical and human perspective. It focuses on the sources of water, how water is used, why it is important, and what knowledge gaps remain. The Himalayan Climate Change Adaptation Programme (HICAP) – through which most of the new science illustrated in this Atlas has been generated – is introduced.

'Climate change and its impact on water – past and current trends' presents trends in temperature, precipitation, and the occurrence and duration of extreme events for recent timescales (last 50 years), starting at the regional (HKH-wide) level and then moving down to the individual river basin level. Trends in glacial melt and the influence of black carbon (soot) on glacial melt is also discussed. The implications of the above changes for human societies and ecosystems in the region are highlighted through stories and case studies

'Climate change and its impact on water – future projections' charts the future of water and climate in the region with the use of cutting edge scenarios and projections. Changes in temperature, precipitation, glacial melt, river discharge and the contribution of different water sources (glaciers, snow melt and rainfall) are presented up to the year 2050.

In **'Meeting future water challenges'**, the long-term implications of these changes are examined, including possible solutions to water challenges.

Himalayan Climate Change Adaptation Programme (HICAP)

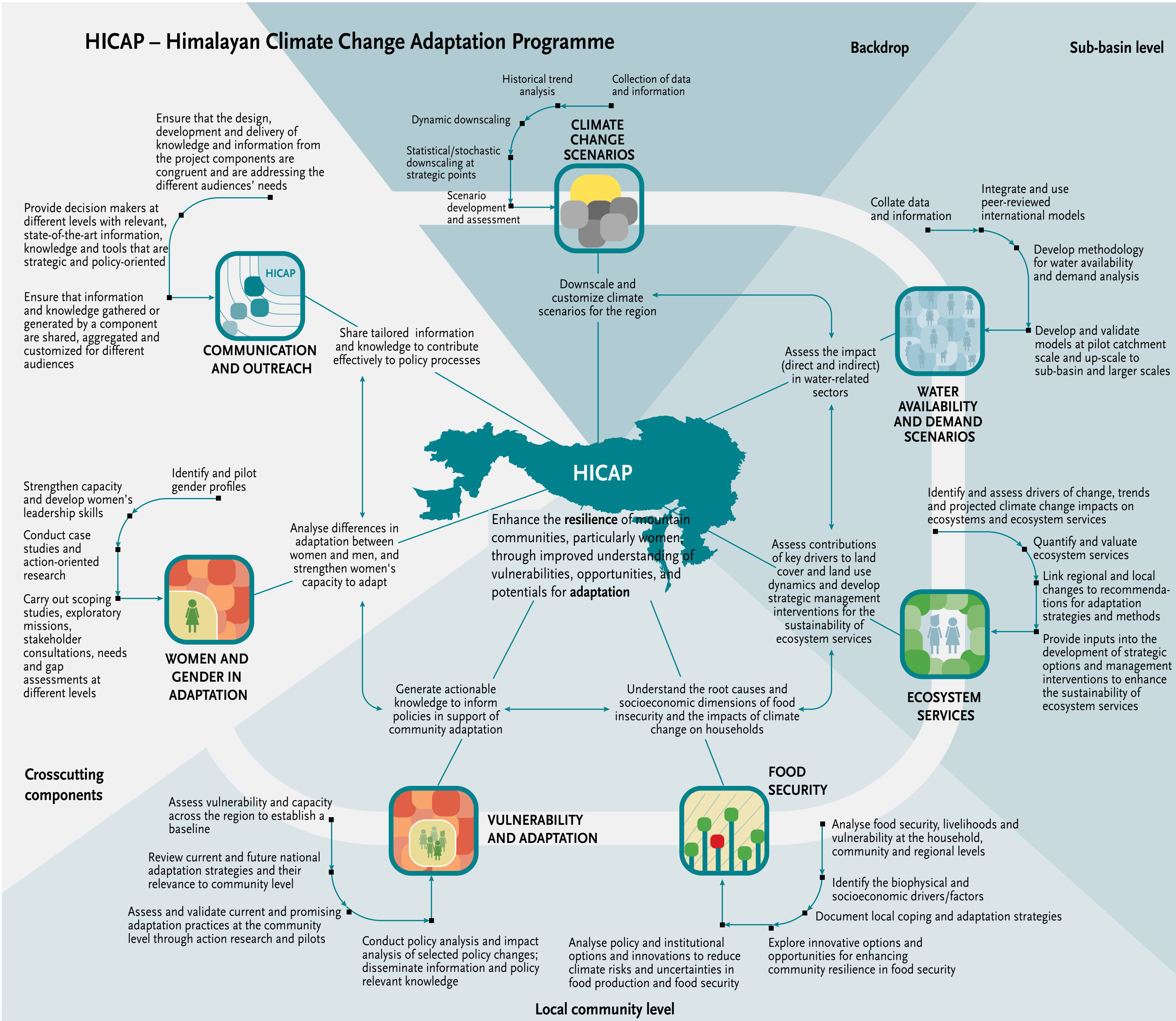
To help meet the challenges emerging in the Hindu Kush Himalayan region, a pioneering programme was created to address critical knowledge gaps on water, climate and hydrology, and thus better understand the future impacts of climate change on natural resources, ecosystem services and the communities depending on them. Since 2011, HICAP has been working in five major Himalayan river systems – the Brahmaputra, Indus, Ganges, Mekong and Salween – across six pilot sites.

Its interdisciplinary approach covers seven components:

- Climate change scenarios
- Water availability and demand scenarios
- Ecosystem services
- Food security
- Vulnerability and adaptation
- Gender and adaptation
- Communications and outreach

HICAP aims to enhance the resilience of mountain communities through improved understanding of vulnerabilities, opportunities and potentials for adaptation. The programme particularly focuses on women, who have strategic responsibilities in the region as stewards of natural and household resources, and who are also more vulnerable than men, as they face more social, economic and political barriers which limit their coping capacity. By making concrete and actionable proposals on strategies and policies (with particular reference to women and the poor) for uptake by stakeholders, including policy makers, HICAP aims at including enhanced adaptation at the highest levels of policy in a sustainable way.

This Atlas is the outcome of new research on climate change and water hydrology in the HKH region undertaken through HICAP. It summarizes the latest science and lessons learnt, in order to enable policy makers, practitioners and implementers working on water-related issues in the region to prepare for the changes to come and develop appropriate policies to support people's resilience.


HICAP – Himalayan Climate Change Adaptation Programme
Backdrop
Sub-basin level
Historical trend analysis
Collection of data and information
Dynamic downscaling
CLIMATE CHANGE SCENARIOS
Statistical/stochastic downscaling at strategic points
Scenario development and assessment
Downscale and customize climate scenarios for the region
Ensure that the design, development and delivery of knowledge and information from the project components are congruent and are addressing the different audiences' needs
Provide decision makers at different levels with relevant, state-of-the-art information, knowledge and tools that are strategic and policy-oriented
Ensure that information and knowledge gathered or generated by a component are shared, aggregated and customized for different audiences
HICAP
COMMUNICATION AND OUTREACH
Share tailored information and knowledge to contribute effectively to policy processes
Collate data and information
Integrate and use peer-reviewed international models
Develop methodology for water availability and demand analysis
Develop and validate models at pilot catchment scale and up-scale to sub-basin and larger scales
Assess the impact (direct and indirect) in water-related sectors
WATER AVAILABILITY AND DEMAND SCENARIOS
HICAP
Enhance the resilience of mountain communities, particularly women, through improved understanding of vulnerabilities, opportunities, and potentials for adaptation
Strengthen capacity and develop women's leadership skills
Identify and pilot gender profiles
Conduct case studies and action-oriented research
Carry out scoping studies, exploratory missions, stakeholder consultations, needs and gap assessments at different levels
WOMEN AND GENDER IN ADAPTATION
Analyse differences in adaptation between women and men, and strengthen women's capacity to adapt
Identify and assess drivers of change, trends and projected climate change impacts on ecosystems and ecosystem services
Quantify and valuate ecosystem services
Link regional and local changes to recommendations for adaptation strategies and methods
Provide inputs into the development of strategic options and management interventions to enhance the sustainability of ecosystem services
Assess contributions of key drivers to land cover and land use dynamics and develop strategic management interventions for the sustainability of ecosystem services
ECOSYSTEM SERVICES
Generate actionable knowledge to inform policies in support of community adaptation
Understand the root causes and socioeconomic dimensions of food insecurity and the impacts of climate change on households
Crosscutting components
Assess vulnerability and capacity across the region to establish a baseline
Review current and future national adaptation strategies and their relevance to community level
Assess and validate current and promising adaptation practices at the community level through action research and pilots
VULNERABILITY AND ADAPTATION
Conduct policy analysis and impact analysis of selected policy changes; disseminate information and policy relevant knowledge
FOOD SECURITY
Analyse food security, livelihoods and vulnerability at the household, community and regional levels
Identify the biophysical and socioeconomic drivers/factors
Document local coping and adaptation strategies
Analyse policy and institutional options and innovations to reduce climate risks and uncertainties in food production and food security
Explore innovative options and opportunities for enhancing community resilience in food security
Local community level

The Hindu Kush Himalayan region

Physical characteristics

The vast Hindu Kush Himalayan region extends 3,500 km across eight countries – Afghanistan, Bangladesh, Bhutan, China, India, Nepal, Myanmar and Pakistan – covering an area of more than 4 million km^2. As an area dominated by high mountains, vast glaciers, and large rivers, it has earned many names: As it contains all 14 of the world's highest mountains, those reaching over 8,000 m in height, as well as most of the peaks over 7,000 m, it has been dubbed the 'Roof of the World'. As the third most glaciated place on Earth after the Arctic and Antarctic, it is also known as the 'Third Pole'. Finally, as the source of ten major river systems that provide water, ecosystem services and the basis of livelihoods to more than 210 million people upstream in the mountains and some 1.3 billion people downstream, the region is also referred to as the 'Water Towers of Asia'.[7]

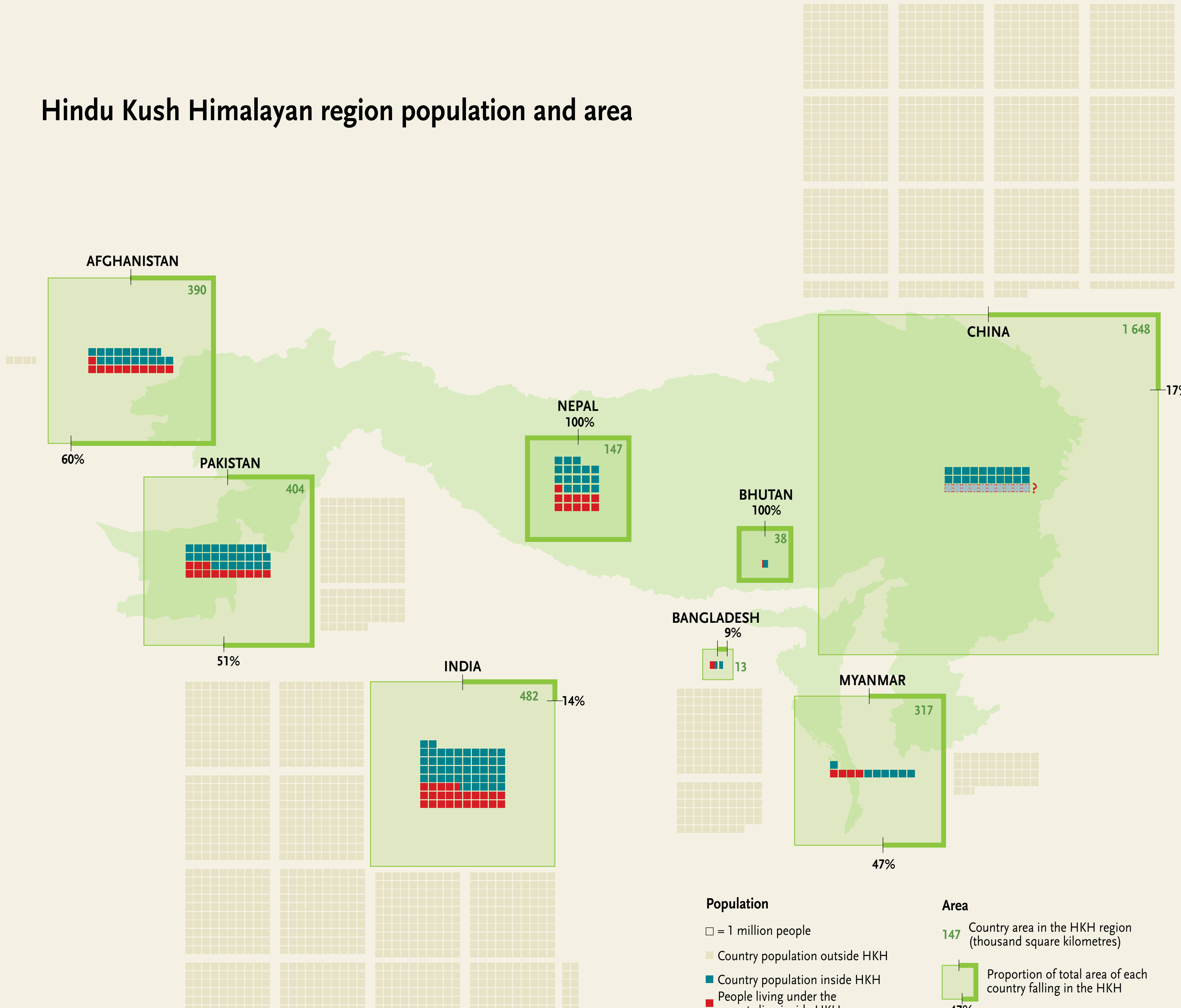
The high mountain ranges strongly influence atmospheric circulation and meteorological patterns across the region. As a result of its varied topography, the HKH is endowed with rich biodiversity and diverse ecosystems, which provide a basis for the livelihoods of the many people who live there. Its physical characteristics, however, also make the Hindu Kush Himalayas one of the most hazard-prone regions in the world. As the youngest mountain chain in the world, the HKH are also the most fragile. Heavy rains, steep slopes, weak geological formations, accelerated rates of erosion and high seismicity contribute to serious flooding and mass movements of rock and sediment affecting the lives and livelihoods of millions. The vulnerability of people living in the HKH to natural hazards is exacerbated by poverty and limited access to development services. The effect of disasters is, however, not limited to the mountains. Flooding affects many millions more downstream, sometimes with loss of life numbering in the thousands and costs to the economy in the hundreds of million.[8]

Demographic and socioeconomic characteristics

The population of the Hindu Kush Himalayan region is approximately 210 million. The communities are largely agrarian, relying heavily on local natural resources and subsistence farming on small plots of land. Like many agrarian mountain societies, they experience high levels of poverty making them vulnerable to both rapid environmental and socioeconomic changes. Already situated in one of the poorest regions of the world, poverty in the mountains is on average 5% more severe than the national average of the respective HKH countries, with 31% of the HKH population living below the official poverty line.[9] Only in India is the situation reversed, because of high levels of poverty in the plains of some of the north Indian states.

Mountain communities are challenged by a fragile environment, depleted natural resource systems, limited availability of suitable agricultural land,

Hindu Kush Himalayan region population and area



Source: Sharma, P; Pratap, T (1994) *Population, poverty and development issues in the Hindu Kush Himalayas: Development of poor mountain areas.* Kathmandu: ICIMOD; Gerlitz, J et al. (2014) *Poverty and vulnerability assessment: A survey instrument for the Hindu Kush Himalayas.* Kathmandu: ICIMOD; World Bank Open Data. http://data.world-bank.org/

physical inaccessibility and poor local infrastructure. The harsh climate, rough terrain, poor soil and short growing season in the mountains leads to low agricultural productivity, undernourishment and food insecurity. High rates of malnutrition are found in many parts of the HKH with nutritional security further threatened by poor diet, hard physical labour and poor sanitary conditions.[10]

Poverty and food insecurity in the mountains are compounded by lack of access to safe water and adequate sanitation. In 2010, the United Nations General Assembly declared access to clean drinking water and sanitation a human right. As of 2012, however, most HKH countries remain behind, with less than half of their populations having access to improved sanitation facilities – despite progress on sanitation worldwide.[11] Likewise, in half of the HKH countries, at least 10% of the population does not have regular access to improved drinking water sources.[12] In the mountains, many households still use open pits as toilets and obtain their drinking water from open, untreated springs.

Poverty has led to a major outward migration of people, mostly men, from rural areas of the HKH to seek employment in the cities and abroad. The HKH now has the highest rate of outmigration in the world, accounting for 15% of the world's total peacetime migration. Migration is highly gendered in the HKH, with up to 40% of men absent from their communities.[13] As a result, it is women and the elderly who are left to look after the farms and families. Due to their increased work burden, women tend to have less time to take care of their children, who are often not breastfed long enough, leaving them unprotected against gastro-intestinal infections and exposed earlier to diseases from contaminated water and food.[14]

The overall poverty and lack of development increases the vulnerability of mountain people to natural hazards such as floods and landslides. Because women often lack the capacity and resources to fully participate in decision-making, they are left particularly vulnerable.

Downstream communities in South Asia are also highly dependent on upstream ecosystem services for dry-season water for irrigation and hydropower, drinking water, and soil fertility and nutrients. With limited land resources, inadequate energy supply and growing water stress, providing enough water and energy to grow enough food for the burgeoning population is ever more challenging.[15]

Hydrological characteristics

The rivers flowing from the Hindu Kush Himalayas provide the region with one of the most valuable resources: fresh water. Ten large Asian river systems originate in the HKH – the Amu Darya, Brahmaputra (Yarlungtsanpo), Ganges, Indus, Irrawaddy, Mekong (Lancang), Salween (Nu), Tarim (Dayan), Yangtse (Jinsha) and Yellow River (Huanghe). These ten river basins cover an area of 9 million km^2, of which 2.8 million km^2 fall in the Hindu Kush Himalayan region. Downstream, millions of people depend on the waters from these rivers for domestic use, agriculture, hydropower and industry. The rivers are fed by rainfall, meltwater from snow and ice, and groundwater. The amount of water from each source varies by river. It also varies depending on the location within each basin.

Precipitation falls as either snow or rain, depending on the temperature, which is closely linked to elevation. Snow can be stored as long-term (perennial) snow or become ice and contribute to the growth of glaciers. Snow can also be stored in the short term as seasonal snow before melting and turning into runoff. Precipitation falls as rain when temperatures are no longer low enough to form snow.

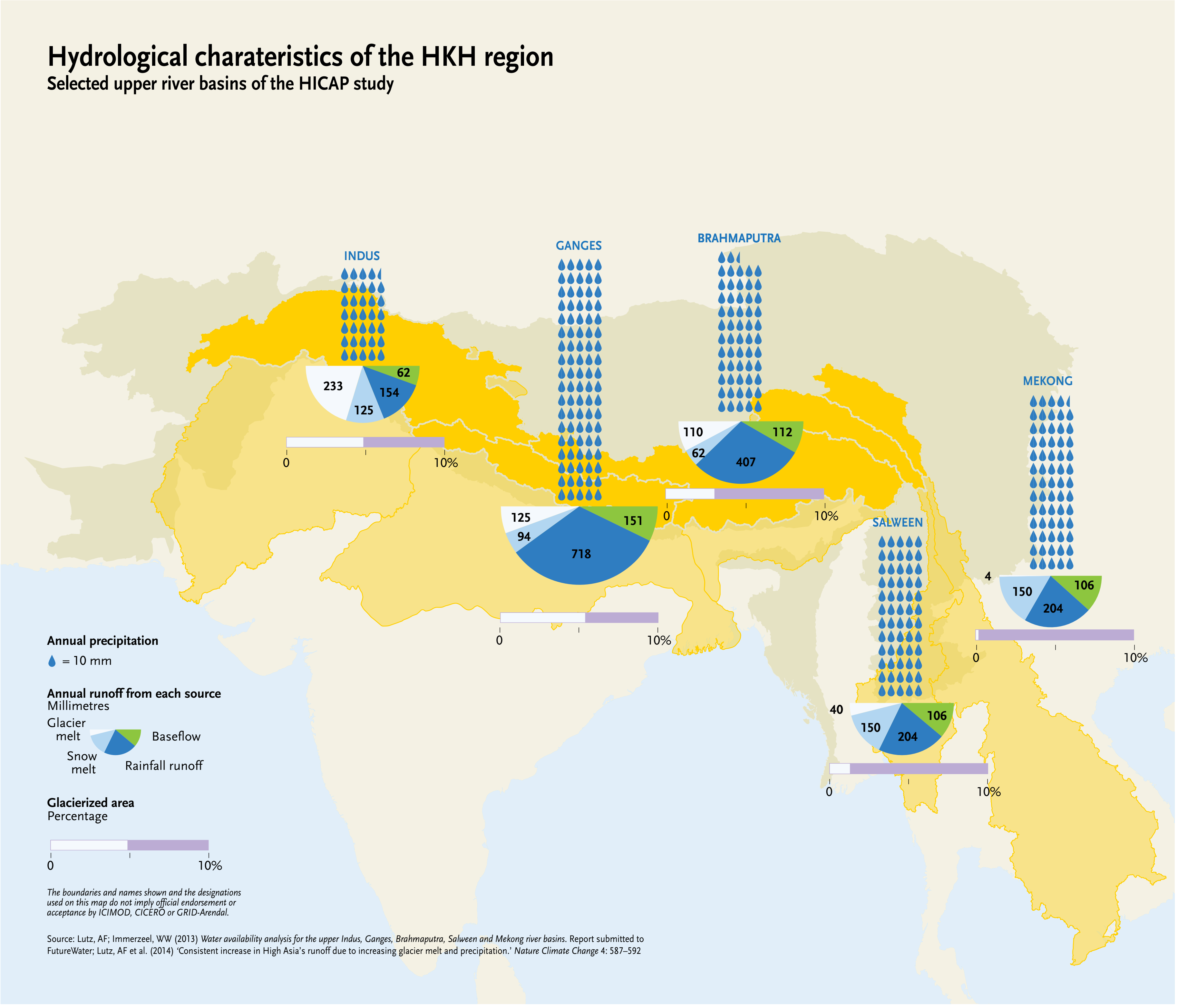
Precipitation in the Hindu Kush Himalayas is dominated by the southwest monsoon in the summer and westerly disturbances in the winter. The pre-monsoon and monsoon account for 88% of annual precipitation.[16] Precipitation varies from 3,000 mm in the eastern Himalayas to 100 mm in the southern plain desert on the western side.[17,18] A large proportion of annual precipitation falls as snow, especially at the higher altitudes. The climate of the eastern Himalayas is characterized by the East-Asian and Indian monsoon systems and the bulk of precipitation falls between June and September as monsoon rain. The precipitation intensity shows a strong north-south gradient, as influenced by the mountains. In the Hindu Kush and Karakoram ranges in the west, precipitation patterns are characterized by westerly and south-westerly flows, resulting in a more equal distribution of precipitation throughout the year. In the Karakoram, up to two-thirds of the annual high-altitude precipitation occurs during the winter months.[19]

Snow and ice are a dominant feature of the Hindu Kush Himalayan mountains. There are over 54,000 glaciers in the HKH region, covering a total area of more than 60,000 km^2. Together the glaciers comprise over 6,000 km^3 of ice reserves, acting as fresh water reservoirs for the greater region. In the drier part of Asia, more than 10% of local river flows come from ice and snow melt.[20]

While the Indus distinguishes itself by a much stronger dependence on glacier meltwater than the other four basins, the Brahmaputra, Ganges, Salween and Mekong are highly dependent on rainfall runoff. The monsoon is, thus, critically important for ecosystems and the local and downstream populations, who depend heavily on this water resource for their livelihoods and health. Overall, the contribution of glacial melt to river flow is highest towards the western side of the HKH and drops towards the eastern side where rainfall dominates.

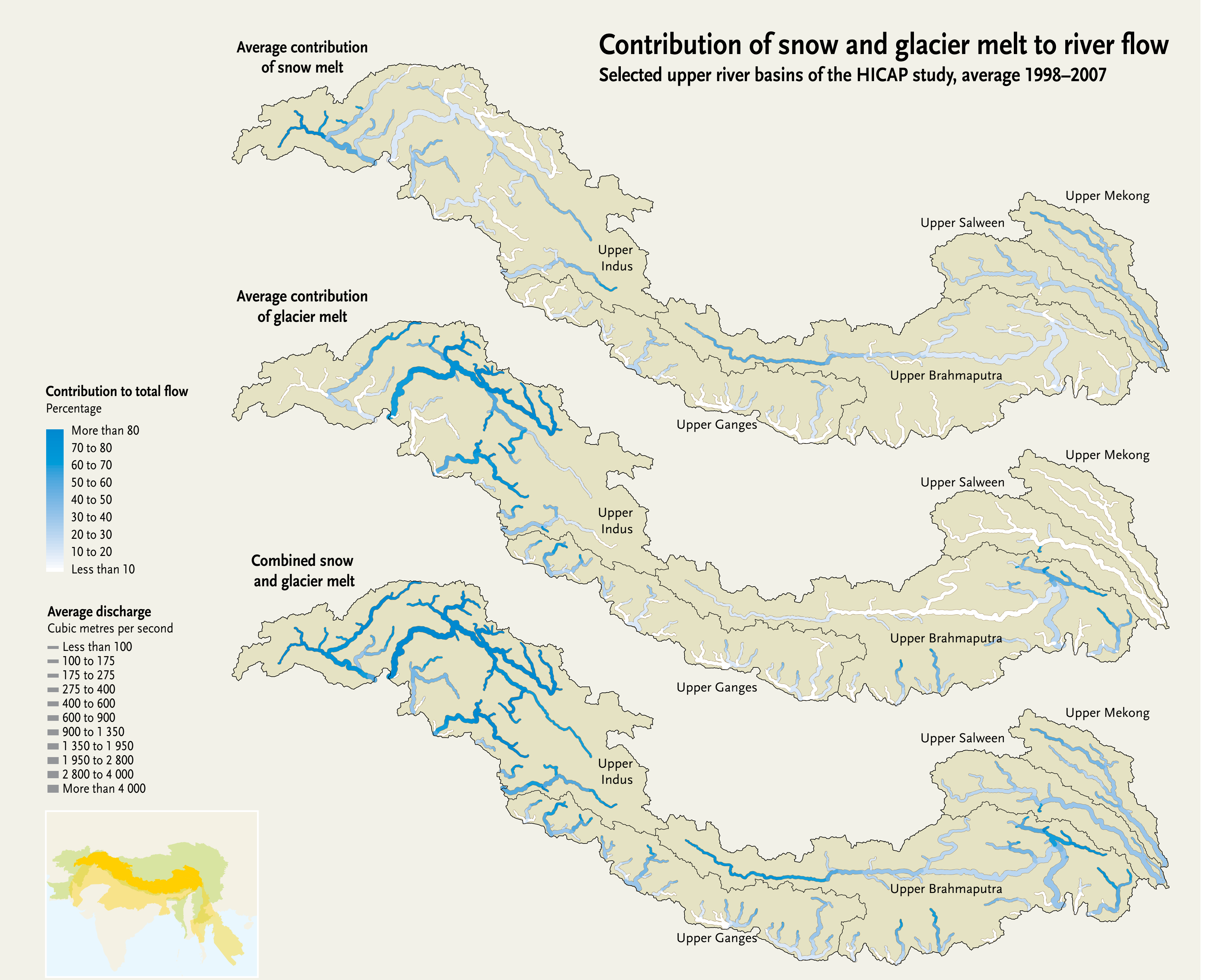
Hydrological charateristics of the HKH region

Selected upper river basins of the HICAP study



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by ICIMOD, CICERO or GRID-Arendal.

Source: Lutz, AF; Immerzeel, WW (2013) *Water availability analysis for the upper Indus, Ganges, Brahmaputra, Salween and Mekong river basins.* Report submitted to FutureWater; Lutz, AF et al. (2014) 'Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation.' *Nature Climate Change* 4: 587–592



Source: Lutz, AF et al. (2014) 'Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation.' *Nature Climate Change* 4: 587-592

Sources of river water: Glacier melt, snow melt, rainfall, groundwater

Rivers originating in the HKH are among the most meltwater dependent in the world.[21] It has been known for quite some time that there is a large variation between rivers basins in terms of the relative contributions of glacial melt, snow melt and rainfall to river flow, although this has often been poorly quantified. As the science and availability of measurements has improved, the importance of glacial melt to total river flow has become better understood.[22,23] Estimates of the number of people who depend (either directly or indirectly) on meltwater from glaciers have also gradually been revised downwards from hundreds of millions (or even billions) to millions of people.[24]

Generally speaking, the contribution of glacial melt to river flow is less important in river basins experiencing monsoon-dominated precipitation regimes and more important in the drier, westerly-dominated river basins such as the Indus.[25,26] Recent findings from HICAP research within upper river basins indicate that stream flow in the Indus river basin is dominated by glacial melt (up to 41%), while rainfall is of greater importance to the other four river basins.[27] Average runoff composition within each upper basin are:

- *Upper Indus:* runoff is dominated by meltwater: glacial melt (41%) and snow melt (22%), and rainfall is of minor importance to total runoff (27%)
- *Upper Ganges:* runoff is dominated by rainfall (66%) and meltwater contributes about 20% to total runoff
- *Upper Brahmaputra:* runoff is dominated by rainfall (59%) and meltwater contributes about 25% to total runoff
- *Upper Salween:* runoff is dominated by rainfall (42%), but snow melt is also important contributing 28%; glacier melt contributes about 8% to total runoff
- *Upper Mekong:* runoff is dominated by rainfall (44%), but snow melt is also important contributing about 33%; glacier melt contributes approximately 1% to total runoff

In general, the relative contribution of different runoff sources can be explained by the weather systems and altitudinal effects. The climate in the eastern part of the Himalayas is driven by the East-Asian and Indian monsoon systems, where most precipitation falls between June and September. In the upper Ganges basin, despite the quite large glaciated area, rainfall runoff dominates due to the monsoon rains. The situation is quite similar for the upper Brahmaputra basin. Because a greater proportion of the upper Brahmaputra's basin's area is at high altitude than in the upper Ganges basin, there is a larger contribution of snow and glacier melt. Although rainfall is dominant in the upper Salween and upper Mekong basins, there is a large contribution of snow melt in these areas, because large parts of these basins are located on the Tibetan plateau. The magnitude of the contribution of each component to total runoff partly determines the basin's response to climate variability and change.[28]

The importance of water in the HKH

The population of South Asia has tripled over the last 60 years and now accounts for around a quarter of the world's population, with China alone accounting for around one-fifth.[29] An estimated 210 million people living within and 1.3 billion people living downstream of the Hindu Kush Himalayas rely on freshwater obtained directly or indirectly from the rivers and tributaries of the region.[30] There is an extremely high degree of dependence on these freshwater resources to sustain the livelihoods of rural communities and meet the food needs of urban populations. Water also supports navigation, energy production, and terrestrial and aquatic ecosystems. At the same time, the region experiences the largest loss of life and damage in the world from water-related natural disasters.

