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ISSUE BRIEF

IMPLICATIONS OF CLIMATE CHANGE FOR WATER RESOURCES AND POLICIES IN THE INDUS BASIN

KEY FINDINGS FROM THE HIMALAYAN CLIMATE AND WATER ATLAS

This brief provides a general introduction to the water challenges facing the Indus basin and highlights some of the key climate research findings of the Himalayan Climate Change Adaptation Programme (HICAP). The brief is based on and is complementary to The Himalayan Climate and Water Atlas (2015).[1]

Much of the HICAP research focussed on the Upper Indus basin, which plays an extremely important role in providing water resources to the whole basin. Understanding the changes taking place here, especially in relation to the glaciers, is crucial for adaptation especially for communities living immediately downstream from glaciers who are most vulnerable to glacial changes.

The brief finishes with a series of practice, policy and research recommendations for strengthening adaptation to climate change.

Introduction

The Indus basin ranks among the most important river basins 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 people living in the basin. The Indus is also the second most water-stressed basin in the world with very little spare capacity in the system. Over the coming years and decades, the Indus basin faces the challenge of producing more food with the same or less water available while coping with a changing climate.

Agriculture plays a critical role in the Pakistan economy, accounting for a significant share of the GNP, employing almost half of the labour force, and supporting many rural livelihoods.[2] Almost 90% of this vital sector depends on the Indus River. Much of the agriculture in the arid to semi-arid climate of the basin is only made possible through the extensive irrigation system. However, the total amount of water withdrawn each year almost equals the total available annual renewable supply.[3] A growing population is expected to place further pressure on the resource. At the same time, increasing use of groundwater will lead to falling groundwater tables and increasing salinity in many places.[4]

While some opportunities may arise and deserve to be explored, climate change will intensify existing water challenges, posing additional risks to food security and increasing the urgency to implement sustainable solutions in the agricultural sector.

The Indus river basin

Key Findings from the Himalayan Climate and Water Atlas for the Indus Basin

- Since the 1960s, winters are getting warmer, summers are getting cooler, and extreme hot days are getting hotter, threatening crop productivity.

- Temperatures are projected to rise by 2–4°C across the Indus basin up to 2050, and even more in the northern/upper parts of the basin, where an increase of up to 5°C is projected by 2100. Increases in temperature will place increasing demand on water resources, not only because water bodies will evaporate more quickly but also from of the increasing the water requirements of crops (greater evaporative demand).

- Since the 1960s, precipitation patterns have changed across the Indus basin although there is no consistent pattern. Up to 2050, projected changes in rainfall vary across the basin, increasing in some areas while decreasing in others. However, significant uncertainty still exists in projecting rainfall patterns into the future.

- The changing and more unpredictable precipitation patterns may have serious consequences for the region, including flash floods in the north and increased droughts in the southern plains.

- The upper Indus River is highly dependent upon meltwater, with 41% of river flow coming from glacial meltwater and 22% from snowmelt. Only 27% of the river's flow comes from rainfall so any change in snow and glacial melting will have serious consequences for water availability in the basin.

- As the glaciers retreat, more glacial lakes will form, increasing the risk of Glacial Lake Outburst Floods (GLOFS), which are already becoming increasingly common and hazardous in Northern Pakistan. While most glaciers across the Himalayas are strongly retreating, some in the Karakoram region remain unchanged or have increased slightly in recent decades. However, by 2050, the glacial areas within the Indus basin are projected to decrease by 20–30%.

- No significant decrease in runoff is projected in the Indus basin up to 2050, and the contribution of glacial melt to total river flow will continue to increase up until 2050. However, higher variability