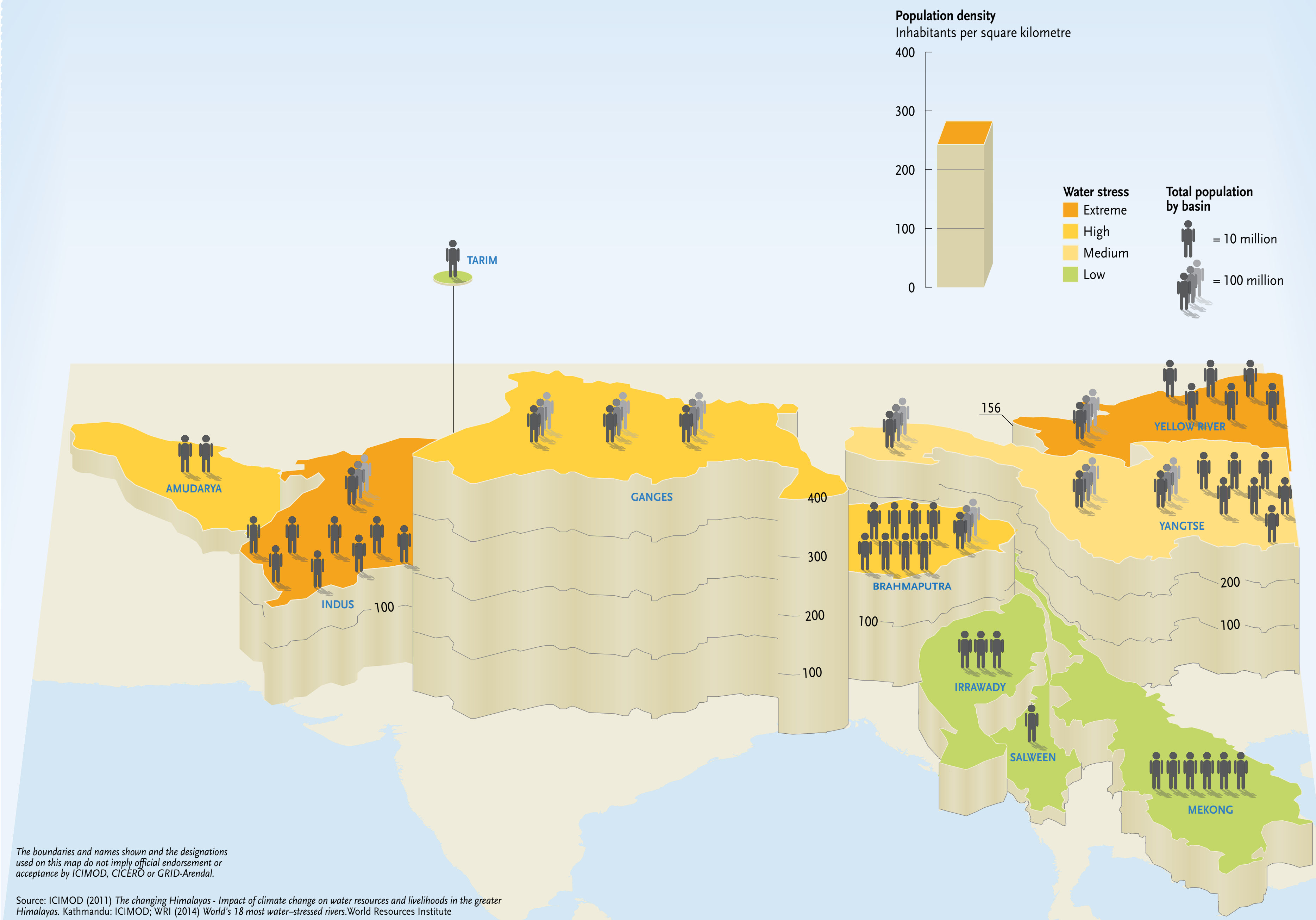
Agriculture and food security for billions of people

The economies of the HKH countries and the livelihoods of the majority of people within them are highly water dependent. Agriculture accounts for about 90% of all water withdrawals in HKH countries (higher than the world average of 70%).

Although agriculture's contribution to gross domestic product (GDP) is declining across South Asia and China, it remains an important component of the economies of HKH countries. Large proportions of the population are still based in rural areas and rely on agriculture, forestry, fisheries and livestock for their livelihoods. In Nepal, agriculture contributes about one-third of GDP and employs two-thirds of the labour force.[31] In Pakistan, agriculture contributes about one-fifth of GDP and employs just under half of the population.[32] In China, over half of the land is used for agriculture, which contributes almost one-tenth of the country's GDP.[33] The agricultural sectors in all HKH countries remain central to the development of their national economies. However, agriculture is also the sector most vulnerable to climate change, because it is highly susceptible to climate and weather, and also because people involved in agriculture tend to be poorer than urban populations.

The food, water and energy security of individual countries in the region depends heavily on the

Population in the river basins of the Hindu Kush Himalayas



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by ICIMOD, CICERO or GRID-Arendal.

Source: ICIMOD (2011) *The changing Himalayas - Impact of climate change on water resources and livelihoods in the greater Himalayas.* Kathmandu: ICIMOD; WRI (2014) *World's 18 most water–stressed rivers.*World Resources Institute

status and health of the large river systems. Water from the Indus river enables the production of more than 80% of food grains in Pakistan.[34] The Ganges river system is the main source of freshwater for half the population of India and Bangladesh and almost the entire population of Nepal.[35] Likewise, the Brahmaputra basin supports irrigation, hydropower and fisheries in large parts of Bangladesh, Bhutan and India. Rivers from the HKH region not only provide water, they also transport soil and nutrients to downstream areas, which makes the floodplains of South Asia particularly fertile, thereby contributing to the productivity of agriculture and fisheries.

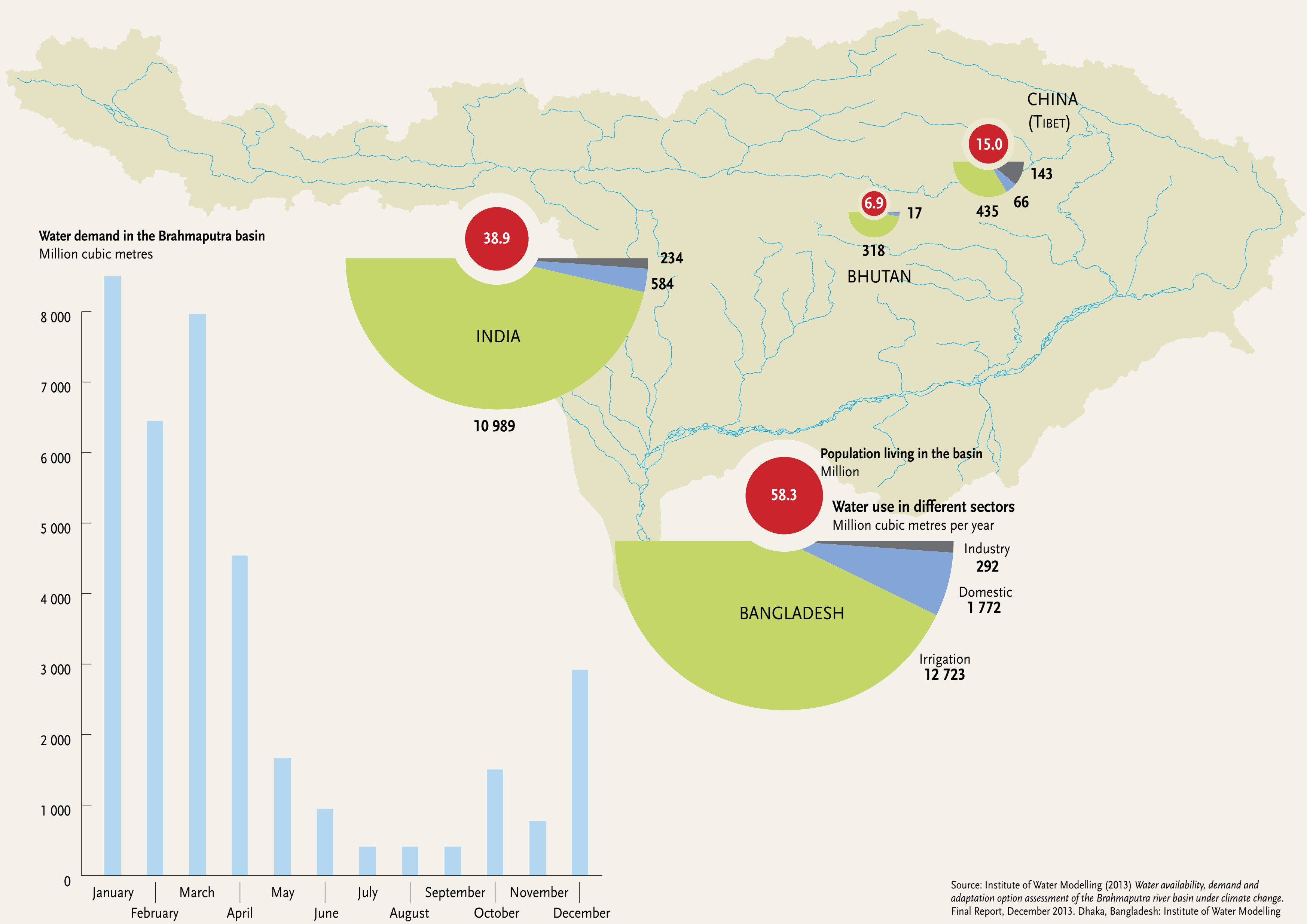
The Himalayan rivers also hold a high level of freshwater fish biodiversity (the Ganges has 265 species of fish) and support the livelihoods of many people. An estimated 2.5 million fishers in India and 400,000 fishers in Bangladesh rely on Himalayan rivers for income and nutrition.[36] More than 33,000 people depend on fisheries from the Koshi (a tributary of the Ganges) and other rivers in Nepal. In China, where 56 ethnic groups rely on fisheries, some major rivers originating in the HKH, such as the Yangtze and Yellow River, are home to hundreds of freshwater species. These rivers provide aquatic resources inland (the Yangtze alone provides over 70% of the national total production of river fisheries) and contribute to marine fisheries in the East China Sea, thanks to their rich nutrient runoff.

With huge volumes of water passing through the rivers each year and their large altitudinal drop, the Himalayan rivers have vast hydropower potential (estimated at 500 GW[37]), most of which is currently untapped. In China alone, hydropower capacity reached 282 GW in 2014.[38] In India, 79% of the total hydropower potential is within the Himalayan region, but just a fraction has been developed.[39] In Pakistan, only 11% of the hydropower potential has been realized.[40] Nepal, where over a quarter of the population lives below the poverty line[41] and where there is up to 16 hours of load shedding a day in the dry season, has one of the largest untapped hydropower potentials in the world.[42]

The demand for water resources will rise significantly in the future, which will place pressure on already strained water resources and ecosystems. South Asia, already home to 35% of the world's undernourished,[43] has a growing population that is expected to reach 2.2 billion in 2025, while cereal demand will double compared to the year 2000 (from 246 to 476 million tonnes in 2025).[44] While the population is growing, the amount of land available per person has been steadily decreasing and the amount of food produced has either been growing slowly or stagnated. Climate change is expected to disrupt food production, especially of cereals, across Asia, due to variations in the monsoon onset and duration, higher rainfall variability, and extreme events such as floods and droughts.[45,46] Good projections are difficult as there is a lack of disaggregated data for mountains, but yields of rainfed rice, corn, and wheat are expected to decline. Estimated reductions are highest for maize (40%), followed by rice (10%) and wheat (5%).[47]

All of the countries in South Asia face serious problems in providing enough food, energy, safe water and sanitation to their populations without further degrading their natural resources. Even in China, which is the least severely affected by undernourishment among the HKH countries, nearly 10% of the population is undernourished.[48]

Water use: The case of the Brahmaputra river basin



Source: Institute of Water Modelling (2013) *Water availability, demand and adaptation option assessment of the Brahmaputra river basin under climate change.* Final Report, December 2013. Dhaka, Bangladesh: Institute of Water Modelling

Springs in the mid-hills of Nepal

CASE STUDY • Shahriar Wahid, ICIMOD

The springs that flow in the mid-hills of the Nepal are critical to the survival of communities, as streams and rivers often lie far below hill settlements and the cost of carrying water by hand or pumping uphill is prohibitively high. These springs are fed by groundwater, which accumulates in underground aquifers during the monsoon. But many are now drying up, threatening a whole way of life. Increasing temperatures and rainfall variability risk pushing the drying of springs further.

The loss of springs leads to increased domestic drudgery and stress for those whose livelihoods are based on farming. Loss of water can be a significant push factor in the outmigration of rural labour and youth, especially men, from the mid-hills, and there are all-too-frequent reports in the media of entire villages being abandoned due to lack of water.

The physical aspects of spring hydrology are still poorly understood and insufficiently documented, as are the social science aspects related to changing water use. Recent ICIMOD studies suggest policies that focus on enhancing the capacities of all stakeholders and promoting a culture of conservation. Development policies should be framed along the lines of the much cheaper 'learning by doing' grassroots civic science action research method, merging science with community knowledge. Research needs to be continued to establish firmer linkages between local hydrogeology and recharging ponds, as well as to improve spring water flow and management.

Springs are mostly found around a hill slope or 'water tower'. They can be relatively short-lived, providing water for a certain period after the monsoon when the groundwater levels are high, or perennial if fed from a level below the dry season water table. The precise relationship between precipitation/recharge and actual extraction rates is unknown in most parts of the HKH, but experiments have shown that it is possible to increase the life of a spring by increasing the recharge rate during the monsoon through the construction of pits and ponds and by improving vegetation cover.

The Holy Mount Kailash: Bridging communities, countries and rivers

CASE STUDY • Rajan Kotru, ICIMOD

Spread over an area of about 31,000 km^2 the Kailash Sacred Landscape is an ecologically diverse, multi-cultural and fragile landscape. It is located in the remote southwestern portion of the Tibet Autonomous Region of China, with parts falling in the far-west of Nepal and northeastern flank of Uttarakhand in northern India. This landscape has distinct biophysical features and historical and cultural significance, which are well documented (see www.icimod.org/ksl). Across the three countries, the landscape is characterized by a fine network of religious places and sacred sites, high-altitude lakes, snow peaks and permafrost areas. Its network of religious sites spreads across the three countries sharing the landscape. Most important among these are Mount Kailash and lake Mansarovar (both within the Tibet Autonomous Region), which are the ultimate pilgrimage destinations for Hindus, Buddhists, Jains, Sikhs, and Bonpos.

The landscape is also the origin and headwater of four of Asia's major rivers: the Indus, Sutlej, Brahmaputra and Karnali. The Sutlej ultimately meets the Indus and Karnali, and through many other river systems, flows into Ganges. These rivers support the lives and livelihoods of a million people in the Kailash Sacred Landscape alone and have a great significance for ecosystems (rangelands, wetlands, and forests) and their interfaces, mega-habitats, and biodiversity, while also safeguarding the cultural linkages and sustainable development of local populations.

To address accelerated environmental changes due to climatic and other drivers of change (population growth, globalization, and outmigration), Nepal, India and China are implementing a transboundary collaborative programme that has evolved through a participatory, iterative process among various local and national research and development institutions. Through the Kailash Sacred Landscape Conservation Initiative, an integrated ecosystem management approach at a landscape level has been shown to be of immense value in sustaining the ecosystem services that strengthen local livelihoods and cultural heritage, as well as the river systems that are part of greater river basin systems downstream, such as the Ganges, Indus and Brahmaputra.


Kailash sacred landscape
AFGHANISTAN
CHINA
BHUTAN
PAKISTAN
Indus
NEPAL
Brahmaputra
Ganges
INDIA
BANGLADESH
MYANMAR
Lion (Indus)
Elephant (Satlej)
Flows into Indus
Mount Kailash
CHINA
Ganges River
Lake Rakshastal (La-ang)
Lake Manasarowar (Ma-p'ang yung-ts'o)
Lake Kungsheng (Kunggyu Co)
Lapcha Pass
Horse (Yaslung)
Brahmaputra
Taklakot (purang)
Kalapani
Byas
INDIA
Nyala
Peacock (Karnali)
Dojam
Saipal
Mahakali River
Darchula
Joljibi
Gokuleswor
Dami
Jhulaghat
Seti River
NEPAL
Pancheswor
Flows into Ganges
Flows into Ganges
Flows into Ganges

Water-related disasters in the HKH

Despite the essential role that water from the HKH plays in economic development and providing livelihoods and food for millions of people, it is also the source of water-related disasters (such as floods, droughts and landslides), pollution and disease for millions of people – both in the mountains and downstream. An estimated 96% of all flood-affected people worldwide live in Asia and are affected by its rivers.[49] Asian rivers also cause 40% of flood fatalities worldwide.[50] Between 1990 and 2012, an average of 76 disaster events occurred in the Hindu Kush Himalayan countries each year, and about one-third of these were caused by floods.[51] The four largest floods that occurred between 2000 and 2013 killed a combined total of more than 10,000 people and displaced over 50 million.[52]

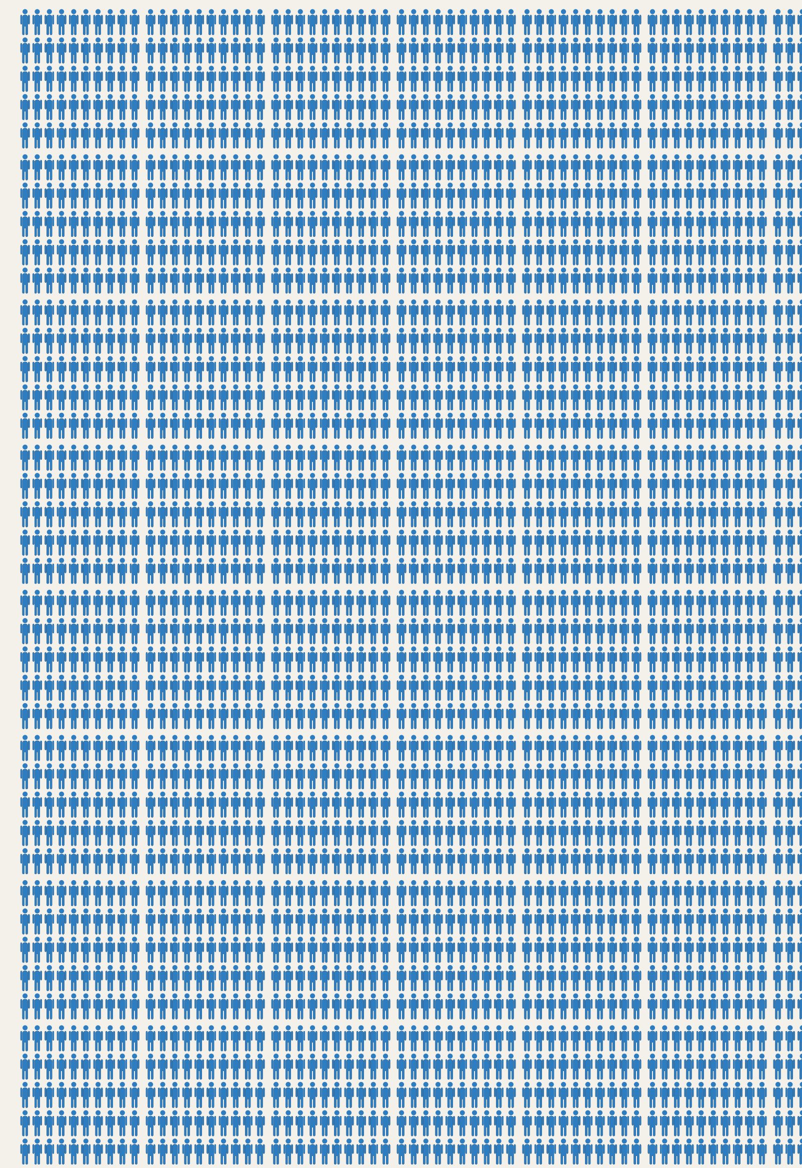
Droughts are also a real issue in certain regions, although the overall impact on human populations is lower than flood events. In Chitral, Pakistan, variations in the frequency and duration of rain are the main reason for prolonged droughts, which affect the socioeconomic conditions of the people.[53] In China, the drought experienced in Baoshan in 2009–2010 was the worst reported in 100 years.

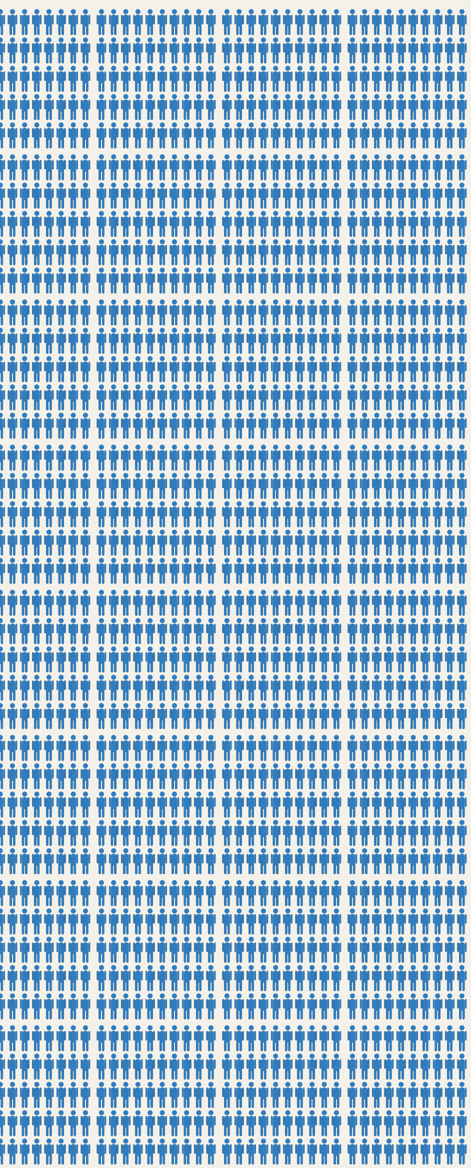
The topography, terrain, physical features and changing climate of the Hindu Kush Himalayas also make this region inherently unstable and prone to hazards. These include earthquakes, landslides, floods, droughts and other natural disasters. Steep slopes, prolonged or intense periods of heavy rainfall and unstable bedrock all promote the conditions for such hazards. Human activities that cause soil erosion and decrease the retention of water, such as deforestation, can further increase the risk of landslides and slope failure. The Hindu Kush Himalayas are also one of the youngest and most geologically unstable mountain ranges in the world. The collision of the Indian and Eurasian tectonic plates – which created the towering Himalayan mountains – is ongoing and makes this region highly vulnerable to earthquakes. The steep slopes and ridges amplify the intensity of seismic waves resulting in increased damage. The 2015 earthquake that hit Nepal killed over 8,900 people, injured a further 22,000 people, damaged or destroyed around 900,000 buildings including homes, cultural sites and schools, and displaced millions.[54]

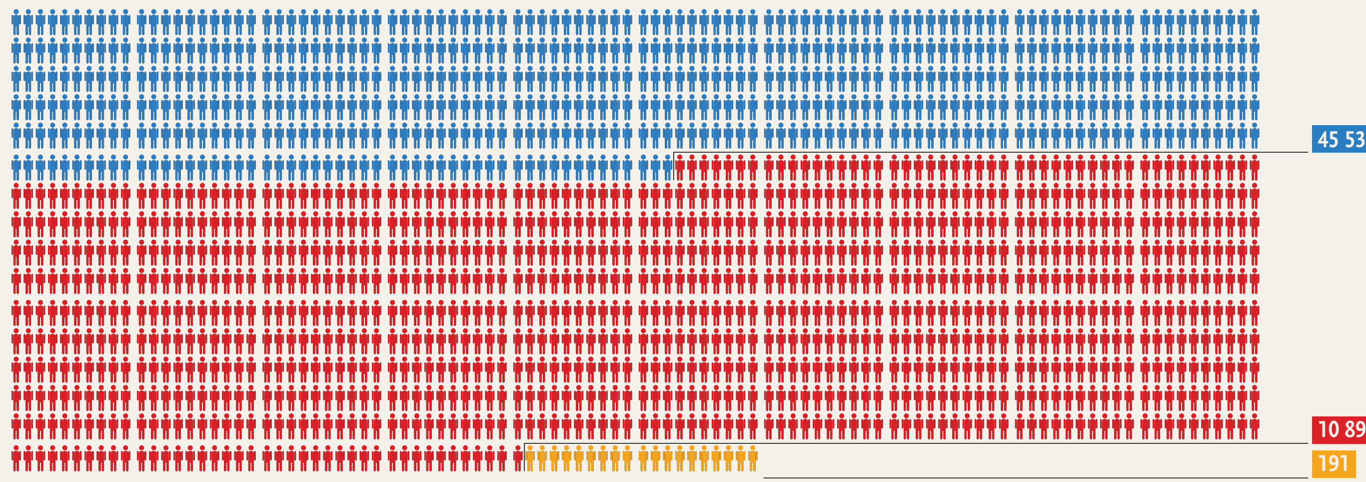
Natural disasters frequently occur in, and severely affect, the region because the human population is both highly exposed and vulnerable to natural hazards. High rates of urbanization and high population levels have led to settlements in areas vulnerable to flood risk. Many villages and farmland in mountainous areas are scattered across steep terrain and vulnerable to landslides. Most of the agriculture in mountains is rainfed and, therefore, highly vulnerable to rainfall variability.

To cope with climate extremes such as floods, flash floods, droughts and water shortages, households often resort to labour migration as a livelihood strategy.

Killed by climate-related disasters in Himalayan countries







People killed between 2000 and 2015

= 10 people

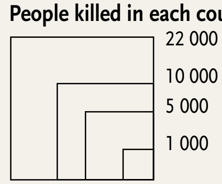
Climate-related disaster cause of death

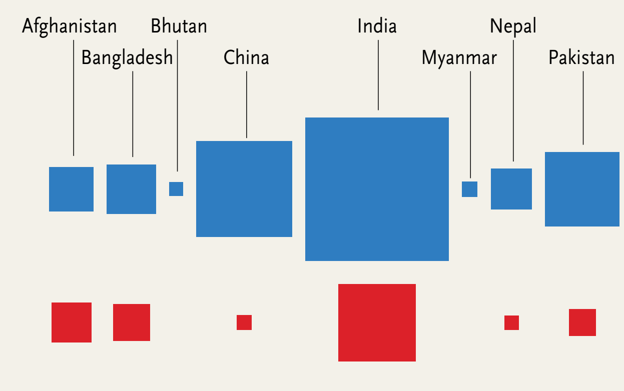
Floods

Extreme heat

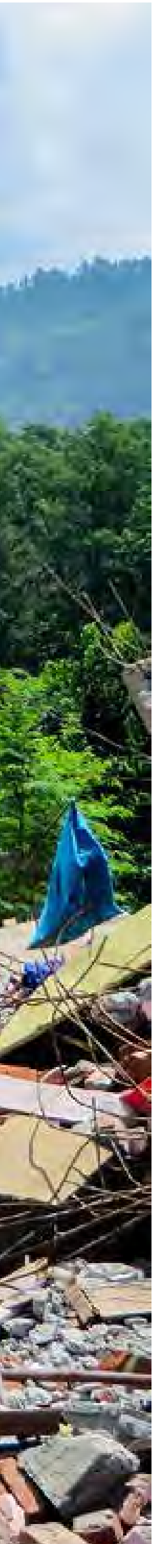
Droughts

People killed in each country

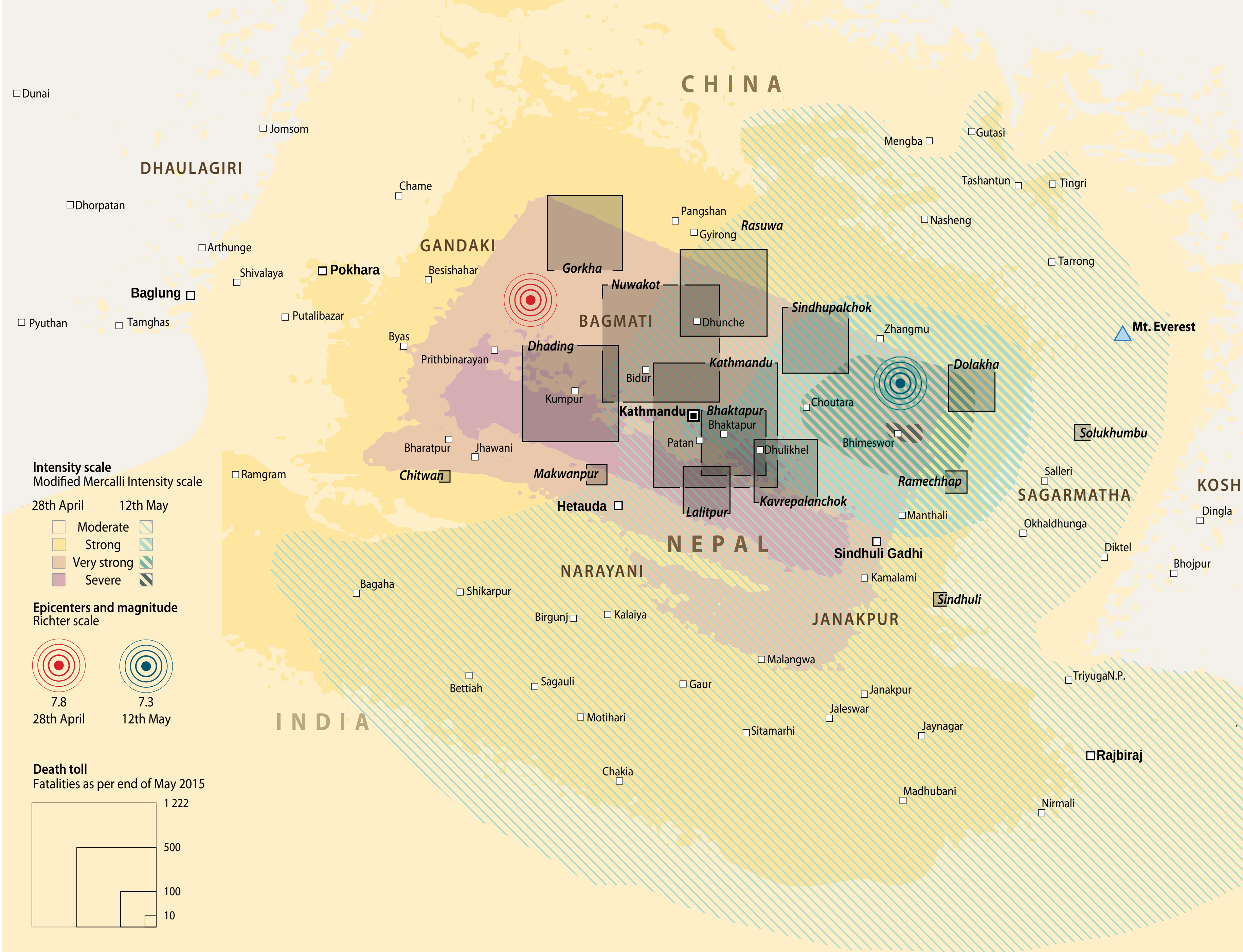




Note: Includes people killed within the national territories of Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan, and beyond the Hindu Kush Himalayan region of each country
Source: Guha-Sapir, D; Below, R; Hoyois, Ph (nd) EM-DAT: *International disaster database*. Belgium: Universite Catholique de Louvain. www.emdat.be



Two terrible earthquakes strike Nepal



Intensity scale
Modified Mercalli Intensity scale

28th April		12th May
	Moderate	
	Strong	
	Very strong	
	Severe	

Epicenters and magnitude
Richter scale

7.8
28th April

7.3
12th May

Death toll
Fatalities as per end of May 2015

1 222
500
100
10

Sources: USGS 2015 http://earthquake.usgs.gov/earthquakes/; MapAction http://www.mapaction.org; The New York Times press review

Glacial lakes and GLOFs

CASE STUDY

All lakes formed by present or past glacier activity are described as glacier (glacial) lakes. A glacial lake can form on the surface of the glacier (supra-glacial), within the glacier ice (englacial), below the glacier ice (subglacial), in front of the glacier (proglacial), at the side/surrounding the glacier (periglacial) or in relict cirques (a steep bowl-shaped depression occurring at the upper end of a mountain valley). The impact of climate change on Himalayan glaciers is becoming apparent with the majority of glaciers shrinking. The formation and growth of glacial lakes is a phenomenon directly related to glacier shrinking. The majority of glaciers are dammed by unstable moraines and have the potential to breach due to internal or external triggers. Once the moraine is breached it can cause a large flash flood known as a glacial lake outburst flood (GLOF), which can cause extensive damage to lives, livelihoods and infrastructure downstream. With climate change accelerating there is a growing concern that the frequency of GLOFs could increase in the future.

A comprehensive inventory of glaciers, glacial lakes and potentially dangerous glacial lakes was compiled in the late 1990s and early 2000. This inventory identified a total of 8,790 glacier lakes in Bhutan, India, Pakistan, Nepal and the Ganges basin in China. Of these, 204 were listed as potentially dangerous glacial lakes.[55] ICIMOD updated the inventory of glacial lakes in Nepal and assessed their GLOF risk based on satellite images from 2000/2001. The updated number of glacial lakes in Nepal is 1,466 covering an area of 64.75 km^2. Of these lakes, 21 are potentially dangerous and 6 are defined as high priority lakes requiring extensive field investigation and mapping.[56]

Thirty-five GLOFs (5 in Bhutan including the Lemthang Tsho GLOF of June 2015, 16 in China and 14 in Nepal) have been reported in the Hindu Kush Himalayan region.[57] Another study reported 21 GLOF events (17 before 1970 and 4 from the 1970s to 2010) in the Tibetan branch of the Kuri Chu and the Chamkhar Chu, Pho Chu and Mo Chu rivers.[58] These GLOFs resulted in significant damage to people, crops, infrastructure and hydropower plants. Thus, GLOF risk assessment has become an issue of considerable significance that must be dealt with urgently.

CLIMATE CHANGE AND ITS IMPACT ON WATER

PAST AND CURRENT TRENDS

Climate trends across the HKH region

Precipitation

The average annual rainfall over the HKH region (5 basins studied here) is approximately 880 mm, with variability of just 5% between years and high spatial variability. The highest rainfall amounts, accounting for more than 70% of the annual total, are received during the summer months with July being the wettest month. The pre-monsoon season receives approximately 16% of the annual total, with only 5% of annual precipitation falling in winter. December and January receive the least precipitation. On average, there are over 215 rainy days per year.

There is considerable variation in the distribution of precipitation across the HKH region. Generally, precipitation is lower in the west than in the east, and lower in the north than in the south. The Tibetan plateau and the southern plains of the Indus basin are much dryer than the southeast. Over the past decades, increased monsoon precipitation has been observed over the high mountain belt of the Himalayas, particularly in the east. The greatest decrease in monsoon rainfall has been observed in the south in the Ganges and Indus basins. Seasonal changes are also being observed: winters are getting wetter over most of the central and southern portions of the five basins, and winter precipitation is decreasing over the northern areas of the five basins. While the number of extreme rainfall events appears to be decreasing, the intensity of each event (amount of rainfall) appears to be increasing, especially towards the western parts of the HKH. In summary, over the last few decades and across the region there has been no discernible trend (increase or decrease) in the amount of rainfall, although there has been considerable year-to-year variability.

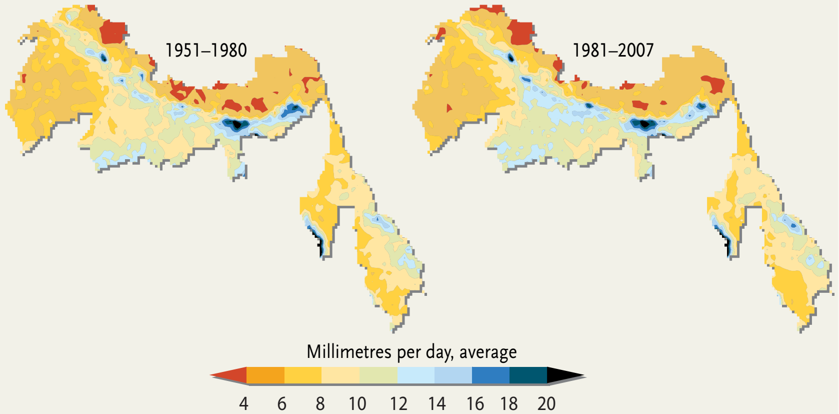
Temperature

Across the HKH region, temperatures exhibit a strong north-south pattern, with altitudinal and latitudinal gradients playing an important role. Temperatures are higher southwards and at lower altitudes. At a finer scale, topography, including the presence of mountains and valleys, also plays an important role in determining local temperature. The current data analysis is best suited to capturing large-scale topographic gradients, but does less well at capturing smaller scale and finer differences in topography.

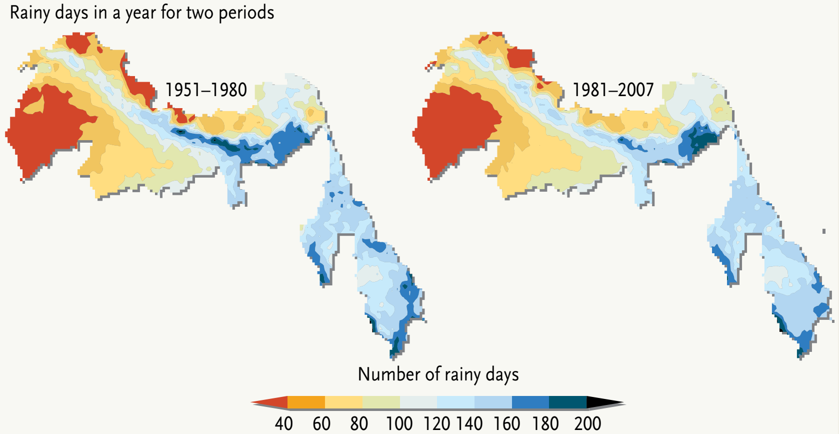
Overall, over the past decades and across the HKH region, the minimum temperatures are getting higher in the three winter months of December, January and February, especially within the southern-most areas of the HKH basins. However, there has been a sharp decrease in minimum temperatures in several areas along the northern high-altitude regions of the basins. At the same time, many of these areas are also experiencing higher maximum temperatures. In other words, the season extremes are getting bigger.

HKH climate indicators – Rainfall

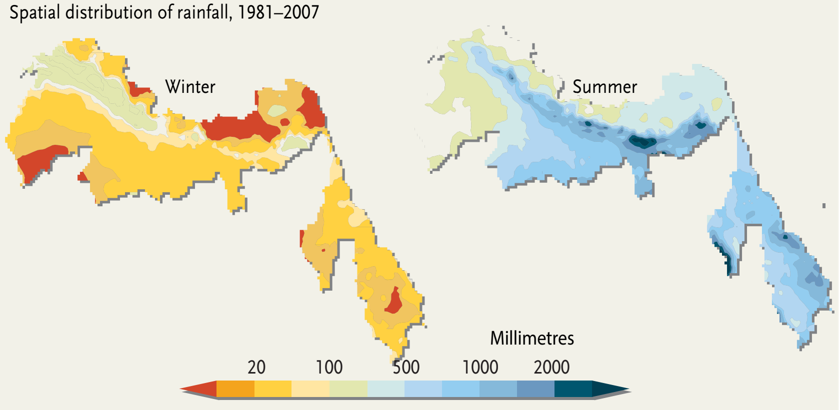
How much does it rain?
Intensity of rainfall on a rainy day



For how long does it rain?
Rainy days in a year for two periods

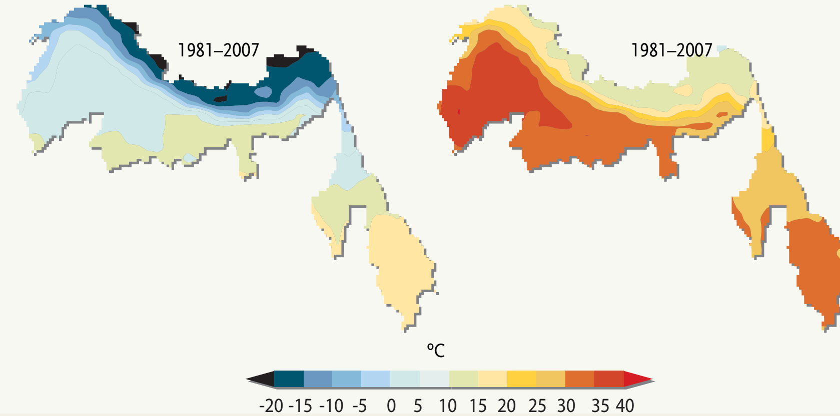


Where does it rain?
Spatial distribution of rainfall, 1981–2007

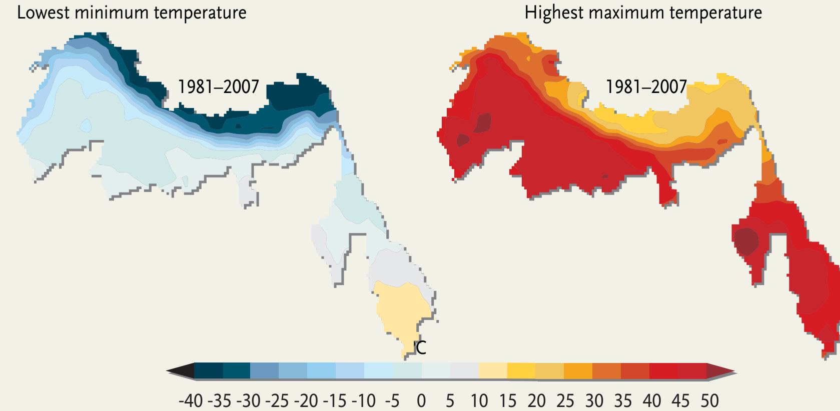


Temperature

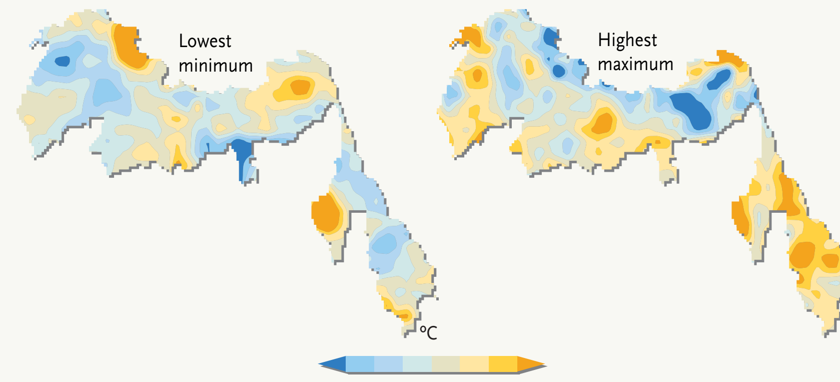
Where is it hot and where is it cold?
Average winter minimum temperature
Average summer maximum temperature



How hot and how cold?
Lowest minimum temperature
Highest maximum temperature



Temperature changes
Changes in temperature between the past (1951–1980) and recent period (1981–2007)



Trends in glacial melt and implications across the HKH

Glaciers are some of the most sensitive indicators of climate change, as they respond rapidly to changes in temperature and precipitation. Glaciers can provide local water resources in the mountains as well as influence runoff in lowland rivers and recharge river-fed aquifers. The retreat and advance of glaciers has wide-reaching impacts and affects on natural ecosystems and human settlements through effects on water supply and water flow patterns, affecting the availability of water for hydropower generation, agriculture and ecosystems. Over time, glaciers have been responsible for shaping the landscapes of vast areas. Glacial retreat also increases the risk of GLOFs and avalanches, and ultimately contributes to sea-level rise.[59,60]

The contribution of glacial meltwater to river flow varies both in space and time across the Hindu Kush Himalayas. Glacial meltwater is a major source of water in regions with little summer precipitation, but is less important in monsoon-dominated regions.[61] The importance of glacial meltwater contribution varies by river basin: it provides a major contribution to river flow in the Indus basin (41%), a modest contribution in the Brahmaputra (25%) and Ganges (20%) basins, and a minimal contribution in the Salween (8%) and Mekong (1%) basins.

Although major gaps remain in the understanding of the behaviour of the region's glaciers (e.g., through insufficient number of in-situ [on-site] measurements, relatively few high-altitude weather stations and few long-term glacier monitoring programmes), it is accepted that most Himalayan glaciers have both retreated and lost mass since the mid-19th century. Himalayan glaciers are losing mass at similar rates to other glaciated regions around the world. Between 2003 and 2009, Himalayan glaciers lost an estimated 174 gigatonnes of water[62] – equivalent to almost half of the Ganges' annual flow volume. However, there is considerable variation in glacier behaviour between the eastern and western Himalayas. While glaciers in the eastern and central part of the Himalayan region have retreated and lost significant mass and area in recent decades, puzzlingly, some glaciers in the highest parts of the central Karakoram have displayed evidence of growth (known as the Karakoram anomaly).

The Karakoram anomaly

Joseph Shea, ICIMOD

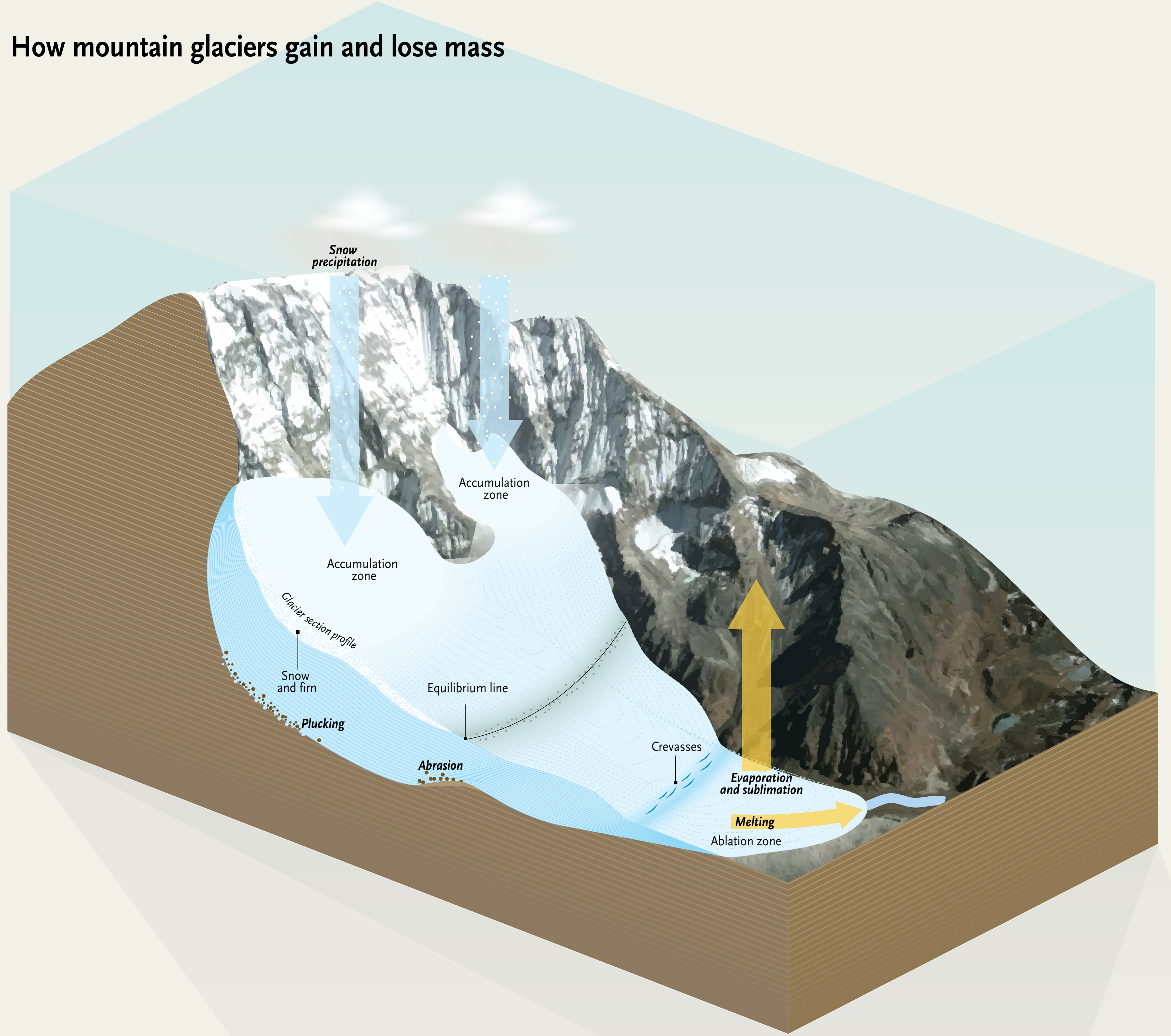
Glaciers respond to climatic changes by gaining or losing mass in the form of snow and ice. Sustained climatic changes will eventually lead to glacier advance or retreat. Glaciers in the HKH region are losing mass and retreating strongly. However, some glaciers in the Karakoram region have either been neutral or slightly gained mass in recent decades,[63] with advancing or stable glacier fronts. The 'Karakoram anomaly', as it is now known,[64] is the subject of intense scientific interest.

The Karakoram region is unique for a number of reasons:

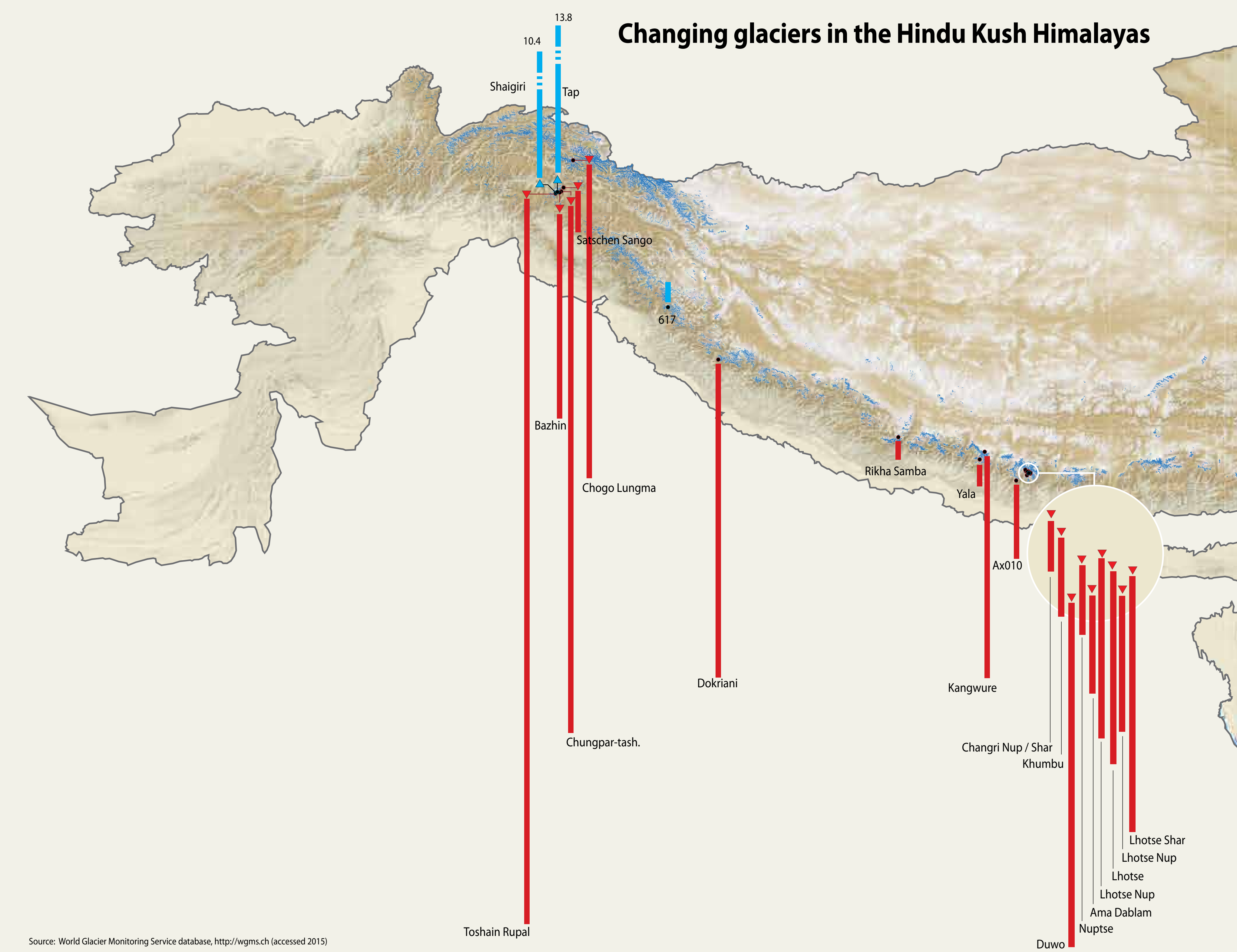
- It has a large concentration of very high and steep mountains, which lead to large avalanche contributions to glacier mass.[65]
- The glaciers in this region have a higher average altitude than other glaciers in the region.[66]
- The glaciers in the Karakoram are nourished primarily through heavy winter snowfalls that come from westerly storms. The central and eastern Himalayas, in contrast, receive most of their snow during the monsoon and only at very high elevations.
- The Karakoram contains a large number of surging glaciers and debris-covered glacier termini. Surging glaciers go through cycles where they accumulate mass at higher elevations and then quickly move it down glacier. The debris cover insulates the ice below from melting.

There is currently no definitive answer as to why glaciers in the Karakoram are behaving differently than the near-global signal of glacier retreat. Increasing winter precipitation together with decreasing summer temperatures could be one possible explanation.[67] There still remains a lack of data to enable us to properly understand why these glaciers are behaving this way. Perhaps the signals of climate change are obscured in a region that receives heavy winter precipitation at high altitudes.

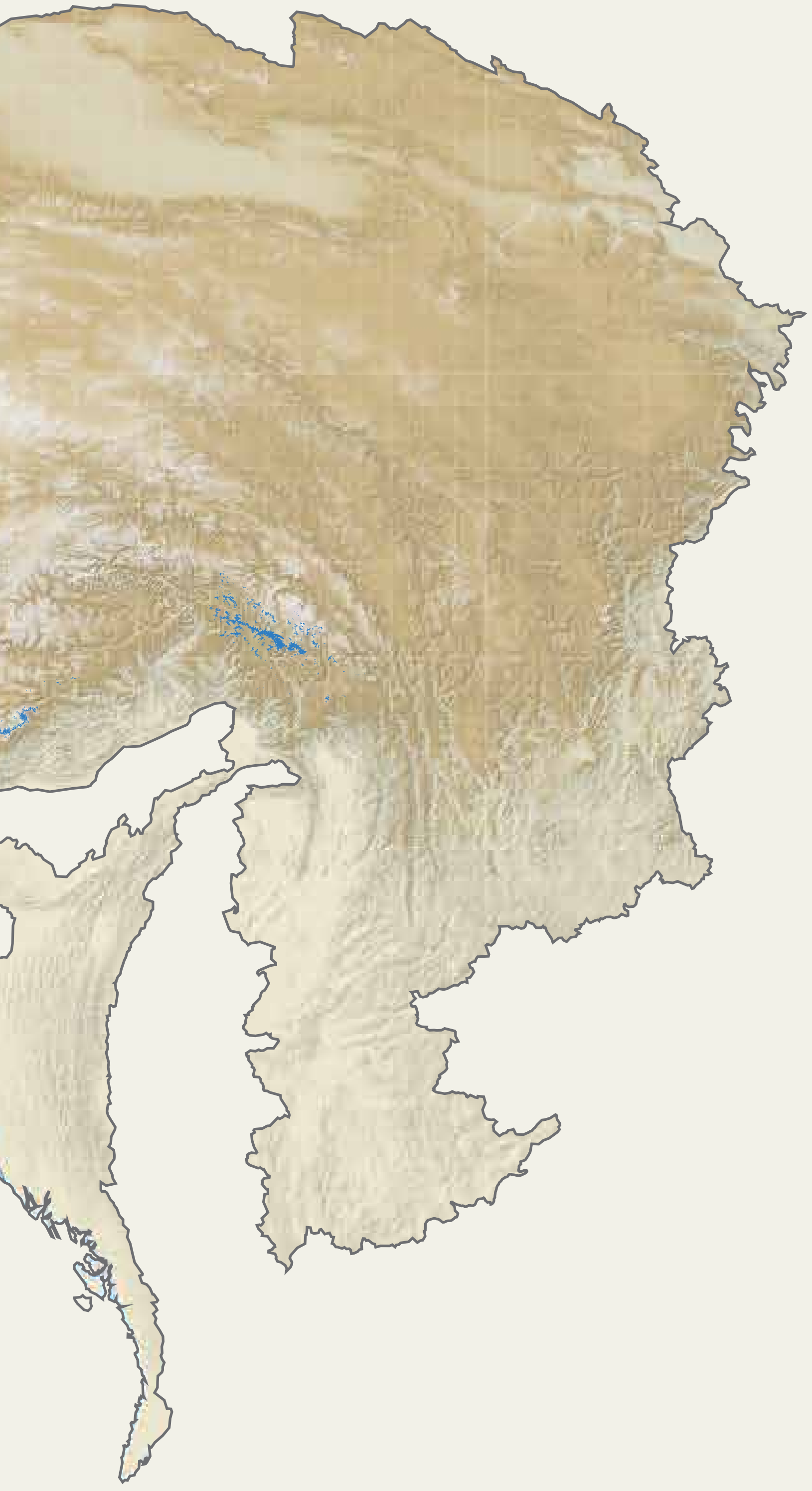
How mountain glaciers gain and lose mass



Changing glaciers in the Hindu Kush Himalayas

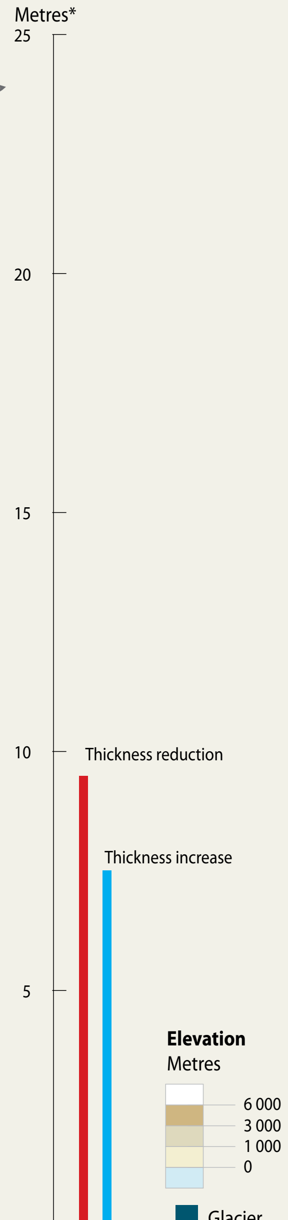


Source: World Glacier Monitoring Service database, http://wgms.ch (accessed 2015)



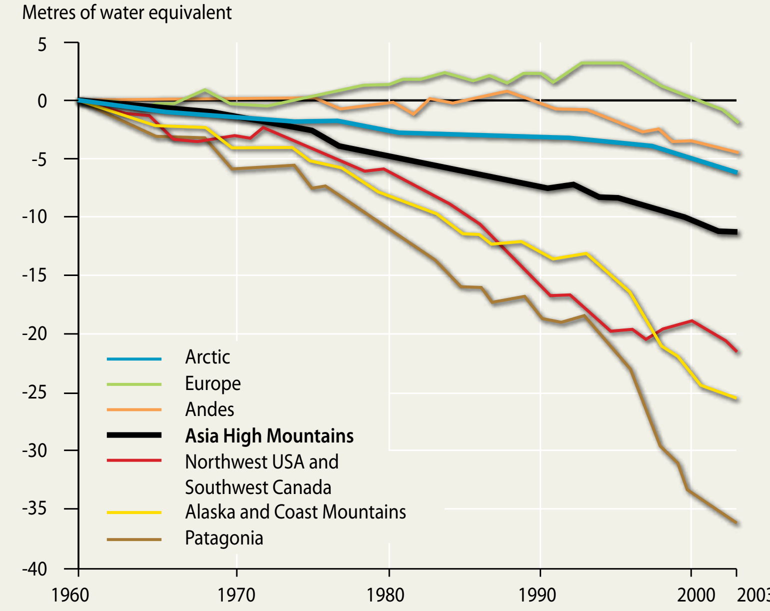
Glacier thickness chang

Measured over different time ranges for each glacier



* Measures the geodetic thickness change between survey and reference year in metres of ice equivalent

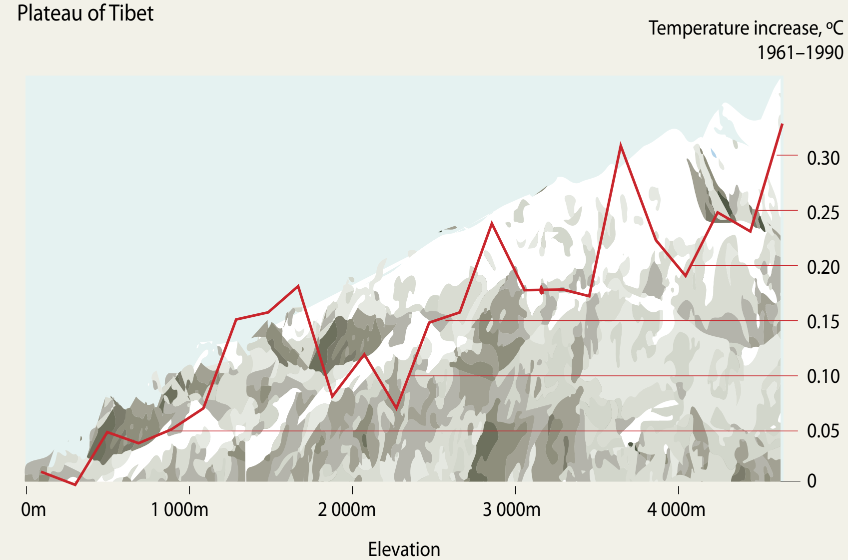
Glacier cumulative mass balance



Source: Dyurgerov, M; Meier, M (2005) *Glaciers and the changing earth system: a 2004 snapshot*. Boulder: Institute of Arctic and Alpine Research, University of Colorado

Temperature increased more in high altitude regions

Plateau of Tibet



Source: Liu, X; Chen, B (2000) 'Climate Warming in the Tibetan Plateau During Recent Decades' *International Journal of Climatology* 20: 1729–1742

Black carbon – An additional factor in accelerated melting of Himalayan glaciers?

CASE STUDY

Black carbon is a product of incomplete combustion (burning that gives off smoke) and is the main constituent of soot. The current level of understanding, which is still evolving, suggests that more than half the black carbon emitted in South Asia comes from the burning of biomass – mainly wood and mostly from cooking fires. Most of the black carbon that is deposited on the Himalayan mountains and southern parts of the Tibetan plateau comes from the South Asian plains, but black carbon can also be transported through the atmosphere over long distances and can come from as far away as Africa, the Middle East, central China and Europe.

Black carbon can affect the climate in the Himalayan mountains in two ways. When deposited onto snow or ice, it darkens the surface allowing more sunlight to be absorbed and, therefore, warming the surface and increasing melting. Black carbon also absorbs sunlight when it is suspended in the atmosphere. The air heated by the atmospheric black carbon is in contact with the mountains, warming them. This is the likely explanation for the more rapid increase in temperatures at higher altitudes over the last few decades. Black carbon is likely to be responsible for a considerable part (around 30%, by some calculations) of the glacial retreat that has been observed across the HKH region.[68] Significant research needs to be done to better establish the relationship between black carbon, glacial melt and water in general.

Trends in extreme events across the HKH

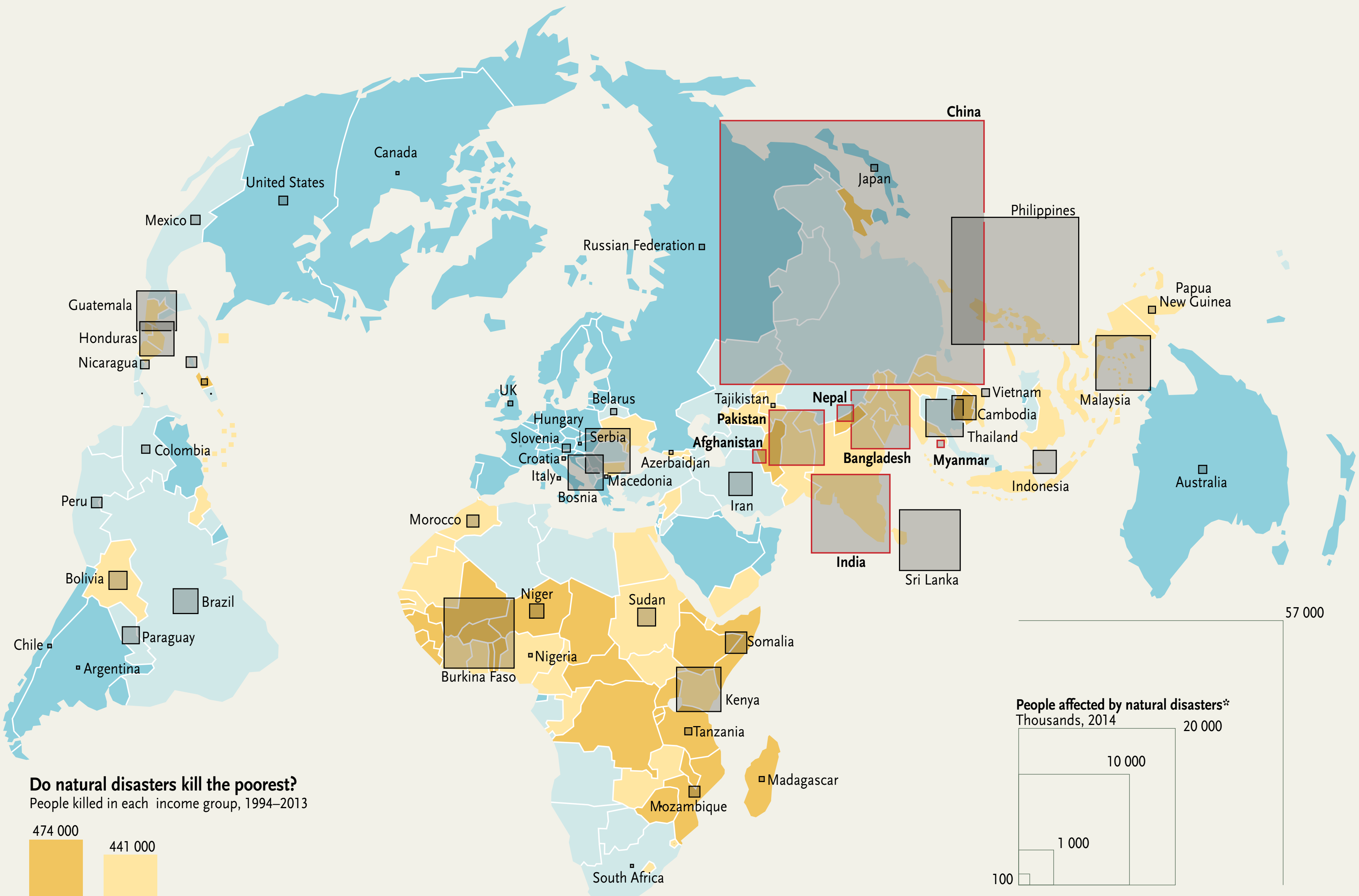
Asia is the most disaster-prone region in the world. In 2014, over 40% of the world's natural disasters were reported in this region.[69] It is also where most people have been killed, the greatest losses have been incurred, and the most frequent disasters are clustered. Within Asia, the HKH region stands out for its water-related disasters and the human toll these take, especially flooding.

Many of the 210 million people living in the Hindu Kush Himalayas and the 1.3 billion people living downstream[70] are exposed to devastating floods every year. Water-related hazards and risks include landslides, debris flows and flash floods in the uplands and riverine and coastal flooding in the lowlands. Across the HKH region, there has been a steady increase in the number of flood disasters reported each decade.[71,72] This last decade saw the highest number of reported flood disasters with the greatest spatial coverage on record. These included the devastating floods in Pakistan in 2010 and the Uttarakhand flood in India in 2013. The 2010 Pakistan floods killed some 2,000 people and submerged about a fifth of Pakistan's land, affecting the lives of 20 million people. Some 5,900 camps sprung up across the country to host the more than 220,000 people displaced by the disaster. This disaster is considered one of the biggest river disasters in recent history. In general, the economic impact of flood disasters within the HKH region is highest in Pakistan, Afghanistan and Nepal, while loss or injury to human life is highest in Bangladesh, Pakistan, Bhutan and India.[73]

At a more localized level, GLOFs pose a significant risk to mountain and downstream communities. Glacier thinning and retreat in the Himalayas has resulted in the formation of new glacial lakes and the enlargement of existing ones due to the accumulation of meltwater behind loosely consolidated end moraine dams. Recent research has shown that many lakes are expanding at a considerable rate. The number of glacial lakes has been increasing across the region over the last 30 years, from 4,600 in 1990 to 5,700 in 2010,[74] resulting in increasing risks over time for downstream communities and environments.

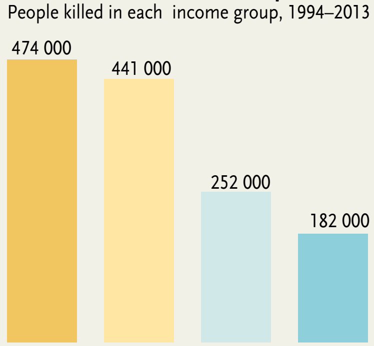
Along with flooding, changing precipitation patterns have also resulted in increased frequency and intensity of droughts in many parts of South Asia. Across the HKH region, ICIMOD's research shows that the number of rainy days has decreased, but there are more intense rainfall events, while the total amount of annual rainfall has stayed the same.[75] The most vulnerable to the effects of drought are people living in already dry arid and semi-arid regions such as the upper Indus basin, Tibetan plateau and Ladakh, or where groundwater resources are low or scarce such as in the high mountains. As the impacts of climate change increase, these regions will become even more vulnerable to the impacts of drought.

Asia, the region most hit by natural disasters in 2014



Do natural disasters kill the poorest?

People killed in each income group, 1994–2013



People affected by natural disasters*
Thousands, 2014

57 000
20 000
10 000
1 000
100

* Includes droughts, floods, wildfire, storms, extreme temperatures and landslides

Countries in the Hindu Kush Himalayan region

Countries by income groups

- Low income
- Lower middle income
- Upper middle income
- High income

Source: Guha-Sapir, D; Below, R, Hoyois, Ph (nd) EM-DAT: *International disaster database*; Brussels: Université Catholique de Louvain. www.emdat.be

The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by ICIMOD, CICERO or GRID-Arendal.

Uttarakhand – What really happened?

CASE STUDY

A major disaster struck on 16 and 17 June 2013 in Uttarakhand after heavy rainfall occurred in several parts of the State. According to the Indian Meteorological Department, on 17 June the state had received 340 mm, more than four times the average rainfall during this period. This abnormally high amount of rain has been attributed to the interplay between westerlies and the monsoonal circulations. This heavy precipitation resulted in the swelling of rivers, in both upstream and downstream areas. Besides the rain water, a huge quantity of water was probably released from the melting of ice and glaciers due to high temperatures during May and June, as well as the outburst of glacial lakes.

This event killed more than 5,500 people and thousands went missing. About 100,000 pilgrims were trapped. It is suggested that the geomorphological setting of the area aggravated the flood impact. The heavy rainfall caused numerous landslides blocking the river and causing the subsequent sudden release of the stored water. There was also heavy damage to infrastructure, including highways and bridges. It is believed that socioeconomic factors further compounded the natural factors resulting in the catastrophic impact of the event. Heavy deforestation, road construction, the unplanned extension of settlements, mining and hydropower development are thought to have contributed to the damage.

The Indian Meteorological Department claims to have provided timely warning of the heavy rainfall event, but lack of proper communication mechanism rendered the warning of little use. Further, lack of proper response mechanisms at the local level and the presence of an overwhelmingly large number of unprepared pilgrims in the area compounded the impact of this disaster.

Extreme precipitation also resulted in floods in the western Nepalese district of Darchula.

Climate trends in the Brahmaputra river basin

The Brahmaputra river basin

Source: Angsi Glacier

Mouth: Bay of Bengal

Length: 2,900 km

Area: 543,400 km^2 [76]

Countries: China (50%), India (36%), Bangladesh (7%), Bhutan (7%)[77]

Main tributaries: Dibang, Lohit, Dhansiri, Kolong, Kameng, Manas, Raidak, Jaldhaka, Teesta, Subansiri

Starting from an elevation of 5,300 m, the Brahmaputra river flows across southern Tibet, passing through the Himalayas, descending onto the Assam plain, and finally emptying into the Bay of Bengal. The river undergoes a dramatic reduction in altitude as it passes through one of the world's deepest gorges in the Himalayas and enters the Assam plain, depositing large amounts of sediment downstream. In the Assam and Bangladesh plains, the river flows in highly-braided channels (numerous channels that split apart and join again) separated by small islands.

The river relies on both the monsoon and snow and glacial melt and, as such, is characterized by a large and variable flow.[78] The monthly average flow rate varies from 3,244 m^3/s in March to 44,752 m^3/s in July. The average annual flow rate is 19,160 m^3/s, the fourth highest in the world.

The annual average water availability in the Brahmaputra basin is about 608,000 million m^3, ranging from a monthly average of 8,408 million m^3 in the driest month to 115,996 million m^3 in the wettest. The estimated total water use in the Brahmaputra basin is approximately 27,457 million m^3/year, of which 2% is used in China (Tibet), 1% in Bhutan, 43% in India and 54% in Bangladesh. Agriculture and domestic use account for 98% of water use in the basin.

Current infrastructure does not allow all potential users access to the water in the Brahmaputra river. Despite this, however, demand still exceeds water availability in the driest months (January to March). As water infrastructure improves and access to water increases, the amount of water available downstream might be further reduced. During the dry months, the pressure on ecosystems and environmental flows may be critical.

While the river can meet human demand for water during the monsoon season, water demand estimates do not include demand for sustaining ecosystems and the environmental flow of the river. The high pre-monsoon and monsoon flow is critical for the spawning of many species of fish in the river and its estuary.

The Brahmaputra river basin is particularly prone to floods and erosion. The floods are caused by a combination of natural factors, such as the monsoon system and weak geological formations, and anthropogenic factors, such as deforestation and high population growth.[79] Floods cause devastation every year, affecting people and the vital agricultural economic base of the region.

Climate trends

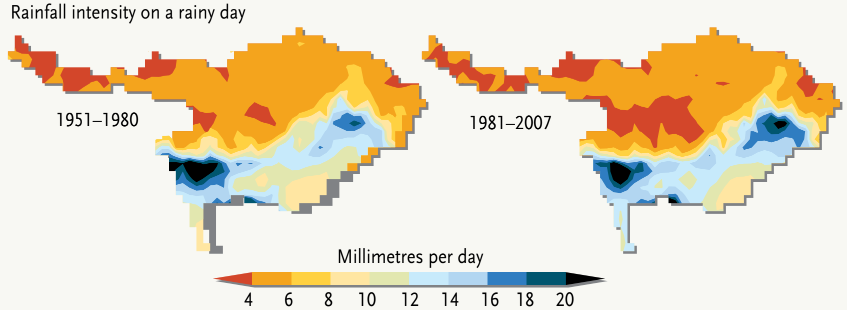
Precipitation

The Brahmaputra basin receives an average of just over 1,100 mm of rain annually. Of the annual total, 70% is received during the monsoon season (June–September) and 20% in the pre-monsoon season. Winter is the driest season.

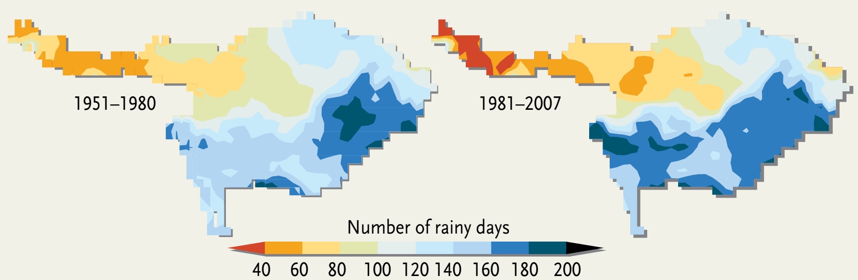

The Brahmaputra river basin
AFGHANISTAN
CHINA
PAKISTAN
NEPAL
BHUTAN
INDIA
BANGLADESH
MYANMAR
PLATEAU OF TIBET
HIMALAYAS
CHINA
NEPAL
BHUTAN
INDIA
BANGLADESH
MYANMAR
Lunpo Gangri
Nyainqentanglha Feng
Gyala Peri
Namcha Barwa
Bairiga
Gangkar Punsum
Kangto
Kangchenjunga
Lhasa
Nyingchi
Xigaze
Gyangze
Punakha
Paro
Thimphu
Gangtok
Siliguri
Alipur Duar
Dibrugarh
Itanagar
Tezpur
Jorhat
Guwahati
Dispur
Shillong
Kohima
Saidpur
Rangpur
Jamalpur
Tangail
Elevation
Metres
6 000
3 000
1 000
0
Main mountain peak
Glacier
Protected area
Hindu Kush Himalayas

Brahmaputra basin climate indicators – Rainfall

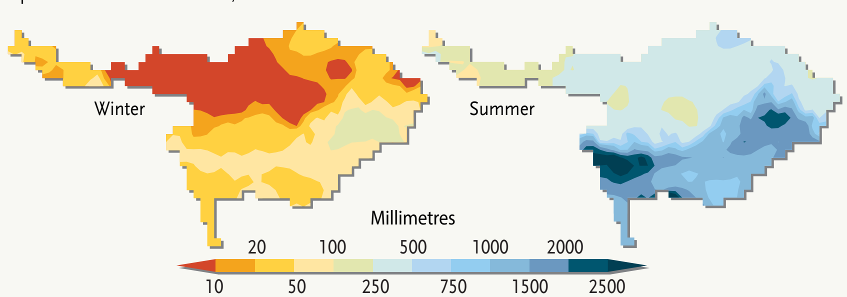
How much does it rain?
Rainfall intensity on a rainy day



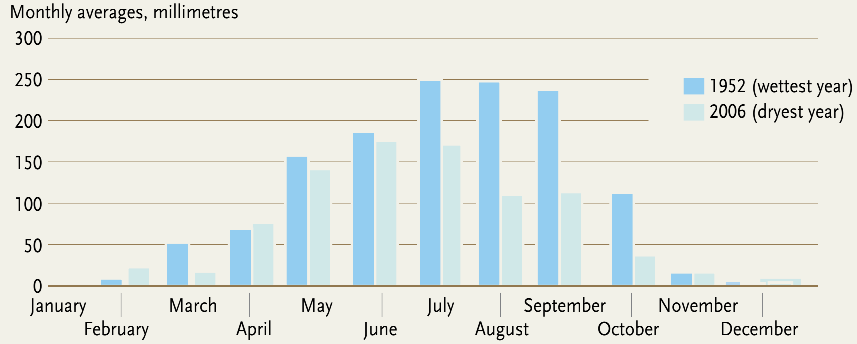
For how long does it rain?
Rainy days in a year



Where does it rain?
Spatial distribution of rainfall, 1981–2007

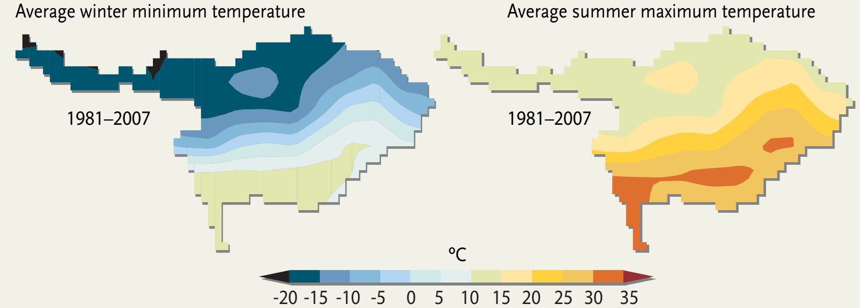


When does it rain?
Monthly averages, millimetres

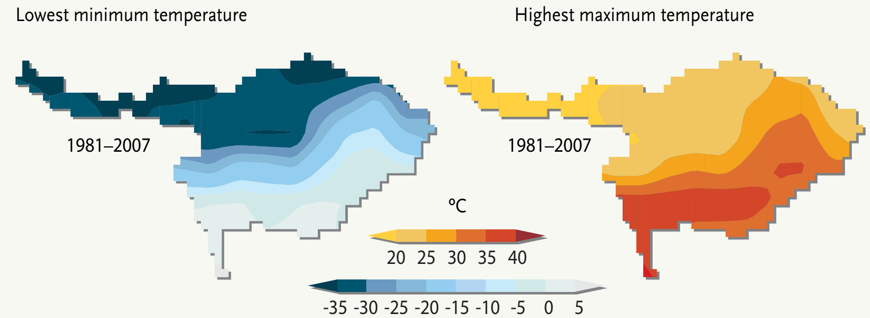


Temperature

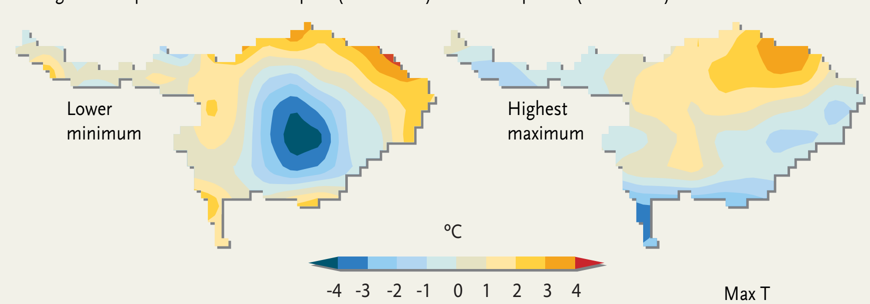
Where is it hot and where is it cold?
Average winter minimum temperature



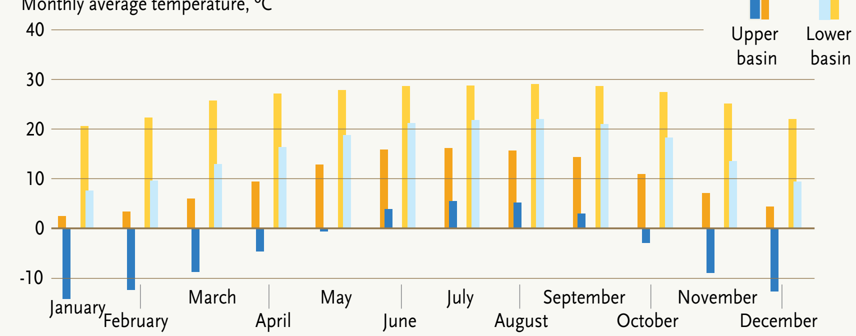
How hot and how cold?
Lowest minimum temperature

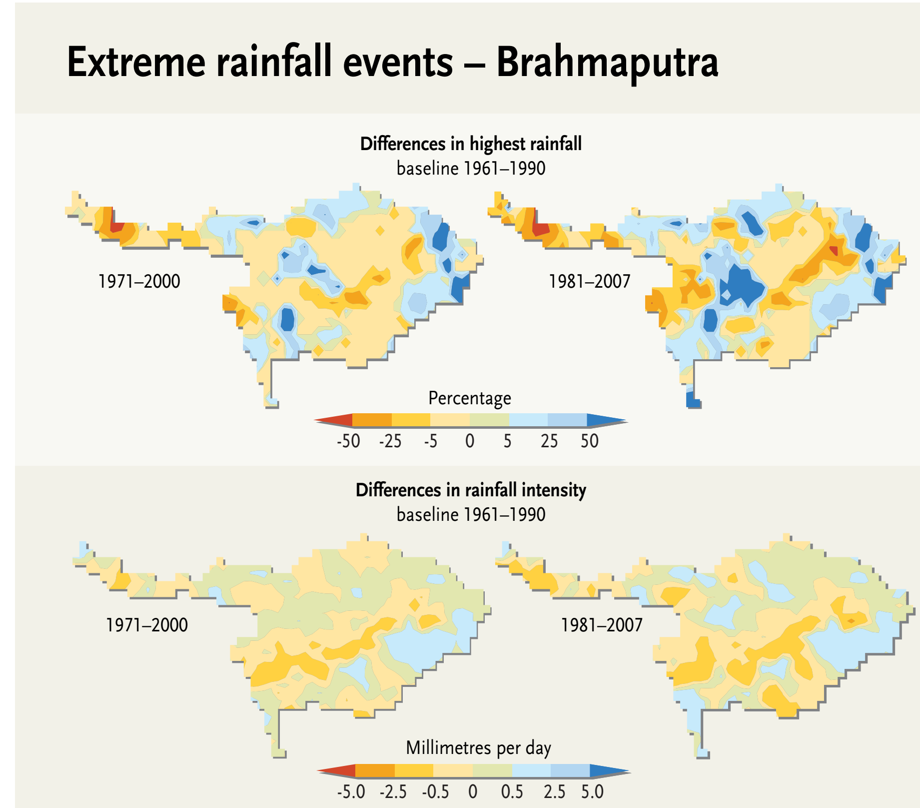


Temperature changes
Changes in temperature between the past (1951–1980) and recent period (1981–2007)



When is it hot and when is it cold?
Monthly average temperature, °C





Rainfall distribution varies considerably between the southern and northern parts of the basin. The lower Brahmaputra basin receives approximately 2,216 mm of rain annually, which is over three times more than the upper basin. There are approximately 164 rainy days a year in the upper Brahmaputra and 214 in the lower Brahmaputra basin.

No specific trend of change in the amount of rainfall has been observed between the baseline period of 1951–1980 and 1981–2007. Extreme rainfall appears to be decreasing in the north, but increasing over eastern portions of the basin. Rainfall intensity (mm/day) has increased slightly over eastern portions of the basin.

Temperature

Over the past decades and across the basin, temperatures are changing over time and showing mixed trends across the seasons and in different areas of the basin. Overall, increasing trends are seen in average winter minimum temperatures, as well as in night-time temperatures.

The average maximum temperature in the Brahmaputra basin is 19.6°C in the summer and approximately 9.2°C in the winter. The average minimum temperature is –0.3 °C in winter and 18.3°C in summer (these figures are seasonal averages for June, July, August and September for summer and December, January and February for winter). Minimum temperatures are showing an increasing trend: there has been a significant rise of 0.5°C in average minimum winter temperature across the basin. Within the pre-monsoon and post-monsoon, the rise is 0.3°C and 0.4°C, respectively. The temperature in the summer (monsoon) has not changed. Average summer maximums are showing a slight increase, but it is not significant. However, night-time temperature shows a highly significant warming trend for winter as well as summer.

Extreme high temperatures (highest maximum temperature) are increasing over the northern parts of the basin (the Tibetan plateau), but decreasing east and southwards. Extreme minimum temperatures are decreasing (getting colder) in the centre of the basin.

Beware, Assam

Reproduced and abridged with permission from The Telegraph, Calcutta, India

Come the monsoon and the mighty Brahmaputra overflows, ravaging parts of northeast India, and leading to some of the most destructive floods in the last 10 years.

There's worse to come, say scientists.

The river has the world's highest specific discharge. The volume of floodwaters and the height to which they will rise is set to increase in the coming years owing to global warming, report scientists at the Indian Institute of Technology, Guwahati (IIT-G) and University of New South Wales.

A team led by Subashisa Dutta, professor at IIT-G's department of civil engineering, has reported the Brahmaputra flood characteristics based on the latest climate projections and the empirical relationship between rainfall and floods in the river basin.

The Brahmaputra is a unique river, different from other peninsular Indian rivers and the Ganges, Dutta explained to KnowHow. The floods occur mostly in the main river channel and the river can flood two times – once owing to pre-monsoon showers from March to May and again during the monsoon.

Dutta says that most international researchers only consider the flood peak – the maximum height to which floodwaters rise – as an indicator of

vulnerability. But his team considered two additional factors – how long a flood wave lasts and how fast a flood wave rises. Fast-rising flood waves do not give people time to adapt or escape.

The analysis shows that the flood peak stage – the maximum height to which floodwaters rise – and flood volume will increase in future. The spells of intense daily rainfall are also expected to increase. It is the pre-monsoon showers, rather than the monsoon, which will increase because of global warming. The scientists say that the duration of floods will decrease, but the height to which floodwaters rise will increase. This means that more areas will be inundated.

Says Dulal Goswami, former professor of environmental science at the University of Guwahati who has been studying the Brahmaputra floods for years, “So far, we were receiving generalised, long-term information that could not be factored into specific local projects. We need short-term, focused information that can be factored into developmental processes; as well as for river and water resources management.”

The findings have huge implications for poor and marginalised farmers in the Brahmaputra riverine area, as their main agricultural activity is in the pre-monsoon season. Many poor farmers take to the riverine area in October and begin to grow crops, till the rain-triggered floods begin. Then the farmers shift in country-made boats to higher areas and wait for the waters to recede.

A second fallout of shorter-duration flood waves during a spell of heavy rainfall is that most water flows away, leaving little water for the catchment area.

Meanwhile, the International Centre for Integrated Mountain Development (ICIMOD) in Kathmandu is testing its community-based flood early warning system (FEWS) to help local communities cope with smaller-scale floods in the Brahmaputra. ICIMOD installed three FEWS along the Jiadhal and Singora rivers in the eastern Brahmaputra sub-basin in 2014, after conducting a risk, hazard and vulnerability assessment of the area. Plans are afoot to install them at the end of July this year too. Discussions on extending the system across other rivers in the Brahmaputra basin, prone to incessant flooding, are also on.

The downside, however, is that the small ICIMOD systems get washed away in massive floods. But, says ICIMOD expert Nand Kishor Agrawal, there are other systems for massive floods, and “quite often people have to deal with small floods more frequently than massive floods. In such situations FEWS prove much more beneficial.”

Source: Padma, TV (2015) ‘Beware Assam.’ *The Telegraph*, Calcutta, India [online], 27 July 2015. http://www.telegraphindia.com/1150727/jsp/knowhow/story_33765.jsp (accessed 16 October 2015)

Climate trends in the Ganges river basin

The Ganges river basin

Source: Gangotri Glacier, Uttarakhand, India

Mouth: Bay of Bengal

Length: 2,525 km

Area: 1,087,300 km^2 [80]

Countries: India (79%), Nepal (14%), Bangladesh (4%) and China (3%)[81]

Main tributaries: Yamuna, Rama Ganges, Gomti, Ghagra, Sone, Gandak, Burhi Gandak, Koshi, Mahananda

The Ganges is one of the three main river basins in the Hindu Kush Himalayas. Its source is high in the Himalayan mountains where the Bhagirathi river flows out of the Gangotri Glacier in India's Uttarakhand state. It takes the name Ganges farther downstream where the Bhagirathi and Alaknanda rivers join.

As the Ganges flows out of the Himalayas it creates a narrow, rugged canyon. It then flows through the Indo-Gangetic plain, a vast fertile area that makes up most of the northern and eastern parts of India as well as parts of Pakistan, Nepal and Bangladesh. Part of the Ganges river is also diverted toward the Ganges Canal for irrigation in the state of Uttar Pradesh. In Bangladesh, the river's main branch is known as the Padma, then downstream as the Meghna, before flowing into the Bay of Bengal and creating the world's largest delta – the Ganges Delta – a vast and highly-fertile sediment-laden area.

Today, the Ganges river basin is the most populated river basin in the world with 400 million people. It has a population density of about 390 people per km^2. Many Hindus visit the Ganges river in Varanasi, which is considered the holiest of cities. The city's culture is also closely tied to the river, as the Ganges is the most sacred river in Hinduism.

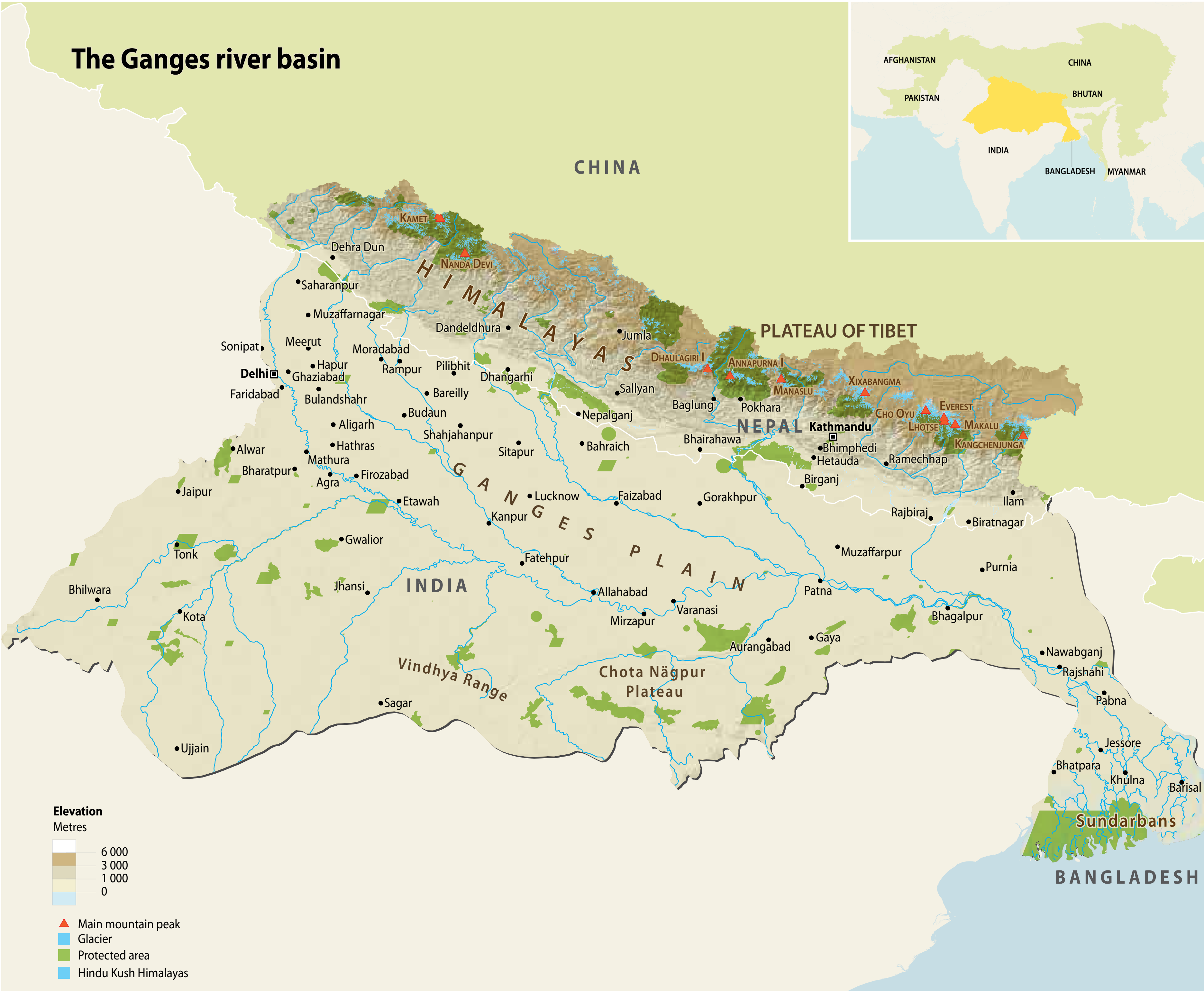
Climate trends

Precipitation

The Ganges basin receives nearly 1,000 mm of precipitation annually. The greatest amount of rain – 84% of the annual total – falls during the monsoon season. Of the remainder, 7% falls during the pre-monsoon season, 5% in the post-monsoon season, and 4% in winter. There are some differences in precipitation between the upper and lower Ganges basins. Although there is not much difference between the annual amount of precipitation in the lower and upper parts of the basin, the number of rainy days varies considerably. In the upper basin, there are 179 rainy days, whereas in the lower basin there are 152 rainy days. The monsoon season accounts for 75% of the rain in the upper basin and 85% of the rain in the lower basin.

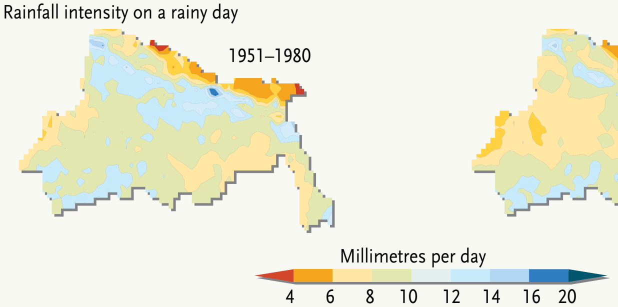
For both the upper and lower basins, the number of rainy days is increasing, but the occurrence of rainfall greater than 10 mm/day is decreasing. The monsoon season shows a slight decreasing trend across the basin (although the trend is statistically insignificant, the amount may be significant). There is also an increasing trend in the duration of the monsoon season, with more dry spells within each season. During the winter season, there is an increasing trend in rainfall over most parts of the basin, and a decreasing trend in the central, southwest and extreme north of the basin.

The Ganges river basin

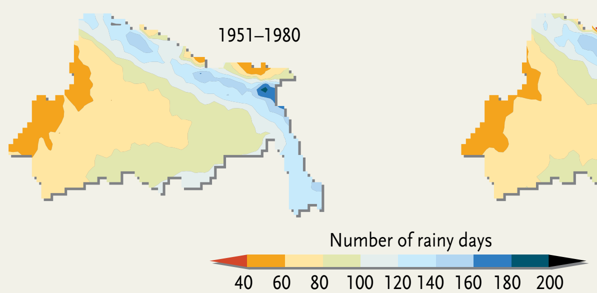


Ganges basin climate indicators – Rainfall

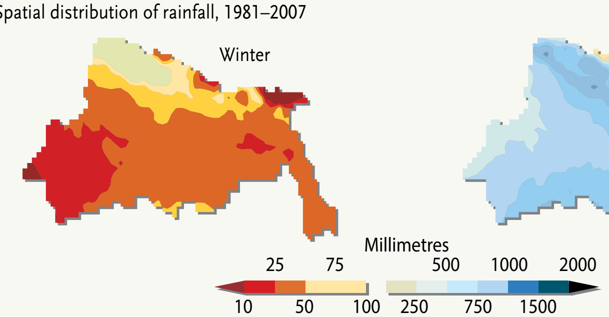
How much does it rain?
Rainfall intensity on a rainy day



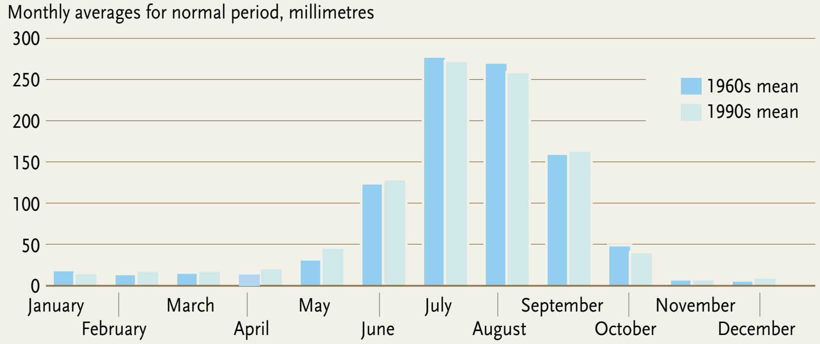
For how long does it rain?
Rainy days in a year



Where does it rain?
Spatial distribution of rainfall, 1981–2007

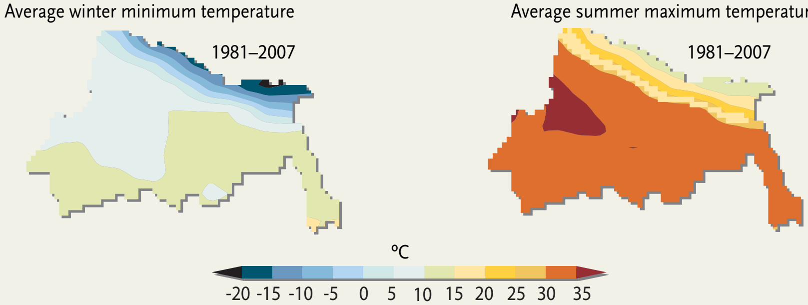


When does it rain?
Monthly averages for normal period, millimetres

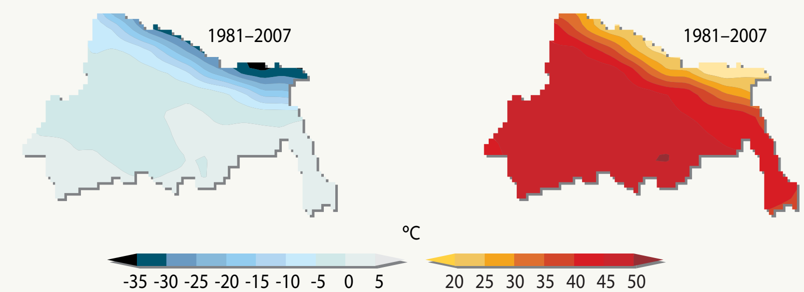


Temperature

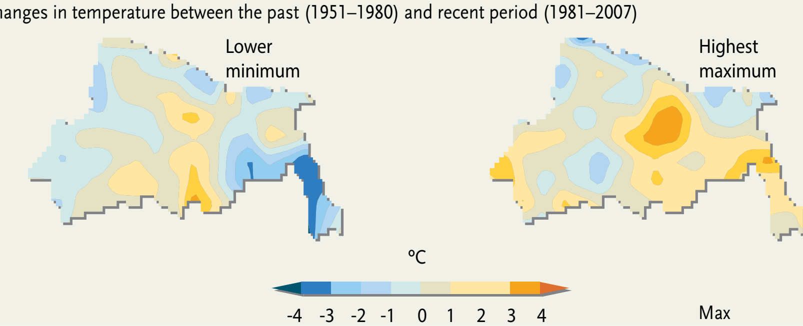
Where is it hot and where is it cold?
Average winter minimum temperature
Average summer maximum temperature



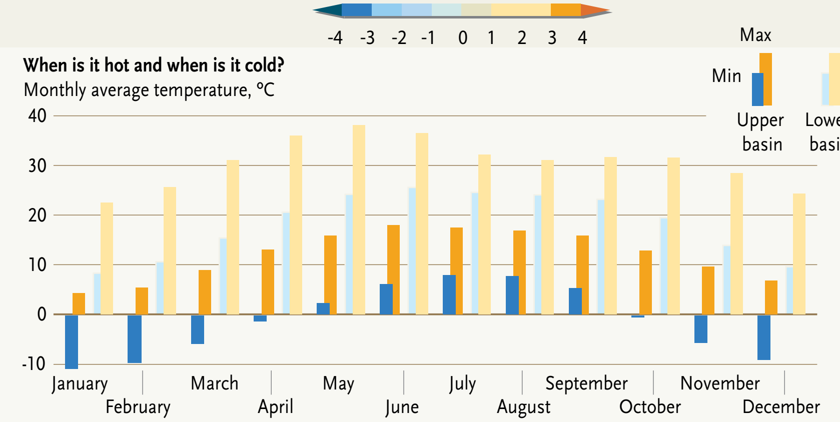
How hot and how cold?
Lowest minimum temperature
Highest maximum temperature



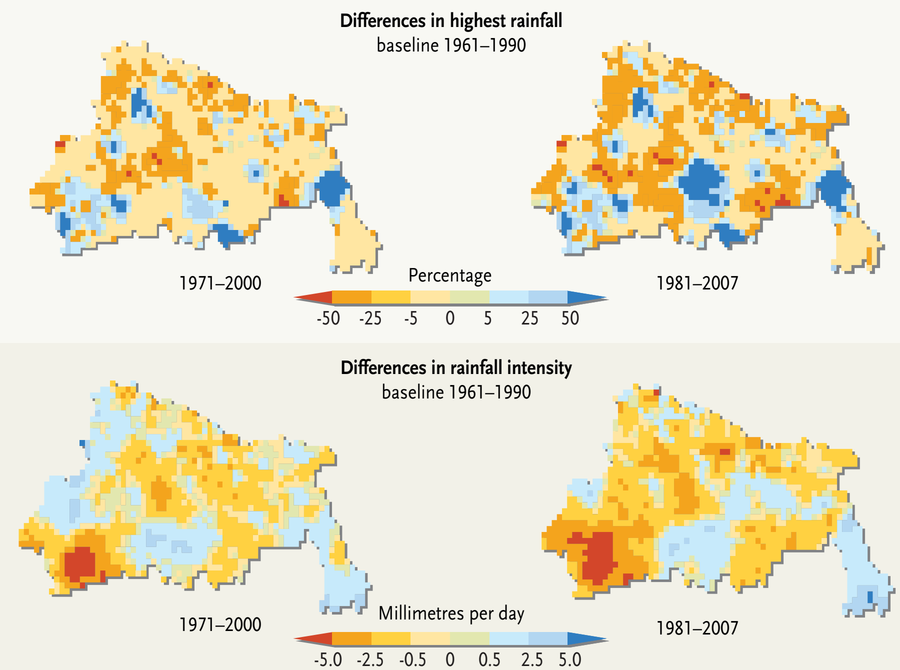
Temperature changes
Changes in temperature between the past (1951–1980) and recent period (1981–2007)



When is it hot and when is it cold?
Monthly average temperature, °C



Extreme rainfall events – Ganges



There are changes in extreme rainfall events and the number of rainy days, but these changes vary across the basin, increasing in some locations and decreasing in others. Rainfall intensity shows a decreasing trend over the western section of the southern part of the basin.

Temperature

Over the past decades and across the Ganges basin, winters are getting warmer, but summer average temperatures have remained constant. Summer extremes are becoming more intense, while winter extremes are showing mixed trends across the basin. The average maximum temperature across the basin is 30.3°C in summer and 21.1°C in winter. The average minimum temperature across the basin is 21.5°C in summer and 6.4°C in winter. The pre-monsoon season is the hottest in the Ganges basin with an average temperature of 31.4°C, with June being the hottest month in the upper basin and May the hottest in the lower basin. The coldest month is January across the whole basin.

Over the last decades, there has been no significant trend in terms of changes in maximum temperatures, but there has been an increase in minimum temperatures in every season across the Ganges basin, with as much as a 0.7°C increase in winter minimum temperature. Night-time temperatures are also showing an increasing trend. Extreme high temperatures (highest maximum) are generally increasing across the basin. Extreme low temperatures are rising (getting warmer) in most parts of the basin with more severity over the central part of the basin, while in the northern-most part temperatures are decreasing (getting colder).

Winter water scarcity in Nepal

Nina Bergan Holmelin, CICERO, Norway

Access to sufficient amounts of water at the right time is of crucial importance for agricultural production. In Dolakha, a mountain district of Nepal, great seasonal variations in rainfall are challenging cultivation, as there as both too much and too little water available for cultivation. During the summer monsoon season there is plenty of water available for irrigated rice cultivation and rainfed maize, millet, potatoes and vegetables. However, the average landholdings are too small to feed the average family throughout the year. Most families in the area are only self-sufficient in food from own production for six months of the year.

In recent years, farmers have started to cultivate winter season vegetables for sale at local and national markets. While most of the fields are planted with winter wheat, the option to cultivate winter vegetables offers a chance to earn additional income during the lean winter season. Cauliflower, soybeans, sugar snaps, radishes, garlic and chilli serve a double purpose as food and cash crops. However, water scarcity in winter creates a problem. Only 2% of the annual precipitation falls from December to February.

People have now begun to take small loans to invest in small water tanks and plastic pipes. Using this simple technology they can irrigate their orchards in the driest period. Said a woman cultivating her plots in the downhill slope:

> *The water dries up in the winter. But we have built a water tank now, of 7,000 litres. It is enough for two households – for us and our neighbour. We invested and built it together two years ago. It was expensive, but now we have enough water for winter vegetables. The tank recharges from a larger well uphill.*

Not everyone lives downstream from a permanent water source. For those who live and cultivate higher up on the ridge, the rainfall is erratic and the wells are small. According to a female farmer:

> *There is a creek, but no water in it. We could grow vegetables in the winter, if there was more water – cauliflower, soybeans, peas and radishes.*

Climate change is expected to increase the average temperatures in Dolakha, especially during night-time, which would improve the conditions for cultivation in the cold season. However, warmer weather is insufficient for cultivation if not accompanied by sufficient water. Water harvesting by means of tanks and pipes can be sufficient to meet the dry season need for water for those who have access to a well. However, the diverse geography of the Himalayas make no single solution universally applicable. The vast differences in micro-climates at the local level call for a diversity of adaptation options, as rich as the diversity of the mountains themselves.

Climate trends in the Indus river basin

The Indus river basin

Source: Lake Ngangla Rinco, Tibetan plateau, China

Mouth: Arabian Sea

Length: 3,180 km

Area: 1,120,000 km^2 [82]

Countries: Pakistan (47%), India (39%), China (8%) and Afghanistan (6%)[83]

Main tributaries: Kabul, Panjnad

The Indus is the 12th largest river in the world and has its source at Lake Ngangla Rinco on the Tibetan plateau. The river basin contains seven of the world's highest peaks in addition to Everest, including K2 (8,600 m) and Nanga Parbat (8,100 m). The basin stretches from the Himalayan mountains to the north to the dry, alluvial plains of Sindh province in Pakistan and flows out into the Arabian Sea.

The upper Indus river basin lies in a high mountain region resting in the Hindu Kush, Karakoram and Himalayan ranges. The high mountains limit the intrusion of the monsoon. Precipitation patterns in the Hindu Kush and Karakoram ranges are characterized by westerly and south-westerly flows, and most of the precipitation falls in winter and spring from the west. Outside of the polar regions, this basin contains the greatest area of perennial (multi-year) glacial ice in the world (20,000 km^2).[84]

Water in the basin is sourced from glacier melt, snow melt and rainfall in the mountains of Pakistan, India and China. River flow is significantly dependent on meltwater from glaciers, which accounts for approximately 41% of total runoff.[85] Glacial melt is crucial for upstream reservoirs to store and release water to downstream areas when most needed. The glaciers serve as natural storage reservoirs, providing year-round supplies to the Indus and some of its tributaries. Adequate discharge of water from the upper Indus basin into the storage lake behind Tarbela Dam is considered crucial. This dam provides water for a substantial proportion of Pakistan's agricultural production. It also provides 49% of Pakistan's total hydroelectric power capacity and approximately 13% of total power output. Approximately 80% of the total discharge in the Indus River basin occurs between May and September.

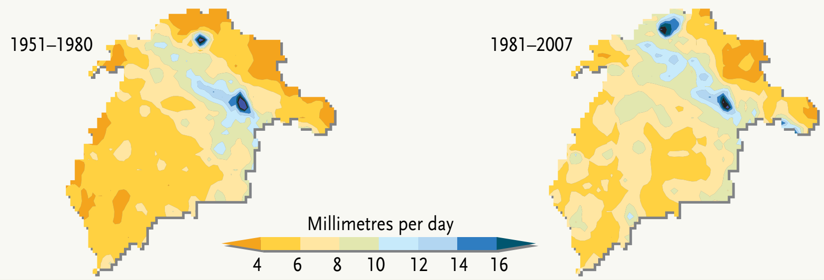
The Karakoram range, which lies partly within the Indus basin, has received international attention due to the observation that the glaciers within this range have remained stable or even increased in mass, whilst other glaciers worldwide and within other Himalayan mountain ranges have receded (the Karakoram anomaly). The ice is thought to be sustained by a unique and localized seasonal pattern that keeps the mountain range relatively cold and dry during the summer.

The Indus basin is the 2nd most water stressed basin in the world.[86] At the same time, it ranks among the most important in the world in terms of human dependence, supporting about 215 million people, both directly and indirectly. It is the main source of water for agriculture, energy production, industrial use and human consumption for the people living in the basin. The Indus basin occupies 65% of the territory in Pakistan, which is considered one of the world's most water stressed countries in the world, with an average rainfall of less than 240 mm per year. About 90% of Pakistan's agriculture depends on this river. Pakistan has the world's largest irrigation system, with much of the water from the Indus diverted for irrigation.

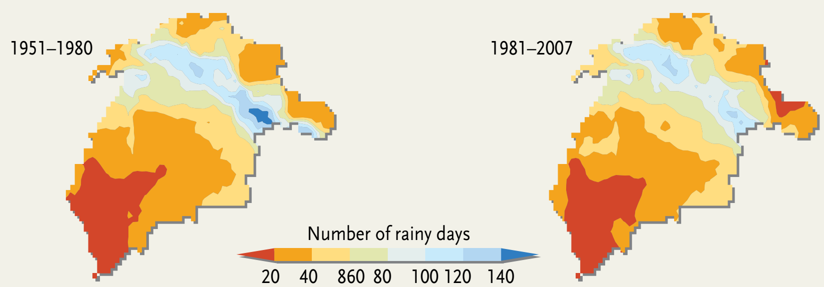
The Indus river basin

Indus basin climate indicators – Rainfall

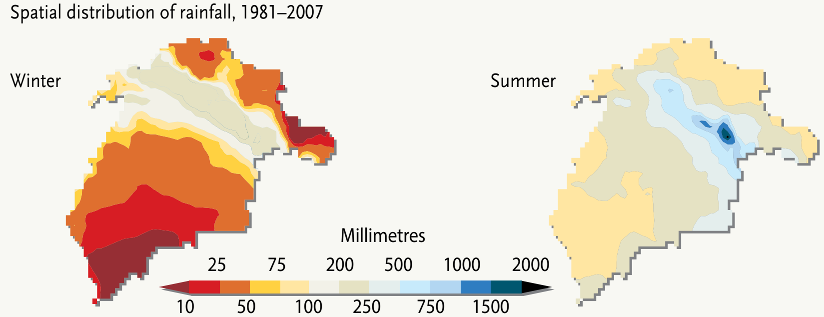
How much does it rain?
Rainfall intensity on a rainy day



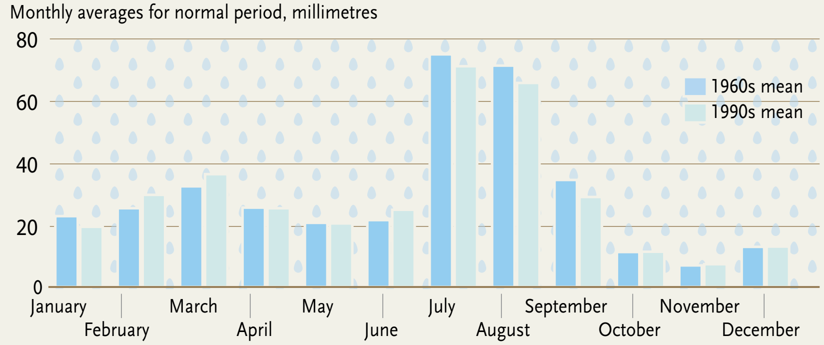
For how long does it rain?
Rainy days in a year



Where does it rain?
Spatial distribution of rainfall, 1981–2007



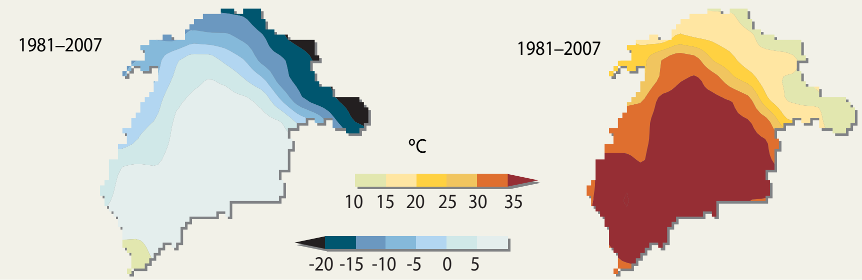
When does it rain?
Monthly averages for normal period, millimetres



Temperature

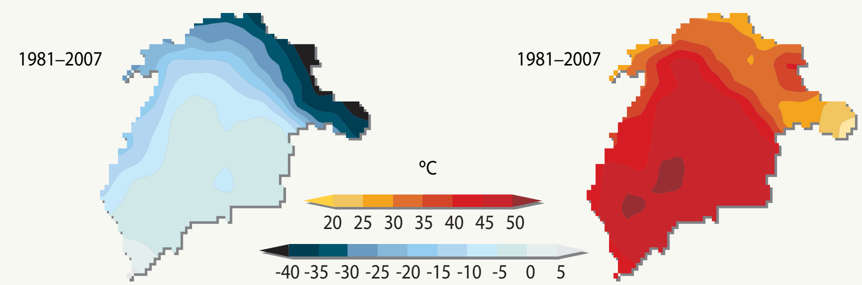
Where is it hot and where is it cold?
Average winter minimum temperature

Average summer maximum temperature

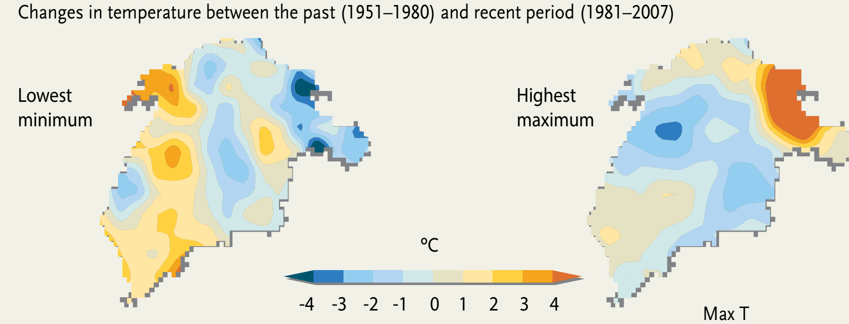


How hot and how cold?
Lowest minimum temperature

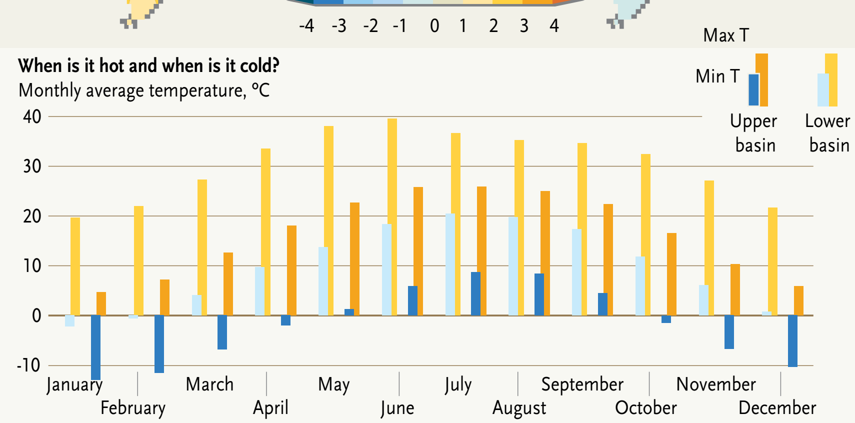
Highest maximum temperature



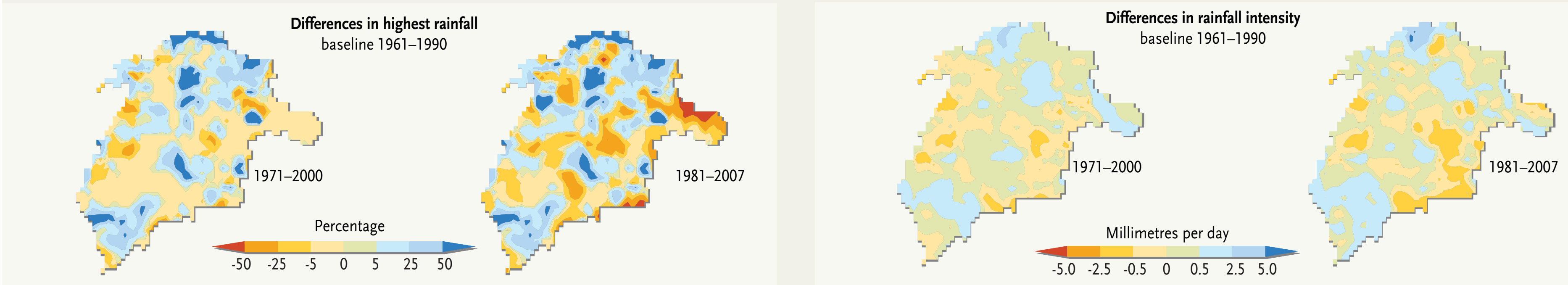
Temperature changes
Changes in temperature between the past (1951–1980) and recent period (1981–2007)



When is it hot and when is it cold?
Monthly average temperature, °C



Extreme rainfall events – Indus



Climate trends

Temperature and rainfall within the Indus basin paint a complicated picture. Changes are happening, but no clear trend has been identified so far.

Precipitation

Overall, the upper basin receives more precipitation than the lower basin and plays an important role in water availability in the whole basin throughout the year. Within the upper basin, the main mountain range is important, because it receives the most precipitation and of the highest intensity, both of which are showing increasing trends.

The average annual precipitation in the Indus basin is 365 mm, although the variation across the basin is considerable, particularly between the upper and lower basins. The upper Indus receives nearly 500 mm, whereas the lower basin receives just under 300 mm. The highest annual precipitation occurs along the main mountain range in the upper basin, which can reach up to 3,000 mm in some areas. The lowest precipitation (lower than 100 mm) occurs within the lower basin and northeastern parts of the upper basin. Overall, the upper basin experiences 132 rainy days a year, compared to 84 days in the lower basin. Fifty-five per cent of precipitation falls during the monsoon season. However, compared to the other basins, winter precipitation also plays an important role. Winter contributes 17% of the total annual precipitation for the whole basin and as much as 30% in the upper basin.

Summer precipitation has decreased over a large part of the basin, particularly over the southern slopes of the main mountain range, and especially in the east where the highest (maximum) rainfall is observed. Winter precipitation has increased overall, but with the exception of some parts of the upper basin towards the northeast. Contrary to general climate trends, rainfall variability was greater during the 1960s and has decreased slightly in recent years.

Extreme rainfall events have increased in intensity over the main mountain range in the upper basin, especially in the eastern section, while the number of rainy days has decreased. In summary, this area now receives more rainfall in fewer rainy days. Within the rest of the basin, the intensity has decreased, while the number of rainy days has remained the same.

Temperature

Over the past decades and across the basin, winters are getting warmer, but summers are getting cooler. However, extreme hot days are getting hotter and extreme cold days are getting milder.

Across the Indus basin, the average maximum temperature is about 30°C in summer and 13°C in winter. Average minimum temperatures range from 18°C in summer to −0.3°C in winter. The coldest month is January and the warmest is June.

The average temperature has shown an increasing trend, driven mainly by increases in winter temperatures, and more prominently since the 1980s. Average maximum temperatures have slightly decreased (0.5°C), while minimum temperatures have increased (1.2°C) in the winter. Average minimum temperatures have increased in both seasons.

The extreme maximum temperature is increasing most prominently over the upper basin, whereas the trend is decreasing over the lower basin (except for a large area in the southwest). The extreme minimum temperature is decreasing over the central part and in a small area over the northeast and southwest; elsewhere it is on the rise with the highest severity over the north and west.

Water stories

Changing growing seasons in the upper Indus valley

Tor H Aase, CICERO, Norway & Sher Ahmed, Mountain Agricultural Research Centre, Gilgit-Baltistan, Pakistan

Mild weather does not necessarily imply a longer growing season in the upper Indus valley. The winter of 2014 was particularly mild in the Hindu Kush mountains, raising optimism among farmers along the Sai river in Gilgit, Pakistan of an early spring and a long growing season with rich harvests. Gilgit is a semi-arid cool region where summer cultivation is dependent on gravity-fed irrigation. Irrigation canals divert water from streams that originate in the high mountains and ultimately feed into the Indus river. Because precipitation is modest in the settled valleys, water discharge in streams is conditioned by snow melt in the higher reaches. Irrigation water is particularly important in spring when summer wheat is sown. An early spring allows for a second crop of maize after the wheat is harvested in June, while a late spring may cause damage to ripening maize, which should be harvested before frost nights occur in November.

Contrary to expectations of good crops, 2014 turned out to be a particularly difficult year. The mild winter brought cloudy weather in March and April, which prevented sunshine from melting the snow in the high mountains. The snow melt started two weeks later than usual and the wheat sowing had to be postponed accordingly. Some farmers harvested green wheat and used it for livestock fodder in order to allow for an autumn maize crop, while others faced damage to their maize in late autumn. Indeed, several years of late snow melt has motivated many farmers to grow wheat for fodder and buy flour for consumption from the market. Villagers increasingly prefer to make bread using high-quality wheat flour brought to Gilgit from Punjab via the Karakoram Highway, while the locally grown wheat is given to livestock.

The mild winter of 2014 had another effect on local livelihoods. Historically, villagers have collected firewood from the Sai river, which has been more or less sufficient for a full year. Winter avalanches cut down trees in the high mountains, which are brought to downstream villages by the spring floods. The mild winter decreased avalanche activity in the mountains and less branches and logs flowed down the river. The decreased amount of firewood available for household use was compensated for by an increase in the use of gas and kerosene.

Farmers in the Hindu Kush have learnt that there is not necessarily a correlation between temperature and the length of the growing season, and that the timely availability of water must also be taken into account.

Climate trends in the Mekong and Salween river basins

The Mekong river basin

Source: Lasagongma Spring, Tibetan plateau, China

Mouth: South China Sea

Length: 4,350 km

Area: 795,000 km^2 [87]

Countries: Laos (25%), Thailand (23%), China (21%), Cambodia (20%), Vietnam (8%) and Myanmar (3%)[88]

Main tributaries: Nam Khan, Tha, Nam Ou, Mun, Tonle Sap, Kok, Rual

Like the Salween and Yangtze rivers, the Mekong river arises in the Three Rivers Source Area high in the Tibetan plateau in Qinghai, China. The Sanjaingyuan National Nature Reserve was established to protect the headwaters of these three major rivers. For approximately 300 km of its length, the Mekong runs parallel to the Salween and Yangtze rivers through the Three Parallel Rivers World Heritage site in Yunnan province, China. It is the 12th longest river in the world and the 7th longest in Asia. Flowing through six countries, the Mekong drains into the South China Sea through the Mekong Delta in Vietnam. At times along its course it forms the international border between Myanmar and Laos, and between Laos and Thailand. About one-fifth of the river lies in the upper basin in the Tibet part and in mainland China.

The flow in the upper Mekong is dominated by rainfall runoff (up to 44%), followed by snow melt (approximately 33%), and glacier melt (approximately 1%).[89] The contribution of snow melt to runoff is the highest of the five river basins covered in this Atlas. Accordingly, the Mekong river experiences strong seasonal variations in flow. Peak discharge is directly related to peak rainfall during the monsoon season.[90]

The mean annual discharge at the mouth of the Mekong river is approximately 475 km^3 or 13,000 m^3/s. About 12% of the average annual discharge (60 billion m^3) is used for agriculture, industry and other consumption in the lower Mekong basin.[91] There are plans for 11 hydroelectric dams on the lower Mekong river.[92]

The Salween river basin

Source: Northeastern Tibetan plateau, China

Mouth: Andaman Sea

Length: 2,815 km

Area: 320,000 km^2 [93]

Countries: China (53%), Myanmar (42%), Thailand (5%)[94]

Main tributary: Moei

The Salween river originates approximately 4,000 m above sea level on the Tibetan plateau in China and flows southward through steep mountain canyons until emptying into the Gulf of Martaban in the Andaman Sea. For 120 km, it forms the international border between Myanmar and Thailand. Passing through a series of deep gorges, it is often referred to as the 'Grand Canyon of the East'. It is also one of the longest free-flowing rivers in the world, although there are plans to build a series of 13 dams along the Chinese portion of its course. A swift and powerful river, it is only navigable up to 90 km from its mouth, and then only during the rainy season. The river is used to float timber to saw mills downstream.

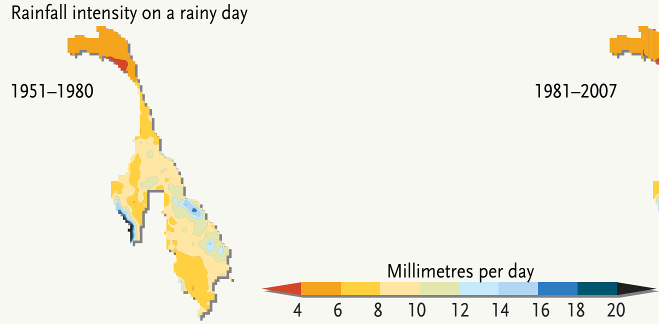
The Salween river basin supports one of the most diverse eco-regions in the world and is home to numerous endemic species and 80 rare and endangered species of fish and wildlife.[95] With over 255 of the world's animal species and as much as 50% of China's species, it is a biodiversity hotspot.[96] In 2003, UNESCO designated the Chinese portion of this area as the Three Parallel Rivers World Heritage Site. Unfortunately, the river also has the distinction of being one of the ten most polluted rivers in the world and the natural resources of the basin are undergoing high rates of exploitation.[97]

Runoff in the upper Salween basin is dominated by rainfall (42%). Because large parts of the basin are located on the Tibetan plateau, snow melt also contributes a sizeable portion (28%).[98] Meltwater from glaciers accounts for another 8% of total runoff. Peak discharge from the Salween is during the monsoon season. Discharge is dominated by snow melt in the early months of the monsoon season and by rainfall during the later months.

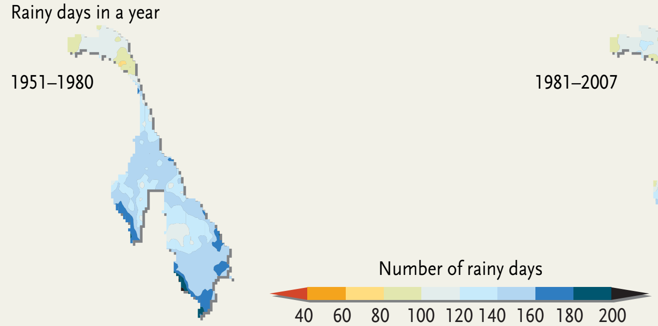

The Mekong and Salween river basins
NEPAL
BHUTAN
BANGLADESH
INDIA
MYANMAR
CHINA
SALWEEN
MEKONG
Nagqu
Qamdo
Dali
Baoshan
Simao
Phongsali
Louang Namtha
Ban Houayxay
Louangphrabang
Muang Xaignabouri
Vientiane
Loei
Udon Thani
Thakhek
Taunggyi
Naypyidaw
Loikaw
Chiang Rai
Mae Hong Son
Chiang Mai
Lamphun
Lampang
Taungoo
Pyu
Bangkok
Tak
Chaiyaphum
Bua Yai
Roi Et
Yasothon
Saravan
Pakxe
Attapu
Kon Tum
Buriram
Surin
Sisaket
Aranyaprathet
Sisophon
Siem Reap
Battambang
Stoeng Treng
Kracheh
Senmonorom
Kampong Cham
Trat
Kampong Spoe
Takeo
Tan An
My Tho
Elevation
Metres
6 000
3 000
1 000
0
Main mountain peak
Glacier
Protected area
Hindu Kush Himalayas
AFGHANISTAN
PAKISTAN
CHINA
NEPAL
BHUTAN
INDIA
BANGLADESH
MYANMAR

Salween-Mekong basins climate indicators – Rainfall

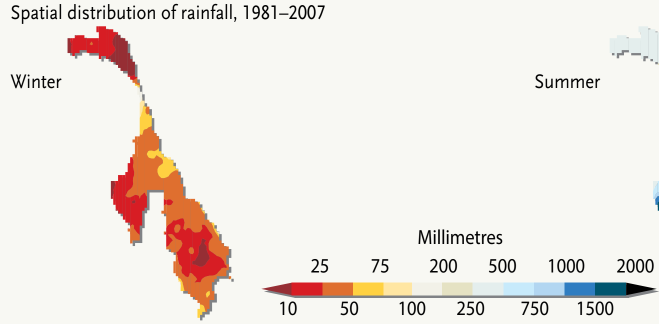
How much does it rain?
Rainfall intensity on a rainy day



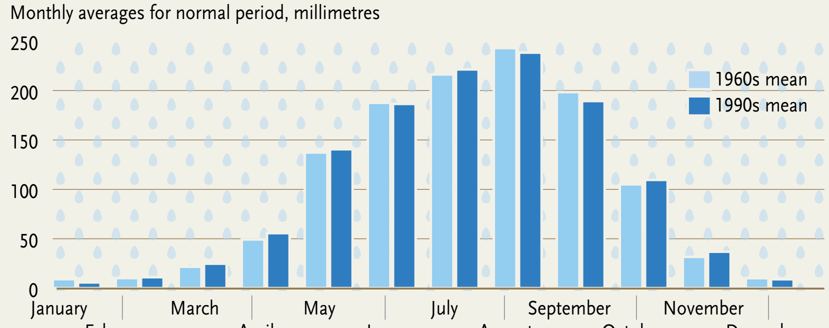
For how long does it rain?
Rainy days in a year



Where does it rain?
Spatial distribution of rainfall, 1981–2007

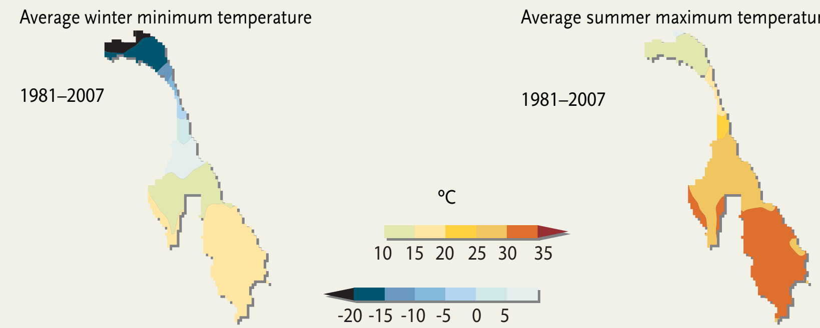


When does it rain?
Monthly averages for normal period, millimetres

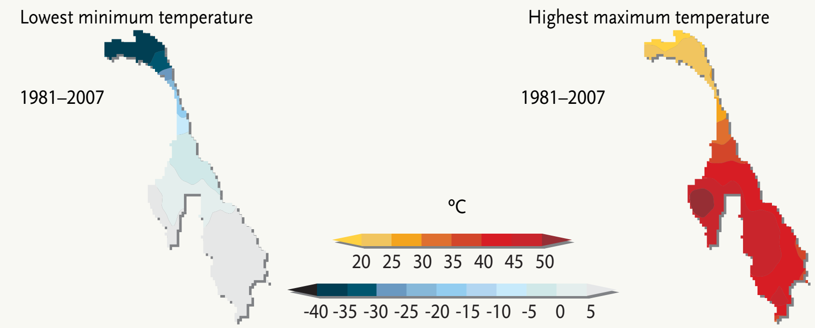


Temperature

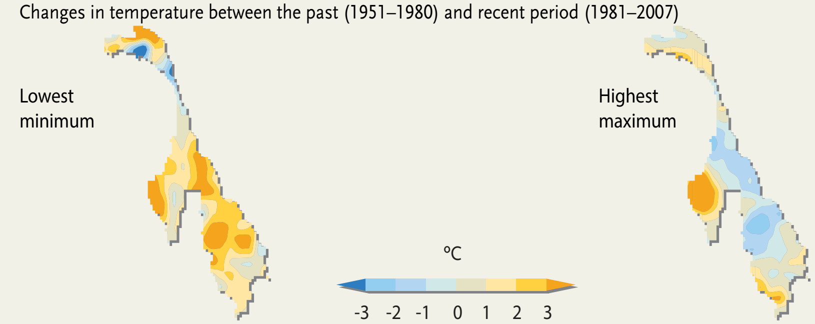
Where is it hot and where is it cold?



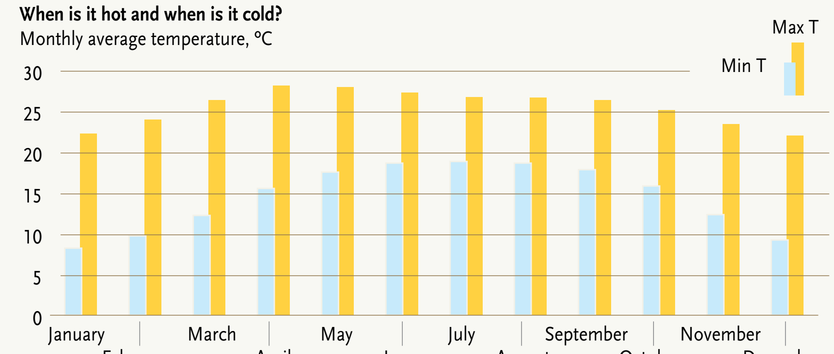
How hot and how cold?



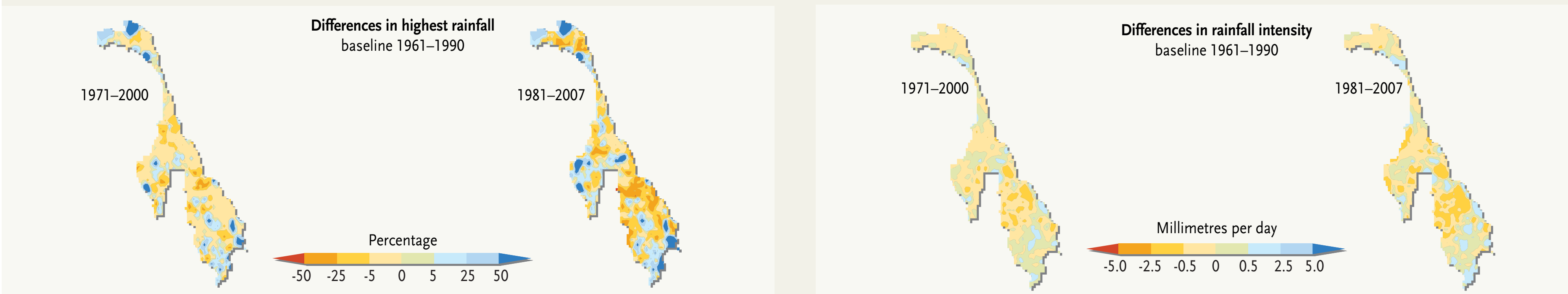
Temperature changes
Changes in temperature between the past (1951–1980) and recent period (1981–2007)



When is it hot and when is it cold?
Monthly average temperature, °C



Extreme rainfall events – Salween and Mekong



The annual flow of the Salween river basin varies from 68.74 km^3 (2,178.29 m^3/s) in the upper portion of the basin to 200 km^3 (6,337.75 m^3/s) along the Myanmar-Thai border.[99] Water withdrawal from the Salween river basin is currently about 5.1 km^3, most of it from Myanmar (63%).[100] Withdrawals from China and Thailand account for 32% and 5% of the total, respectively. The greatest demand for water is for irrigation, which is about 4.2 km^3 or 81% of the total.[101] The steepness of the Salween river basin leads to deadly landslides during the rainy season. There are concerns that landslides could increase if reservoirs are built or earthquakes are triggered by large dams.[102]

Climate trends

Precipitation

The Salween and Mekong river basins receive an average of 1,226 mm of rainfall per year. Out of the total precipitation, 17% and 69% are received during the pre-monsoon and monsoon season, respectively, whilst 12% is received post-monsoon and only 2% in winter. Higher amounts of rainfall are concentrated in the southern parts of these basins, where the rainfall exceeds 2,500 mm per year. The highest rainfall is concentrated over the southeastern part of the Mekong river basin and western part of the lower Salween basin. Most of the rainfall over the winter months is meagre (less than 50 mm), although the narrow strip of the upper part of the basins receives between 100–200 mm.

Within the monsoon season, rainfall has been increasing over the eastern flank of the southern part of the Mekong basin. Rainfall intensity has not changed significantly over time. The number of rainy days is increasing over the northern part of both basins and the southern part of the Mekong basin.

Extreme rainfall is increasing in the southernmost part of the Mekong basin and southern and southwestern part of the Salween basin, while extremes are decreasing in most parts of the central and southern parts of the Mekong basin. The trend is mixed over the northern part of the basins. Rainfall intensity has not changed significantly over time. The number of rainy days is increasing over the northern part of both basins and the southern part of the Mekong basin.

Temperature

Over the past decades and across both the Salween and Mekong basins, temperatures have risen, especially in the winter. Extreme maximum temperatures show mixed trends across these basins. Extreme minimum temperatures are rising overall with some exceptions.

Overall, the average maximum temperature is around 25°C, ranging from 23°C in the winter to 27°C in the summer. The average minimum temperature is around 14°C, ranging from 18°C in the summer to 9°C in the winter.

For both basins, the average winter minimum temperature rose significantly (by 2°C) between 1951 and 2007, with the greatest warming occurring in the northern tip and central part of both basins (over 1°C). The average maximum summer temperature has also shown an increasing trend of around 0.5°C, although there is some spatial variation. Except for a small area in the north, the average maximum temperature during summer is increasing – with the greatest warming occurring over the southern and northern tips with warming greater than 0.5°C.

In relation to extreme maximum temperatures, the central part of the Salween and Mekong basins shows decreasing trends, while the northern and southern parts of these basins show an increasing trend. The hottest areas in the southern part of the Mekong basin have shifted westwards over time. Extreme minimum temperatures are rising across these basins, apart from a small area in the north and small pockets within the southern Mekong basin.

Grapes from France to the upper Mekong valley in China

Haiya Zhang, ICIMOD

Ci Zhong, a Tibetan-Naxi village nestled in the upper Mekong valley, is renowned for its Catholic Church built by French missionaries in 1914. Along with religion, the French also brought the first grape vine to the valley. Ci Zhong locals inherited the techniques of vineyard cultivation and wine making from the French and do not use synthetic fertilizers or pesticides in their fields. Today, they are still growing the same variety, Rose Honey, brought by the French a century ago. This grape variety has already died out in the rest of the world due to a disease that wiped out almost all grape plantations in Europe at the time. Today, about 160 kilometres north along the valley, the Naxi people of Bamei village have also starting cultivating grapes – Cabernet Sauvignon.

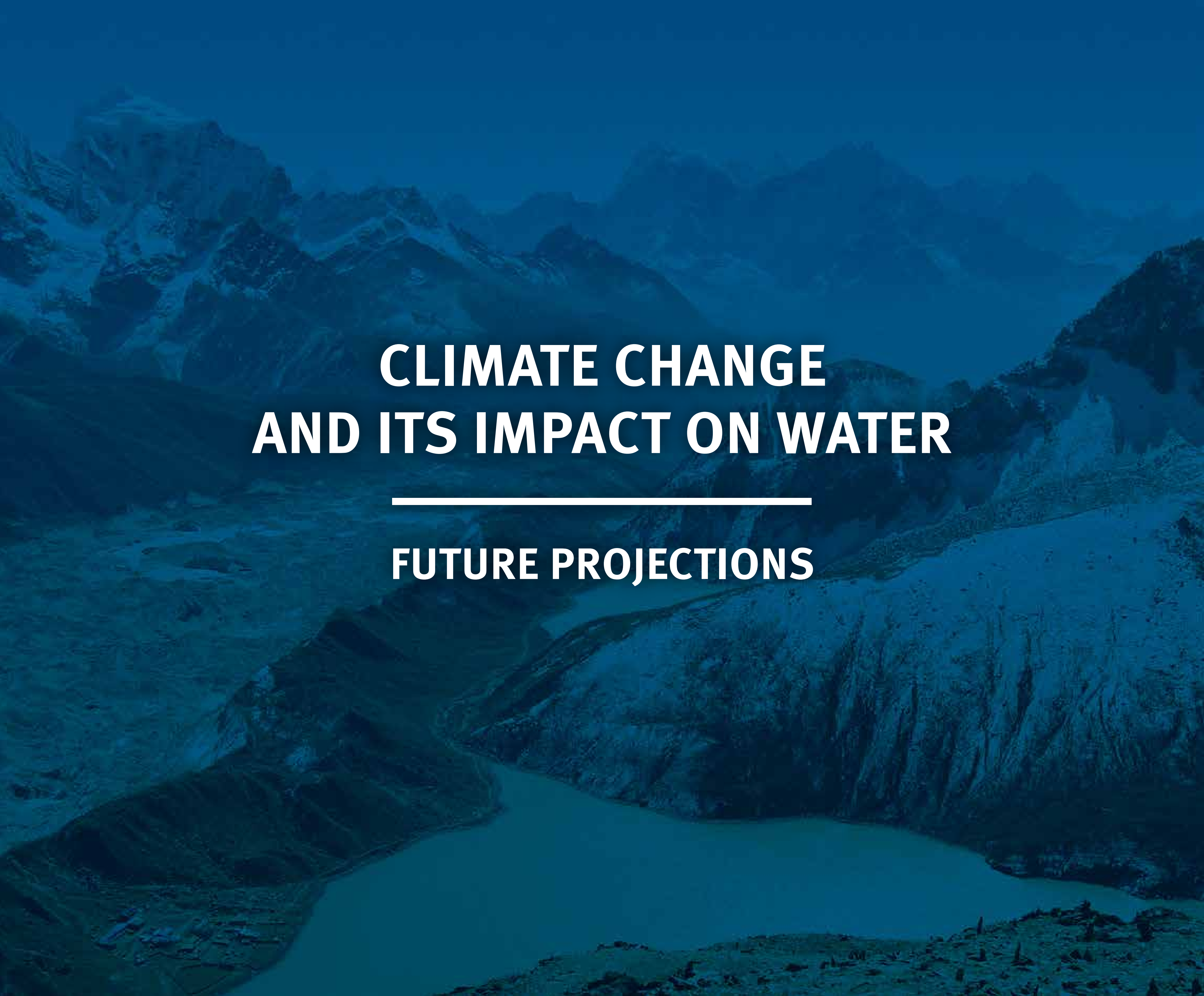
As part of the Himalayan Climate Change Adaptation Programme (HICAP), the Asian International River Center (AIRC), a research centre based out of Yunnan University, is conducting a household survey under its food security component. In Bamei village, situated by the Mekong river at 2,500 metres above sea level, the villagers started grape cultivation in 2009. Grape cultivation was part of a poverty-alleviation programme supported by the Chinese government. Based on a feasibility study, wherein experts deduced that the arid climate in Bamei was favourable for grape and walnut cultivation. Since then, more experts have arrived with grape vines, concrete posts and wires, teaching the farmers how to start and maintain vineyards. All materials and technical costs are paid for by the government.

The Rose Honey grape vineyards surrounding Ci Zhong Church

Tsering Tsomu and her grape plantation

Two years into the programme, the vineyards have yielded grapes and, during the harvest season, government-owned companies from nearby towns buy grapes by the truckload. This particular case presents vineyards as an effective adaptation strategy for mountain farmers in arid zones. A typical vineyard requires less water than traditional highland barley, maize or wheat, and the income from grapes is higher per hectare. The highest income per mu (0.07 hectares) of grapes was about 6,800 RMB (1,097 USD) in Bamei.

Tsering Tsomu, an indigenous Naxi woman in Bamei, recalls the time when locals relied on highland crops and stall-fed animals. She says that, after changing to grape cultivation, the villagers observed a significant increase in income, but also a decrease in available fodder for their stall-fed animals. Like many other villagers, Tsering now grows wheat for fodder in between the grape trellises. Contrary to the grape variety grown in Ci Zhong, the Cabernet Sauvignon grape, requires synthetic fertilizers and pesticides. Additionally, Tsering says that the soil is quite tough and difficult to till. The HICAP-supported research team is looking into the relationship between soil productivity and grape cultivation, as well as drivers of change and impacts on food security along the upper Mekong river.



CLIMATE CHANGE AND ITS IMPACT ON WATER

FUTURE PROJECTIONS

Projected changes in temperature and precipitation

The regional HKH perspective – Indus, Ganges, Brahmaputra, upper Salween, upper Mekong basins

Climate models indicate that both temperature and precipitation patterns are likely to change in the Hindu Kush Himalayas in the future. However, owing to its very diverse topography, the magnitude and extent of these changes will not be uniform over the entire region. There is a high degree of uncertainty in climate projections in the HKH, particularly as global climate models are not able to adequately account for changes relating to topography.[103,104]

By 2050, temperatures across the basins are projected to increase by about 1–2°C on average, and winters will see greater warming than summers in most places. Mountainous and high altitude areas will be particularly affected in both summer and winter, with warming reaching 4–5°C in some places.

Compared to temperature, projected trends in precipitations are more diverse across the whole area and within each basin. By 2050, in the summer, an increase in temperature of about 5% on average is expected, reaching 25% in some areas. But decreases of around –5% are also projected in significant portions of the Brahmaputra, Indus, and Ganges basins, especially in winter – possibly reaching up to –25% in some places.

Extremes in precipitation are likely to increase with wet areas getting wetter and dry areas getting dryer. Areas receiving intense precipitation events are likely to see further intensification of such events.

Projections are made for the period 2021–2050, compared to the baseline period 1961–1990. The two ensemble scenarios used in this analysis – RCP 4.5 and 8.5 – produce broadly consistent projections. However, RCP 8.5 generally shows stronger increases in temperatures and stronger variability in precipitation.

The Brahmaputra basin

Rainfall

Future scenarios project a 5–25% increase in summer rainfall over most of the basin up until 2050. According to the wettest scenario (RCP 8.5), the increase could be more than 25%, especially in the northern and far-western parts of the basin. In winter, projections show an increase over the main mountain range. This winter increase is expected to range from 5–25%. However, the southwest part and central northern part show decreases in winter precipitation of up to 25% for both scenarios. Overall, RCP 4.5 and RCP 8.5 project an increase of 10.5% and 9.5%, respectively, for the monsoon season.

Temperature

Both climate change scenarios show an increase of 1–3°C across the Brahmaputra basin in summer. The RCP 8.5 scenario shows a slightly larger area that will experience a 2–3°C increase. The increase in winter temperature is similar, but occurs over larger areas and with stronger warming (with an increase of more than 3°C in some areas), particularly for the RCP 8.5 scenario. Projections show that winter and summer warming is greater in the north where the increase is mostly more than 2°C.

The Ganges basin

Rainfall

In the summer, both scenarios project a 10–25% increase in rainfall over most of the basin, and exceeding 25% over the central north of the basin. RCP 8.5 results in projections with pockets of lower increase of up to 10% within the central and eastern parts of the basin.

In the winter, both scenarios project a decrease in precipitation over the mountain range of up to 10%. RCP 8.5 shows a decrease extending south through the central and eastern parts of the basin. The rest of the basin will see an increase in precipitation ranging from 5–25%. During monsoon season rainfall is projected to increase by 15% and 14% for RCP 4.5 and RCP 8.5, respectively.

Temperature

Overall, the Ganges basin is projected to become warmer in the summer by about 2°C, with a higher increase projected in the north along the mountain range of up to 3°C. In winter, a projected increase of 2–3°C is widespread across the basin, and of up to 4°C along the mountain range. RCP 8.5 generally results in projections of higher temperature changes.

The Indus basins

Rainfall

Precipitation is projected to increase in summer over the northern, central-eastern and southern parts of the Indus basin, while over the central-western part of the basin it is projected to decrease. In the regions of highest rainfall along the mountain range, the increase is projected to be between 10–25%.

Winter precipitation is also projected to decrease in the central-western part of the basin, as is summer precipitation. Whereas in the northern and southern parts of the basin, it is projected to increase between 5–10%.

In terms of extreme rainfall events, a study by Rajbhandari et al. (2014)[105] suggests an overall increase in the number of rainy days over the northern part, and a decrease over the southern part of the basin. However, it also projects a decrease in the number of rainy days accompanied by an increase in rainfall intensity in the border area between the upper and lower basins, where the rainfall amount is highest.

Temperature

In summer, a major part of the basin is projected to warm by 2–3°C and up to 5°C under RCP 4.5 – and even more under RCP 8.5 in some pockets in the northern part of the basin. The southern part of the basin is projected to warm by a lesser amount, ranging from 1–2°C. Winter is projected to warm by 2–4°C across the basin in both scenarios, with very few areas either exceeding 4°C or lower than 2°C.

The upper Mekong and upper Salween basins

Rainfall

Rainfall projections in summer show an increasing trend over both upper basins, with an increase of about 5–10% over the southern areas where the normal precipitation is low. In the upper part of these basins where the normal precipitation is higher, the projected increase ranges from 10–25%.

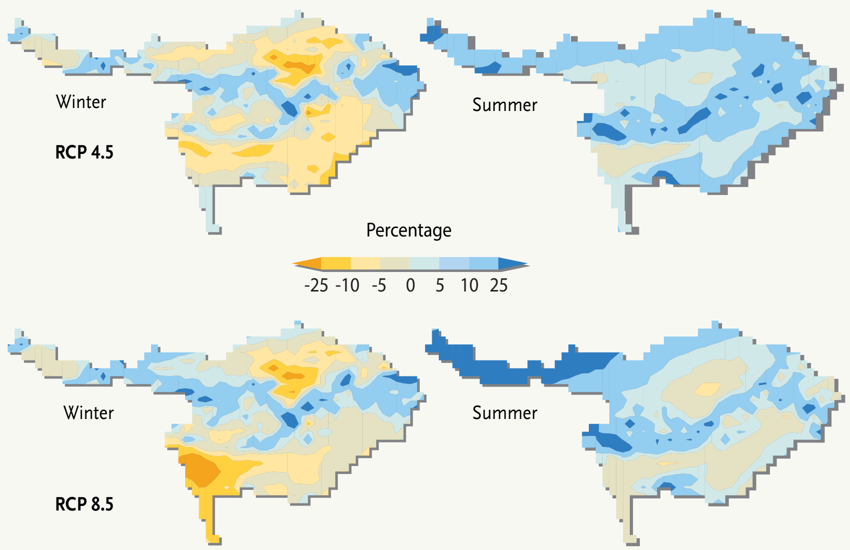
Rainfall projections in winter also show increasing trends of about 10% over most parts of the basins. However, a small area over the southern part of the central area of the basins shows a decreasing trend by up to 5%.

Temperature

Future warming in the summer season is projected over the entire upper Salween and Mekong basins, mostly in the range of 1.5–2.5°C, although it may exceed this in some pockets. RCP 8.5 shows a greater area with warming of between 2–3°C than RCP 4.5. Greater warming is projected in the winter than the summer, although the scenarios differ: RCP 4.5 results in projections of warming between 1.5–3°C, while RCP 8.5 results in projections of warming of 2–3°C or higher.

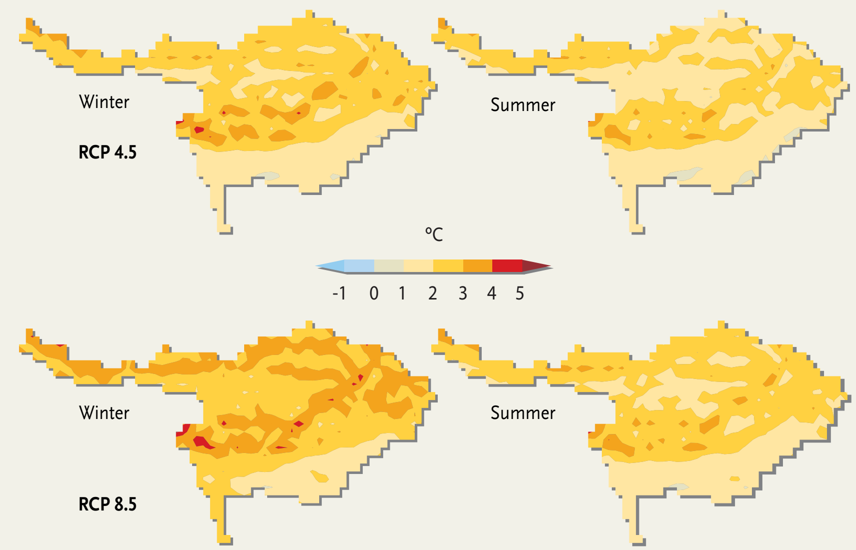
Brahmaputra basin future climate – Rainfall

Change in average rainfall, 2021–2050
baseline 1961–1990

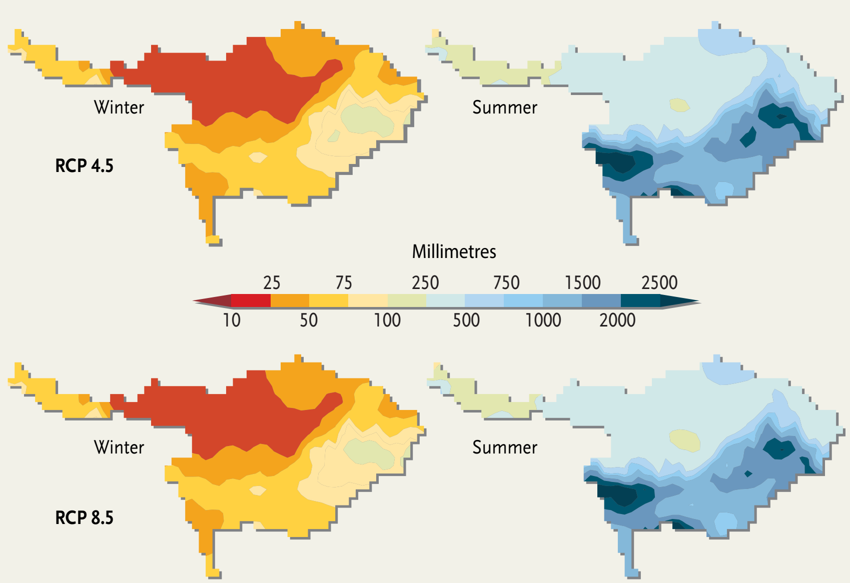


Temperature

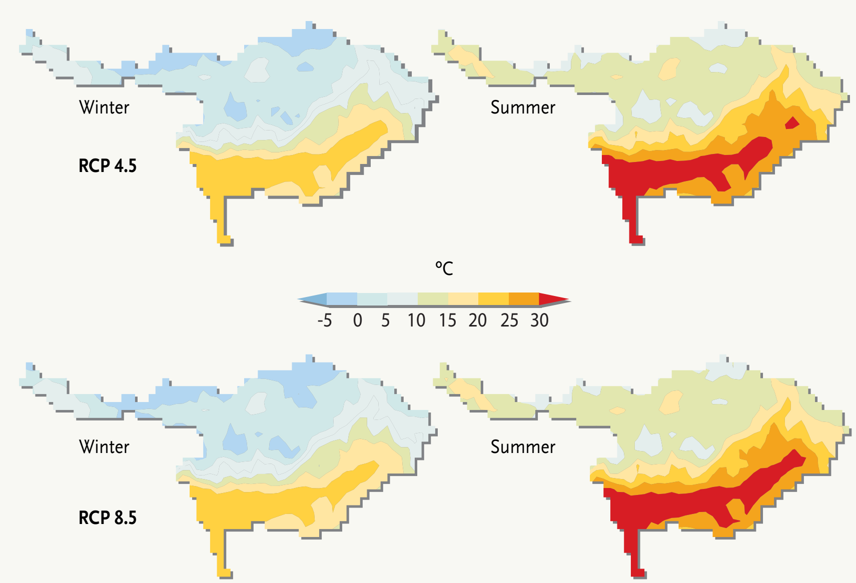
Change in average temperature, 2021–2050
baseline 1961–1990



Spatial distribution of projected future rainfall , 2021–2050

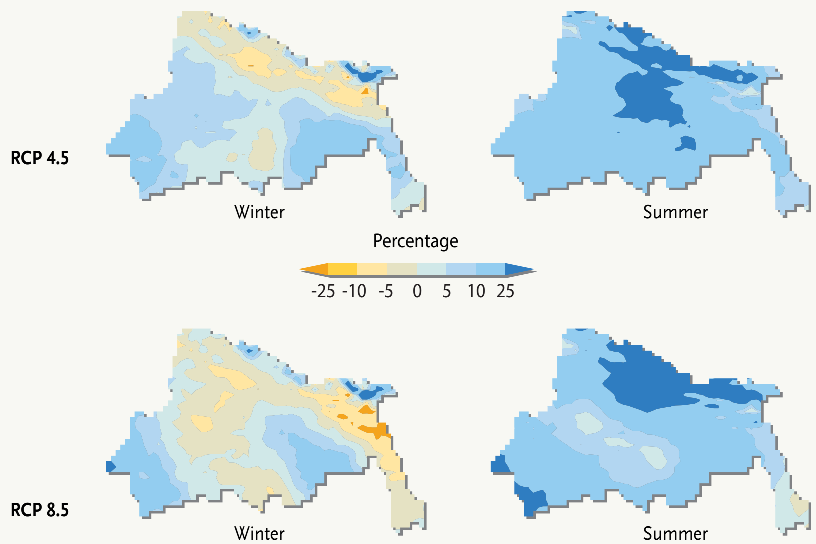


Spatial distribution of projected future temperature, 2021–2050



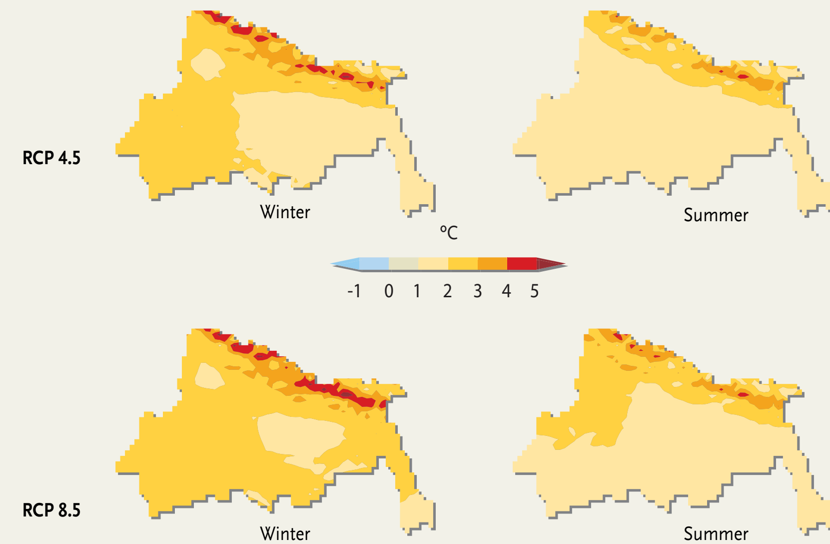
Ganges basin future climate – Rainfall

Change in average rainfall, 2021–2050
baseline 1961–1990

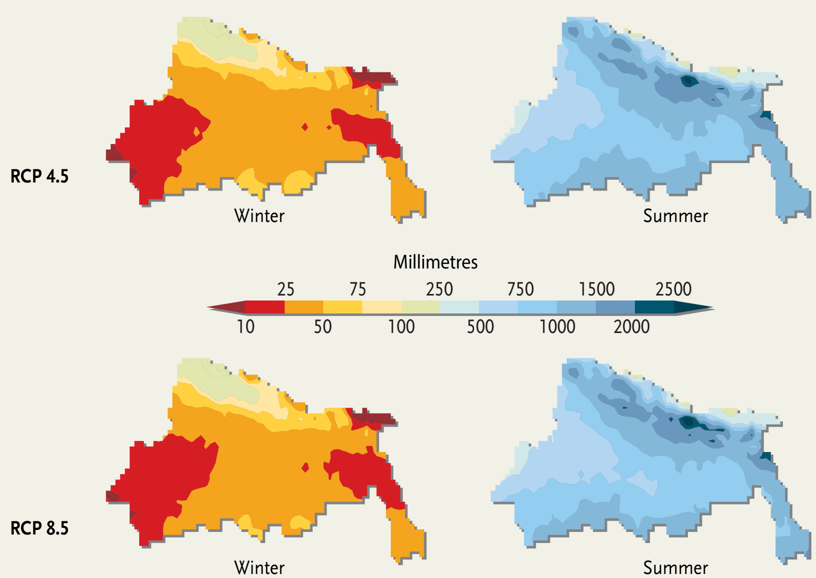


Temperature

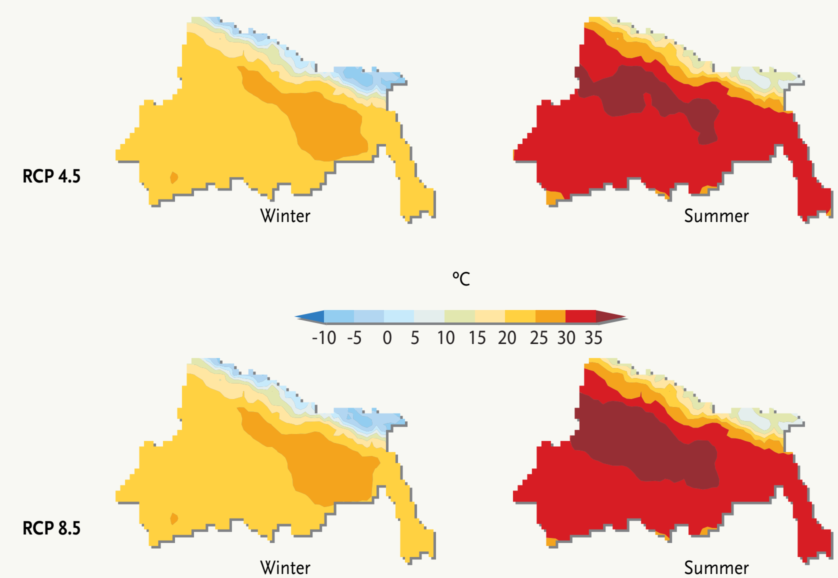
Change in average temperature, 2021–2050
baseline 1961–1990



Spatial distribution of projected future rainfall , 2021–2050

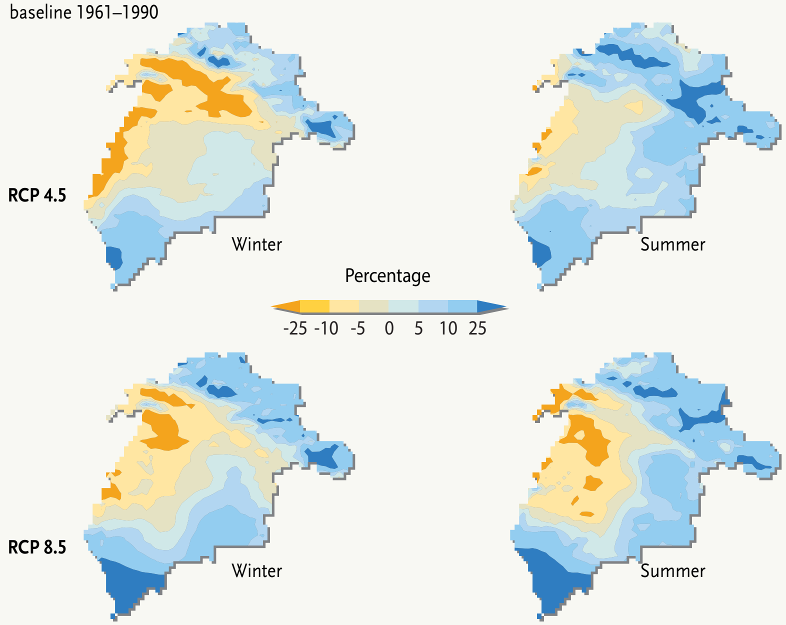


Spatial distribution of projected future temperature, 2021–2050



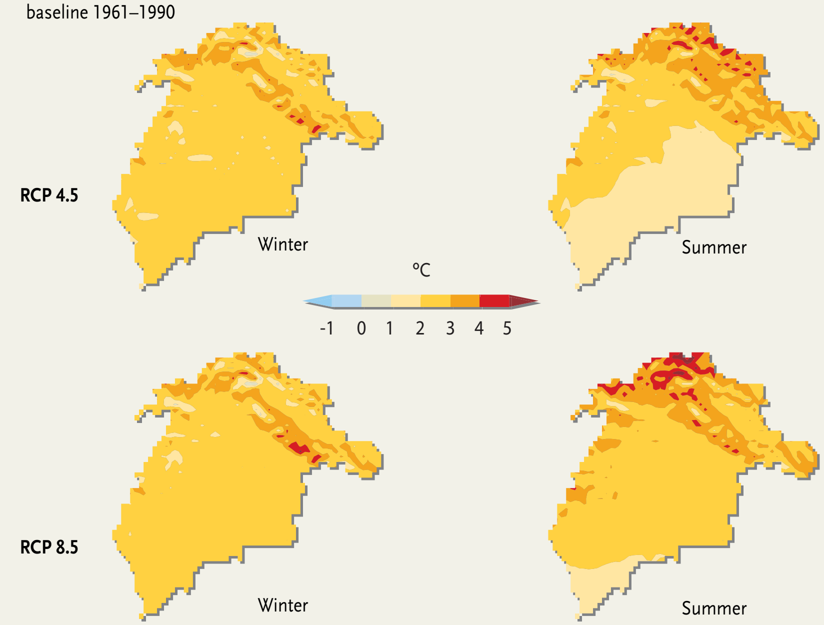
Indus basin future climate – Rainfall

Change in average rainfall, 2021–2050
baseline 1961–1990

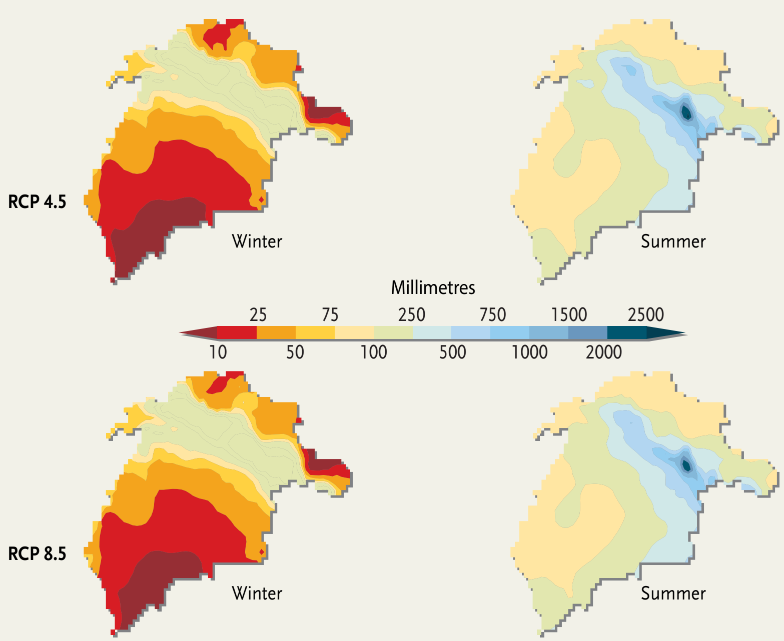


Temperature

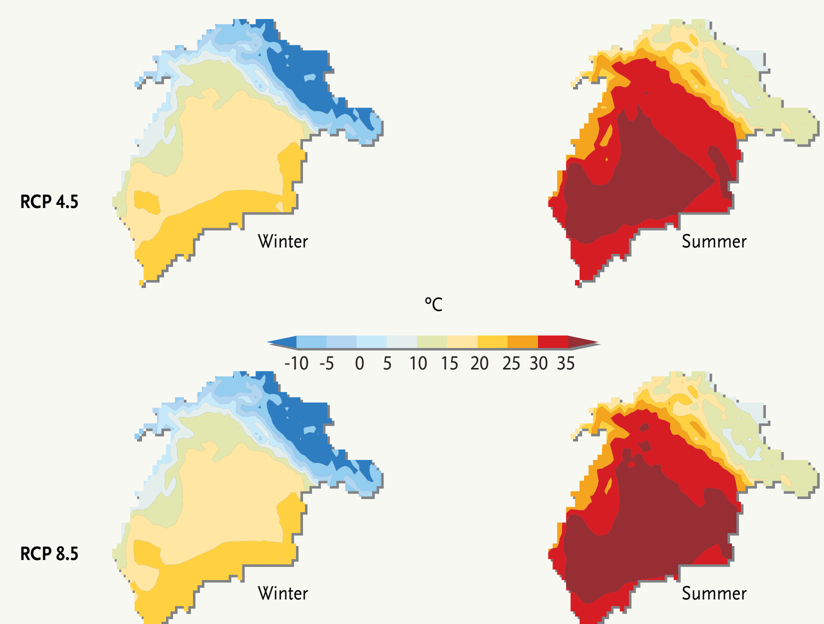
Change in average temperature, 2021–2050
baseline 1961–1990



Spatial distribution of projected future rainfall , 2021–2050



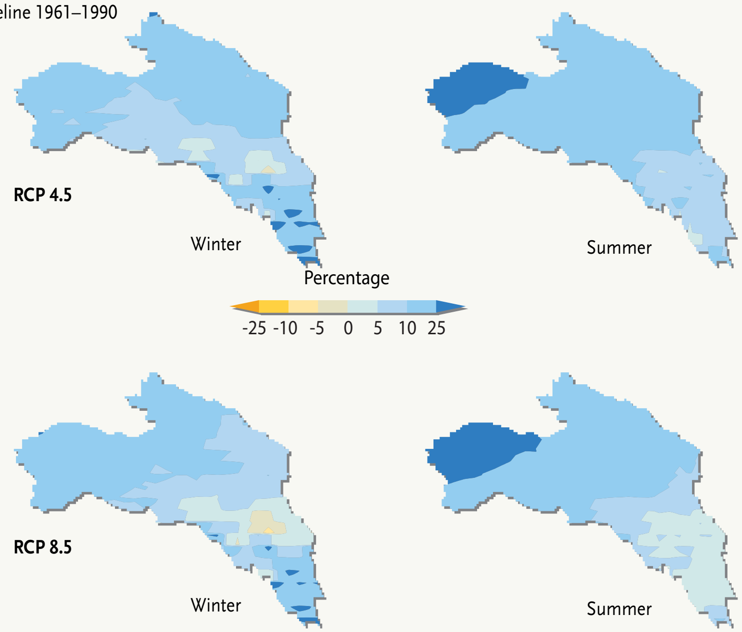
Spatial distribution of projected future temperature, 2021–2050



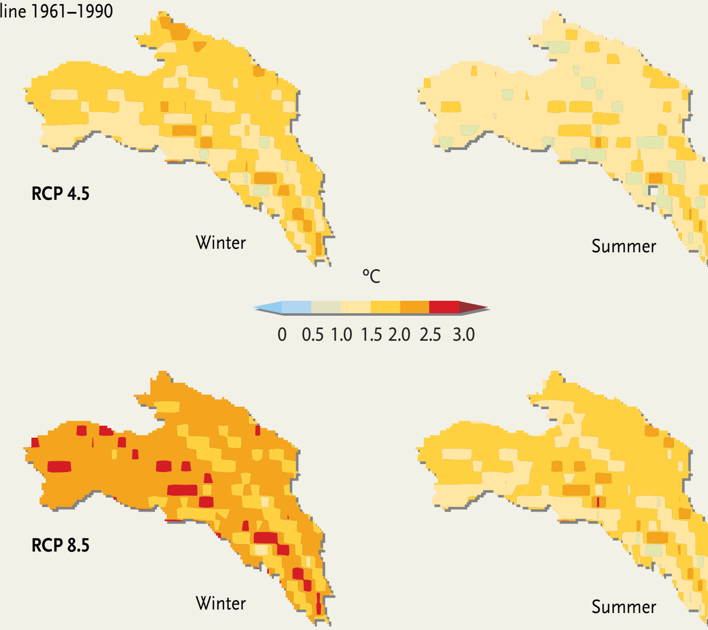
Upper Salween/Mekong basins future climate – Rainfall

Temperature

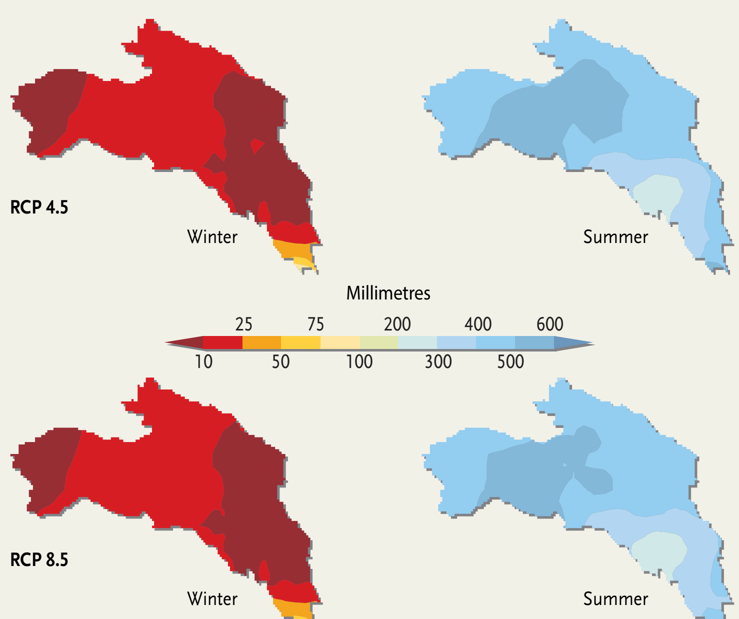
Change in average rainfall, 2021–2050
baseline 1961–1990



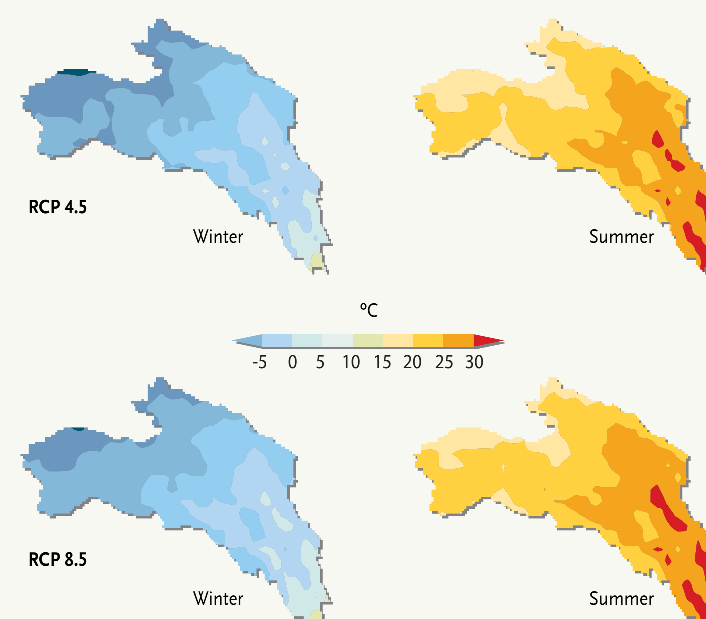
Change in average temperature, 2021–2050
baseline 1961–1990



Spatial distribution of projected future rainfall , 2021–2050



Spatial distribution of projected future temperature, 2021–2050



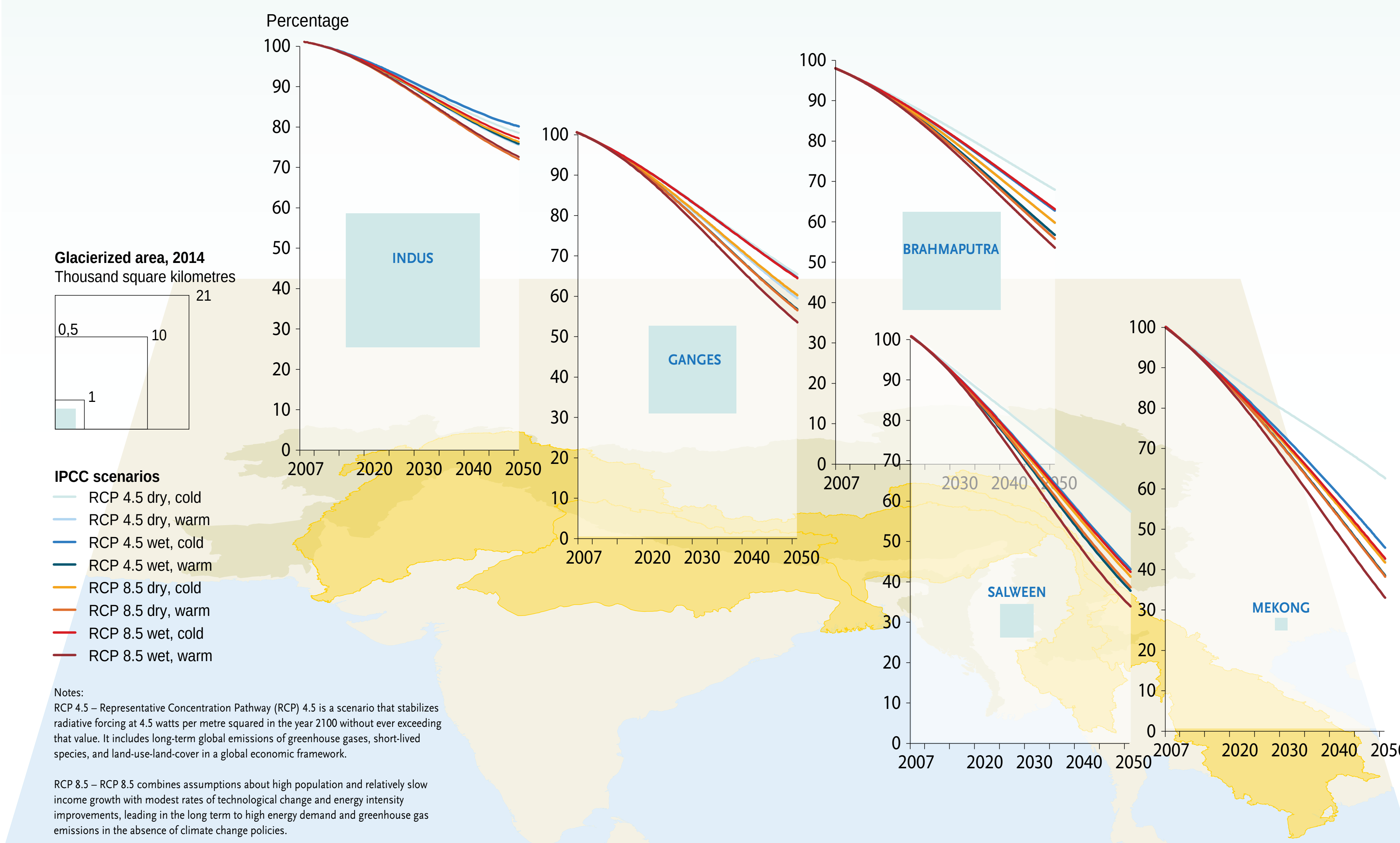
Projected trends in glacial melt

There has been an almost worldwide recession of glaciers since the last ice age, including within the Himalayas.[106] Most Himalayan glaciers have both retreated and lost mass since the mid-19th century, with some exceptions in the Karakoram and northwestern Himalayas.

Most models project substantial glacial mass and area losses in the coming decades for most parts of the Hindu Kush Himalayas.[107] At the upper river basin scale, the Indus, Brahmaputra, Ganges, Salween and Mekong are projected to lose considerable glacial area by 2050.[108] The greatest relative reductions in glacial area are likely to be for the Salween (−44 to −67%) and Mekong (−39 to −68%), as their current glacial areas are the smallest. For the Indus basin, a change in glacier extent ranging from −20 to −28% is projected. Although the Indus basin shows the smallest decrease in percentage because it has the largest glaciated area, the absolute loss is likely to be the greatest in this basin. Changes in glacier area in the Ganges and Brahmaputra basins show similar trends (−35% to −45%).

Even the glaciers in the highest mountains of the world will not escape the effects of climate change. For example, even if today's level of emissions are greatly reduced, glaciers within the Everest region (Dudh Koshi basin, Nepal) are projected to lose between, on average, 39% of their ice by 2050 and around 83% by 2100. For extreme RCPs, the average loss is projected to be much higher. Temperature increases will be the most important determining factor driving glacial mass loss in this region.[109] As temperatures rise, more glaciated area will be exposed to above-zero temperatures. These warmer temperatures will cause the glaciers to melt and will also mean that more precipitation will fall as rain rather than snow, resulting in melting ice not being replenished.

Projected glacial area change by 2050



Notes:

RCP 4.5 – Representative Concentration Pathway (RCP) 4.5 is a scenario that stabilizes radiative forcing at 4.5 watts per metre squared in the year 2100 without ever exceeding that value. It includes long-term global emissions of greenhouse gases, short-lived species, and land-use-land-cover in a global economic framework.

RCP 8.5 – RCP 8.5 combines assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and greenhouse gas emissions in the absence of climate change policies.

Source: Lutz, AF; Immerzeel, WW (2013) *Water availability analysis for the upper Indus, Ganges, Brahmaputra, Salween and Mekong river basins.* Report submitted to FutureWater

Changes in discharge for major rivers until 2050

Changes in discharge

Temperatures in the upper Indus, upper Ganges, upper Brahmaputra, upper Salween and upper Mekong basins are projected to increase with considerable certainty between 1–2.2°C up until 2050, compared to the baseline period (1998–2007). There is more uncertainty about precipitation patterns than temperature, but they are also projected to change between −3.5 to +9.5% for the same period, depending on which upper basin is considered. On average, an increase in precipitation is expected for all of the upper basins, with greater uncertainty for the upper Indus basin, where a decrease in precipitation is also possible.

In response to changing precipitation and temperature patterns, the relative contribution of different sources of water – glacial melt, snow melt, rainfall and baseflow – to river flow will change. Under both RCP scenarios, the amount of glacier and snow meltwater will decrease, while the amount of rainfall-runoff will increase, for the upper basins of the Brahmaputra, Ganges, Salween and Mekong. For the upper Indus basin, the contribution of glacial melt is projected to increase in both scenarios, and the contribution of snow melt and rainfall to runoff are projected to decrease for the extreme cases in the RCP 8.5 scenario.

Overall, no significant decrease in runoff is projected until at least 2050 for all of the basins. An increase in runoff is projected for both RCP 4.5 and RCP 8.5 scenarios for the upper Ganges (1–27%), Brahmaputra (0–13%) and Mekong (2–20%) basins. Increasing precipitation is the main driver of this change, which will compensate for decreasing contributions of glacial and snow melt. For the upper Indus and Salween basins, the picture is uncertain and varies depending on the scenario. Under the RCP 4.5 ensemble mean, the total upper Indus river flow increases (12%), while under the RCP 8.5 ensemble mean, it decreases (−5%) compared to the reference period. In the upper Salween basin, the projected change in total river flow ranges from −3 to +19%. The difference is mainly due to a reduction in snow melt and rainfall runoff under RCP 8.5, caused by a decrease in precipitation, although glacial melt increases in both scenarios.

Seasonality of flow

Depending on the stream flow composition (glacial melt, snow melt, rainfall, baseflow), different rivers within each of the basins will respond differently to climate change. Currently, the peak discharges within the upper Ganges, upper Brahmaputra, upper Salween and upper Mekong basins are all directly related to the peak in rainfall during the monsoon season. Within the upper Indus basin, the Indus river is currently dominated by temperature-driven glacier melt, which is at its maximum during summer when the river flow peaks. However, the Kabul river is currently snow-dominated and river flow peaks during the spring months.

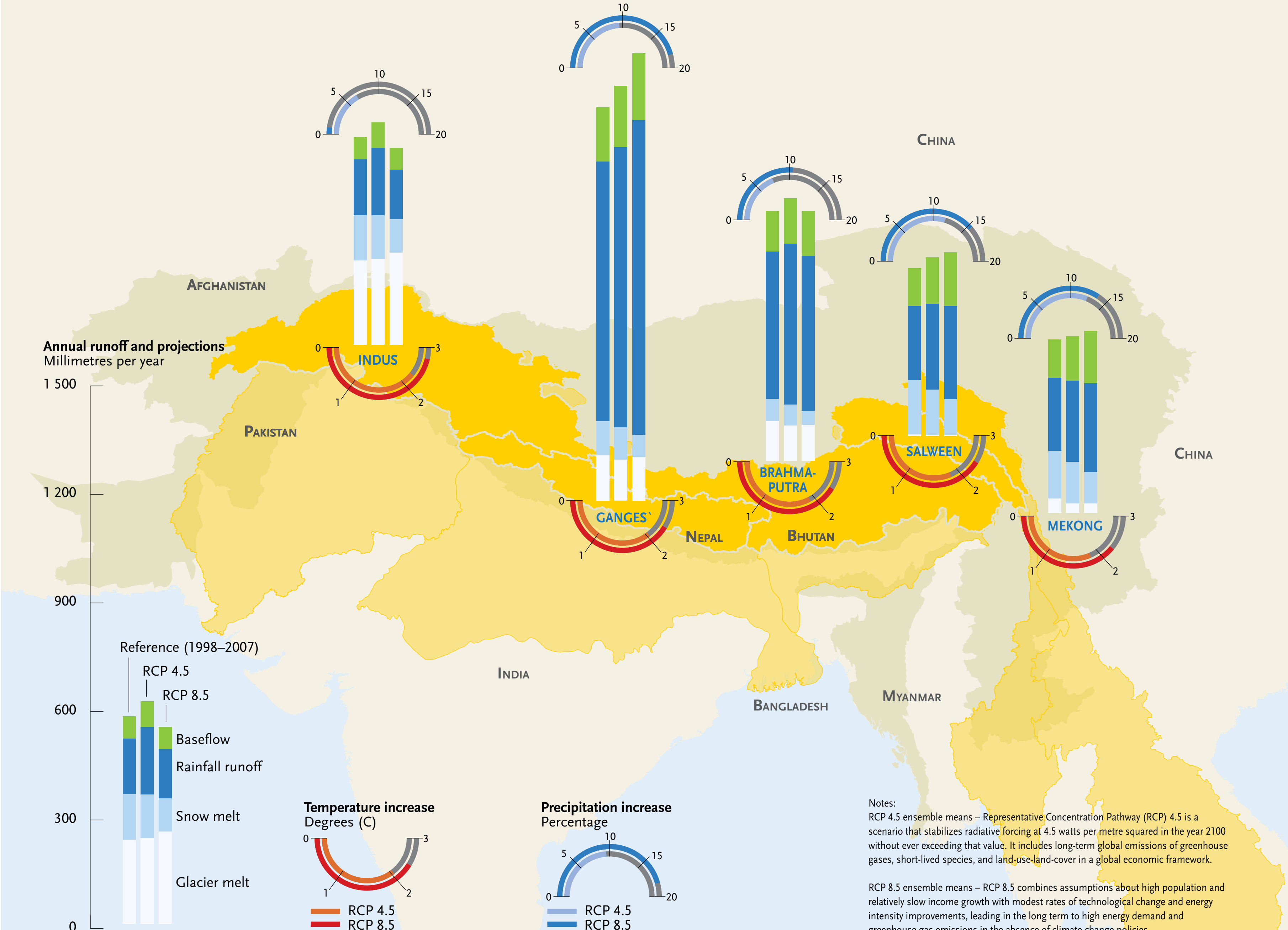
Shifts in the seasonality of flows can have major implications for regional food security, especially when the timing of peak flows and growing seasons do not coincide. However, this study suggests that significant seasonal shifts in flow will not occur by 2050.

A small shift in the seasonality of flow is expected within the Salween and Mekong rivers. Increased flows are expected for August through to May related to increased precipitation and a shift in snow melt to earlier in spring, whereas decreased flows are expected in June and July. The snow melt peak will decrease in magnitude because more liquid precipitation (rain) will fall in response to increased temperatures. Within the upper Brahmaputra, a slight one-month shift in peak flow to later in the year is expected under the RCP 8.5 scenario.

For the upper Ganges and upper Indus, there is no significant change in the seasonality of flow, although for the upper Ganges a slight increase in peak flow is projected under the RCP 8.5 scenario. Within the upper Indus, a decrease in flow is expected from April through to August for the Kabul river under the RCP 8.5 scenario.

The future of climate and water in the HKH region

Projections for selected HKH river basins, 2041–2050



Notes:

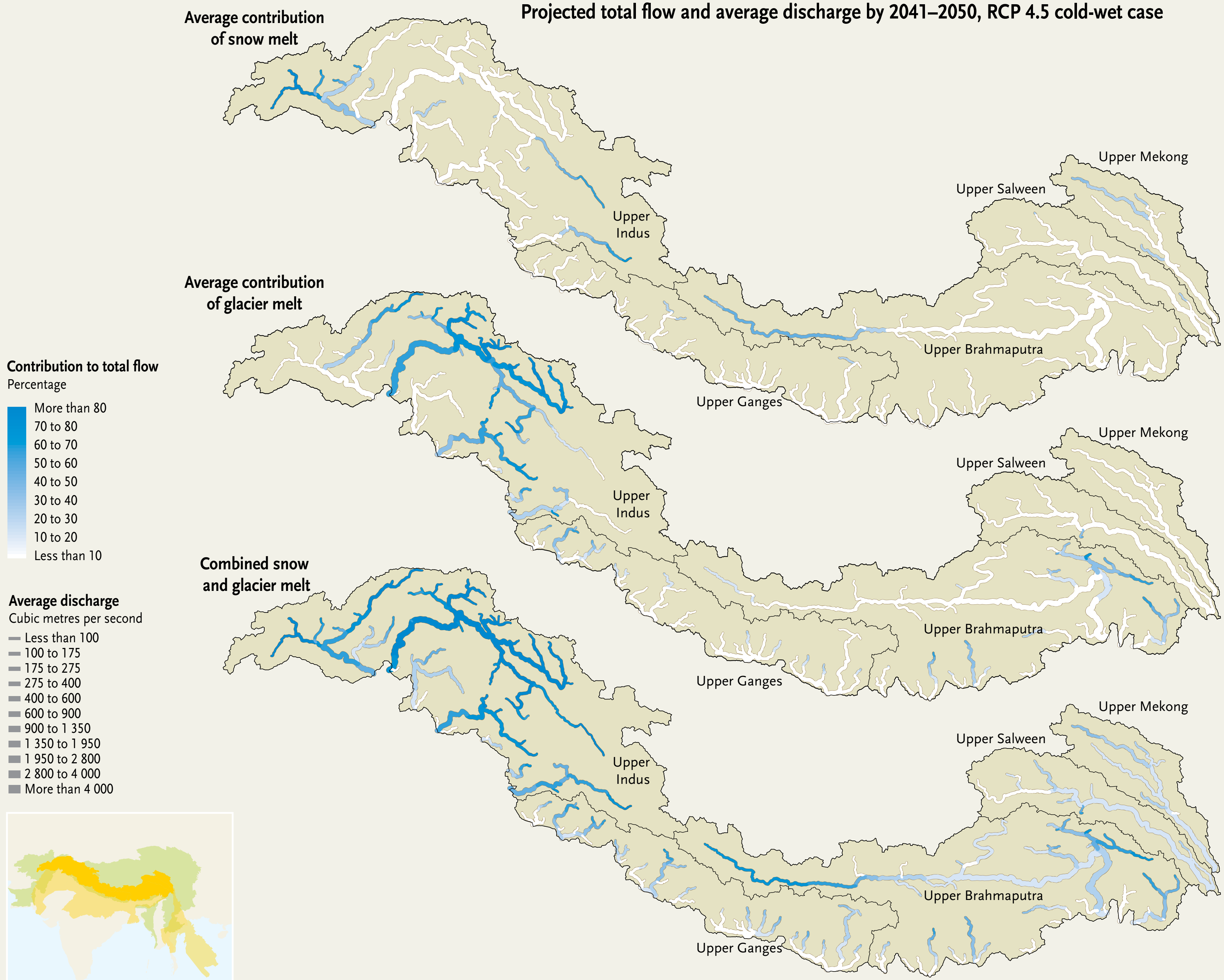
RCP 4.5 ensemble means – Representative Concentration Pathway (RCP) 4.5 is a scenario that stabilizes radiative forcing at 4.5 watts per metre squared in the year 2100 without ever exceeding that value. It includes long-term global emissions of greenhouse gases, short-lived species, and land-use-land-cover in a global economic framework.

RCP 8.5 ensemble means – RCP 8.5 combines assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and greenhouse gas emissions in the absence of climate change policies.

Source: Lutz, AF et al. (2014) 'Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation.' *Nature Climate Change* 4: 587–592

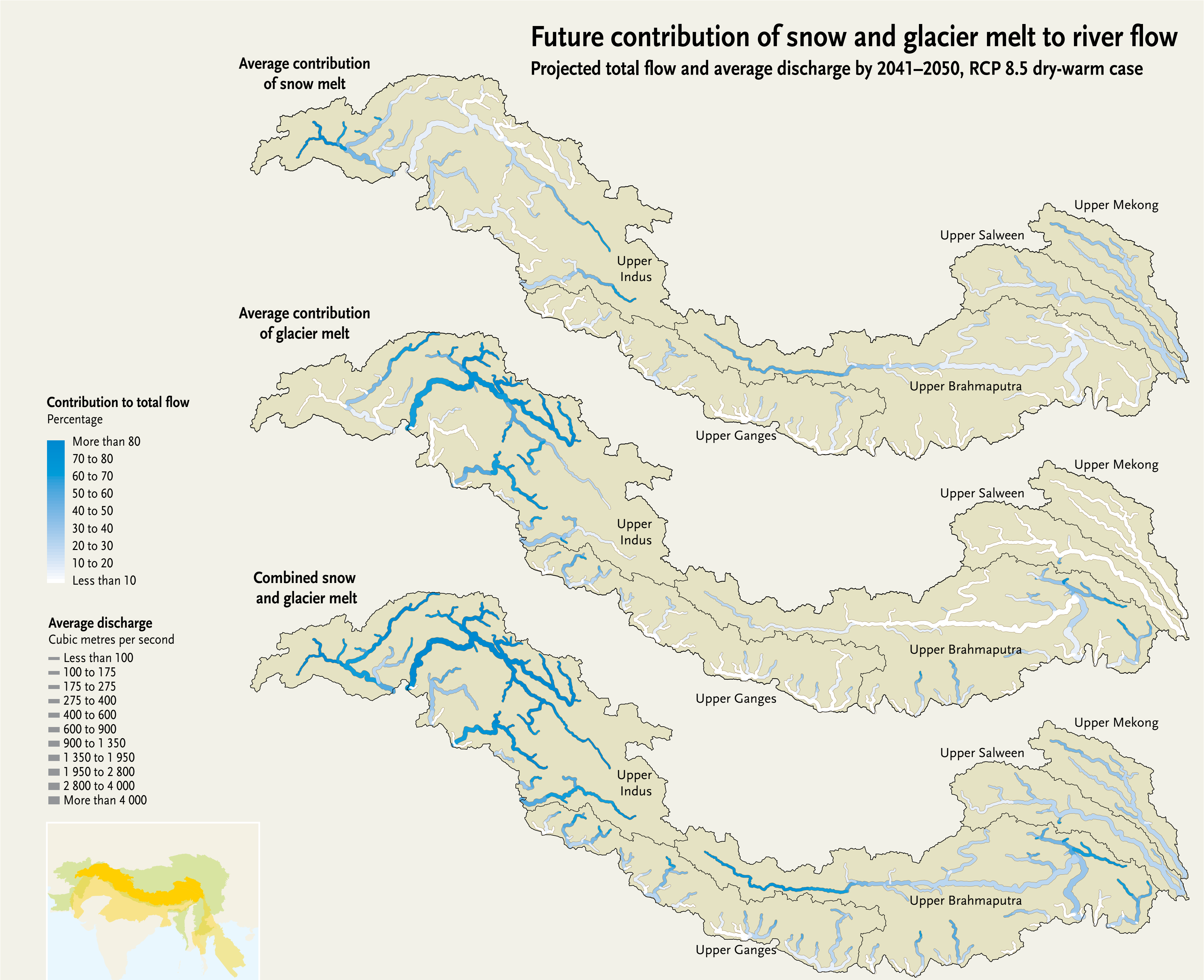
Future contribution of snow and glacier melt to river flow

Projected total flow and average discharge by 2041–2050, RCP 4.5 cold-wet case



Note: HI-SPHY model forced with RCP 4.5 CCSM4-r5i1p1 GCM (cold, wet) case

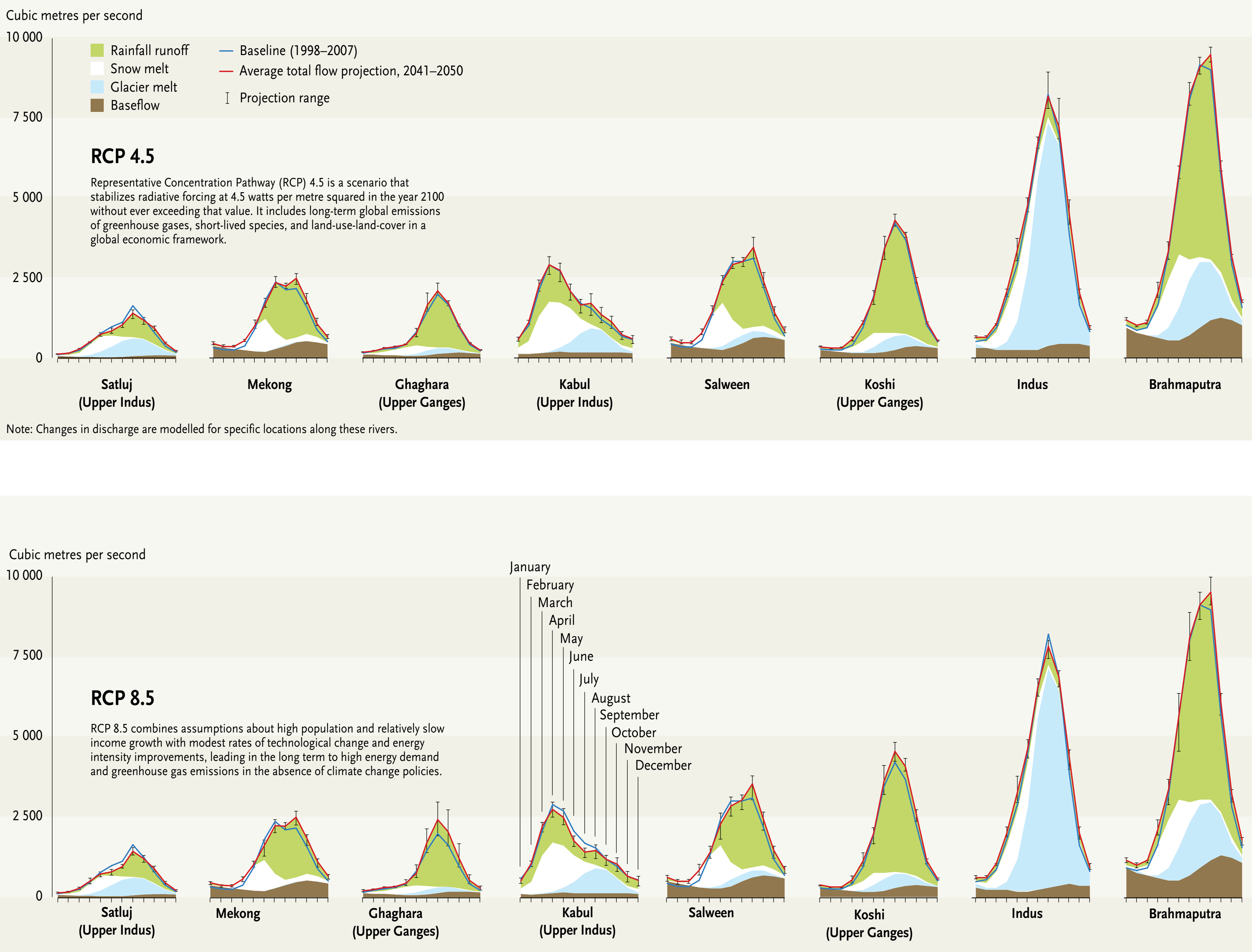
Source: Lutz, AF et al. (2014) ‘Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation.’ *Nature Climate Change* 4: 587–592



Note: HI-SPHY model forced with RCP 8.5 IPSL-CM5A-LR-r4i1p1 GCM (dry, warm case)

Source: Lutz, AF et al. (2014) 'Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation.' *Nature Climate Change* 4: 587–592

Changes in discharge for selected rivers in the HKH region



Source: Lutz, AF et al. (2014) 'Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation.' *Nature Climate Change* 4: 587–592

MEETING FUTURE WATER CHALLENGES

Finding future water solutions

Water challenges arise from an imbalance between water availability and use. Changes in water availability can be caused by changes in glacier melt, precipitation, evaporation and other water balance components, while changes in consumption are governed by demographics, agricultural practices and many other factors.

The current and projected changes in temperature, precipitation and extreme events pose many challenges to people in the HKH, mainly because they are changing water availability at a time when consumption patterns are changing and demand is rising. Changes in water availability due to climate are expected to affect climate and water-dependent sectors such as rain- and irrigation-fed agriculture and consequently food security, and the availability of drinking water and human health, and have large consequences for the functioning of ecosystems including forest and wetlands and the numerous services they provide.

There are no internationally-accepted principles and conditions of sustainability with regard to water security.[110] There are, however, three critical scales of adaptation: local, regional and transboundary. Specific risks and challenges must be assessed and analysed at each level to produce appropriate answers.

At the local level and in the immediate future, adaptation is key. In agriculture, crop diversification may spread the risks of droughts or extreme precipitation. Using a greater variety of crops, with different planting and harvesting times, will minimize the risk of 'losing it all' in case of disaster.[111] More sustainable water use, water conservation techniques and payment for ecosystem services can provide ways to improve water availability and livelihoods, which also take upstream-downstream linkages into account.[112,113] Several early warning techniques already exist and can be more effectively used now and in the future to minimize losses in case of floods. Existing technologies are available, and pilots have been developed and successfully implemented in the region by ICIMOD and its partners (e.g., early warning systems,[114] climate smart villages,[115] regional flood information systems[116] and spring-shed development[117]).

Local people in the HKH have a history of successful adaptation to environmental changes, but the changing nature of water hazards in recent years has made people more vulnerable and rendered traditional adaptation practices less effective. This suggests that governments and communities would mutually benefit from collaborating on these issues.[118] Taking a longer-term perspective, in the context of sustainable development, increases the likelihood that more immediate adaptation actions will also enhance future options and preparedness.[119] To avoid maladaptation, planners should make local scenarios using the full range of possible climate and socioeconomic futures, and combine climate projections with already existing knowledge and best practices. Adaptation knowledge and experience already exists and can be shared to a greater extent across local, regional and international levels.

Changes in the HKH are impacting on people on a large scale – including those living downstream. At the regional level, integration between upstream and downstream areas is critical for food, water and energy security. Transboundary cooperation on water resources development would bring political and social benefits to all countries involved by building trust, stimulating the sharing of data and knowledge, and increasing regional security and economic growth.[120] Equal attention should be paid to the management of HKH ecosystems – especially watersheds, catchments and the headwaters of river systems – as well as to tapping the potential of collaborative gains in water, hydropower and other ecosystem services through coordination across HKH countries.

Data gaps in the HKH are still very large and most of the analyses are based on modelled data. Countries should come together to share data and undertake more rigorous analysis with a high level of confidence. Comprehensive Himalayan glacier and river flow assessments need to be undertaken by the United Nations Framework Convention on Climate Change (UNFCCC) in cooperation with national governments and regional organizations working in water-related fields, keeping in mind the action required at various levels. Research at the micro level is also needed to understand the impacts of climate change on water sources, including farm and field-based research on water management.

It is essential for the governments of the countries sharing the HKH to come together to understand the dynamics of change in the HKH to reduce the speed of change.

The main water-related risks for Asia according to the IPCC

In their latest assessment report, the IPCC has several key messages on water-related challenges at the global and regional level. Below we highlight some of the key risks identified by the IPCC for Asia.[121]

Key regional risks include increased flood damage to infrastructure, livelihoods and settlements and increased drought-related water- and food-shortages, the latter already a medium risk in the near term (2030–2040). Climate change is projected to reduce renewable surface water and groundwater resources in most dry subtropical regions, intensifying competition for water among sectors, and to undermine food security especially in rural areas, which are expected to experience major impacts on water availability and supply, food security, infrastructure and agricultural incomes. There is large agreement between models that wheat, rice and maize production will decline increasingly towards the end of the century if adaptation measures are not implemented, even with moderate climate change. If global temperature increases by about 4°C or more above late 20th century levels, climate change combined with increasing food demand would pose large risks to food security globally.

Urban areas are also increasingly at risk from climate change, including risks associated with heat stress, storms and extreme precipitation, flooding, landslides, air pollution, drought and water scarcity. These risks are amplified for those lacking the essential infrastructure and services or living in exposed areas. Climate change impacts are projected to slow down economic growth, make poverty reduction more difficult, further erode food security, and prolong existing and create new poverty traps, the latter particularly in urban areas and emerging hotspots of hunger. Climate change is also projected to increase the displacement of people, especially those who experience higher exposure to extreme weather events, particularly in developing countries with low income.

Policy recommendations

1. Implement flexible and diverse solutions to address the high level of uncertainty.

Solutions and adaptation measures will have to take into account the overall expected changes as well as the spatial variations and uncertainties in changes. For example, farming systems urgently need restructuring towards higher flexibility so that they can withstand the increased flood risk, lower water availability and other impacts of climate change. As migration, mainly of men, is increasing, it is necessary to develop more gender-sensitive farming approaches while strengthening education and building effective networks for knowledge sharing.

2. Implement structural and non-structural measures to adequately prepare for and manage extreme events.

While the number of extreme events is projected to decrease, the intensity of precipitation events is likely to increase and result in more severe damage to lives and property. Structural measures (such as flood prevention structures) and non-structural measures (such as the implementation and enforcement of building codes, land use planning laws or early-warning systems) are needed to reduce exposure, vulnerability and risks for populations, as well as to adequately manage disaster events if they occur.

3. Strengthen modelling approaches to further reduce uncertainty and undertake research to fill critical gaps.

Climate models are not able to sufficiently capture the sharp horizontal and vertical gradients of biophysical processes in the region. Efforts to improve the models through increasing spatial resolution as well as incorporating more mountain-specific physical processes in the models are essential. Further research is required to understand the factors that impact on the functioning of springs (a major source of water in the mid-hills) and to implement measures to improve the functioning of springs.

4. Improve regional coordination and sharing of data.

Much of the uncertainties in the scientific results stem from the fact that climate monitoring in the HKH region is inadequate, particularly in high altitude areas. There is a strong need for a coordinated regional effort to improve hydrometeorological monitoring in the region and data sharing within institutions. Innovative ways of combining in-situ measurements, remote sensing based measurements and modelling approaches should be undertaken to fill the data gaps.

5. Adopt a river basin approach to protect Himalayan ecosystems to harness the potential of water resources.

Although the total amount of water resources in the HKH may stay roughly the same as present day, they will need to be managed more effectively as demand will undoubtedly increase in the future to meet increasing energy and water-intensive food production needs. Within the region, there exists a high dependency of downstream communities and countries on upstream ecosystem services, particularly for water in the dry-season,[3] and the benefits of sustainable watershed management transcend national boundaries. At the same time, integrated planning and management between sectors, such as water, energy, land, forest, ecosystems and agriculture, is needed to enhance resource use efficiency and reduce environmental impacts.

6. Put mountains on the global climate change agenda.

Globally, mountains provide 60–80% of the world's fresh water. The HKH mountains, home to some of the largest rivers in the world, directly provide water and other services to over 1.3 billion people living within the region and downstream. While water is recognized as one the central issues in the global climate change discourse, the interlinkage between water and mountains is yet to be established as a global priority agenda. Therefore, putting mountains on the global agenda would be in the interest of not only mountain communities, but also the global community.

ADDITIONAL INFORMATION

HICAP's approach to the historical analysis of climate projections

Historical analysis

For the historical analysis of precipitation, daily precipitation analysis using high-resolution gridded precipitation data sets developed by APHRODITE's water resources (Asian Precipitation – Highly-Resolved Observational Daily Integration Towards Evaluation of Water Resources) were used to analyse the rainfall trends and variabilities. For the historical analysis of temperature, one-degree resolution maximum and minimum daily data generated by the Hydroclimatological Group, Princeton University, were used. The data set is bias-corrected and is a hybrid of NCEP/NCAR (National Center for Environmental Prediction/National Center for Atmospheric Research) re-analysis and observations.

Climate projections

Climate modellers all over the world use different models (global, regional and local) to investigate how different patterns of greenhouse gas emissions may impact on our climate over time. These models are based on different scenarios, which are assumptions that inform the model about factors such as policy, socioeconomics, emissions, and the interaction of climate gases with environmental and socioeconomic systems.

The Representative Concentration Pathways (RCPs) are standardized scenarios that include time series of emissions and concentration of the full suite of greenhouse gases and aerosols and chemically active gases, as well as land use/land cover[122] towards 2100. The word 'representative' signifies that each RCP provides only one of many possible scenarios that could lead to the specific radiative forcing characteristics. The term 'pathway' emphasises that not only the

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long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome. There are four main sets of RCPs, which represent different scenarios of global warming due to differences in radiative forcing: the balance between incoming (from the sun) and outgoing (from the earth) radiation into the atmosphere as a result of changes in the atmospheric gas composition (following, for example, greenhouse gas emissions). One of these four scenarios, RCP 8.5, assumes more or less unabated, increasing greenhouse gas emissions over time. This scenario is equivalent to a global average temperature increase of 2°C by 2046–2065, and 3.2–5.4°C by 2100. RCP 4.5, on the other hand, is a scenario of reduced and stabilized emissions, in which total radiative forcing is stabilized shortly after 2100, leading to a mean temperature increase of 2.4°C (range of 1.0–3.0°C) by 2100.

What models and projections are (and aren't)

In climate modelling, scenarios inform models, which then are used to create projections. Scenarios describe plausible trajectories of different aspects of the future that lead to different emission pathways, climate change and consequences. Models use many aspects of scenarios to create projections of potential future levels of climate change and impacts. Models, however, are approximations only, as it is impossible for them to cover all variables and relations between them. Projections, therefore, are inherently uncertain. We do not know which decisions will be made in the near or far future. Therefore, what climate change or its impacts will actually look like in the future will not be any more or less certain, regardless of how well models describe past and current events.

Then what is the purpose of models? They serve to inform decision makers about what may happen given certain decisions and related emission levels. They allow us to test the effectiveness of certain decisions with respect to bringing emissions down, and of adaptation measures. Models can thus be used to define either a pathway towards a desired end goal, or the boundaries and extremes of future climate – the 'best and worst case' scenarios to which local actors must adapt to. A comparison of recent global trends in carbon dioxide emissions indicates that global emissions currently most closely follow the track of the RCP 8.5 scenario[123–125] making this the most likely scenario of change.

HICAP's approach in developing future climate change scenarios

HICAP adopted a delta change approach to downscale global climate models to a finer resolution data for the HKH region. This approach uses differences between simulated present (base period) and future (projection period) climate conditions from global climate models added to observed time series of climate variables. The analysis uses RCP 4.5 and 8.5 scenarios and, for each of these, four different global climate model outputs covering a wide range of changes in temperature and precipitation are used for downscaling. The scenarios presented in this Atlas are ensemble averages of the four outputs. The scenarios are based on published material from Lutz et al. 2014,[126] as well as the final report submitted by Future Water.[127]

Glossary

Disaster: A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceed the ability of the affected community or society to cope using its own resources. Disasters are often described as resulting from the combination of exposure to a hazard, existing conditions of vulnerability, and insufficient capacity or measures to reduce or cope with the potential negative consequences. Disaster impacts may include loss of life, injury, disease and other negative effects on human physical, mental and social wellbeing, together with damage to property, destruction of assets, loss of services, social and economic disruption, and environmental degradation.[128]

Baseflow: The sustained flow of a stream in the absence of direct runoff. It includes natural and human-induced stream flow. Natural baseflow is sustained largely by groundwater discharge.[129]

Discharge: The volume of water that passes a given location within a given period of time. Usually expressed in cubic feet or cubic metres per second.[130]

Ecosystem services: The benefits that people and communities obtain from ecosystems. These include 'regulating services' (of floods, drought, land degradation and disease), 'provisioning services' (food and water), 'supporting services' (soil formation and nutrient cycling) and 'cultural services' (recreational, spiritual, religious and other non-material benefits). The integrated management of land, water and living resources that promotes conservation and sustainable use and provides the basis for maintaining ecosystem services, including those that contribute to reducing disaster risks.[131]

Emission scenarios: These describe future releases into the atmosphere of greenhouse gases, aerosols and other pollutants and, along with information on land use and land cover, provide inputs for climate models. They are based on assumptions about driving forces such as patterns of economic and population growth, technology development and other factors. Levels of future emission are highly uncertain, and so scenarios provide alternative images of how the future might unfold. They are an appropriate tool with which to analyse how driving forces may influence future emission outcomes and to assess the associated uncertainties. They assist in climate change analysis, including climate modelling and the assessment of impacts, adaptation and mitigation. The possibility that any single emissions path will occur as described in the scenarios is highly uncertain.[132]

Flood: An overflow of water onto lands that are used or usable by man and not normally covered by water. Floods have two essential characteristics: The inundation of land is temporary and the inundation is due to overflow from an adjacent river, stream, lake or ocean.[133]

Hydrological cycle: The cycle in which water evaporates from the oceans and the land surface, is carried over the Earth in atmospheric circulation as water vapour, condenses to form clouds, precipitates over the ocean and lands as rain or snow, which on land can be intercepted by trees and vegetation, provides runoff on the land surface, infiltrates into soils, recharges groundwater, discharges into streams and ultimately flows out into the oceans, from which it will eventually evaporate again. The various systems involved in the hydrological cycle are usually referred to as hydrological systems.[134]

Peak flow: The maximum instantaneous discharge of a stream or river at a given location.[135]

Precipitation: Rain, snow, hail, sleet, dew and frost.[136]

Representative Concentration Pathways (RCPs): Scenarios that include time series of emissions and concentration of the full suite of greenhouse gases and aerosols and chemically active gases, as well as land use/land cover.[137] The word 'representative' signifies that each RCP provides only one of many possible scenarios that could lead to the specific radiative forcing characteristics. The term 'pathway' emphasises that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome.[138]

Reservoir: A pond, lake, or basin, either natural or artificial, for the storage, regulation, and control of water.[139]

Resilience: The ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. The resilience of a community in relation to potential hazard events is determined by the degree to which the community has the necessary resources and is capable of organizing itself both prior to the shock and during times of need.[140]

Runoff: Total discharge from the part of precipitation, glacier melt, snow melt or irrigation water that appears in uncontrolled surface streams, rivers, drains or sewers. Runoff may be classified according to speed of appearance after rainfall or melting snow as direct runoff or base runoff, and according to source as surface runoff, storm interflow or groundwater runoff.[141]

South Asia: The United Nations defined geographical region of nine countries in southern Asia. South Asia includes six of the eight HKH countries: Afghanistan, Bangladesh, Bhutan, India, Nepal and Pakistan. China is classified as East Asia and Myanmar as Southeast Asia.[142]

Tributary: A small river or stream that flows into a large river or stream. Usually, a number of small tributaries merge to form a river.[143]

Vulnerability: The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. There are many aspects of vulnerability, arising from various physical, social, economic and environmental factors. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management. Vulnerability varies significantly within a community and over time.[144]

Watershed: The land area that drains water into a particular stream, river or lake. It is a land feature that can be identified by tracing a line along the highest elevations between two areas on a map, often a ridge. Large watersheds contain thousands of smaller watersheds.[145]

Water use: The use of water for a specific purpose, such as for domestic use, irrigation or industrial processing. Water use pertains to human interactions with, and influence over, the hydrologic cycle and includes elements such as water withdrawal from surface and groundwater sources, water delivery to homes and businesses, consumptive use of water, water released from wastewater-treatment plants, water returned to the environment, and instream uses, such as using water to produce hydroelectric power.[146]

Withdrawal (of water): Water removed from a surface or groundwater source for use.[147]

Acronyms

CICERO	Centre for International Climate and Environmental Research-Oslo
FAO	Food and Agriculture Organization
GDP	gross domestic product
GLOF	glacial lake outburst flood
HICAP	Himalayan Climate Change Adaptation Programme
HKH	Hindu Kush Himalayan/Himalayas
ICIMOD	International Centre for Integrated Mountain Development
RCP	Representative Concentration Pathway
UNESCO	United Nations Educational, Scientific and Cultural Organization

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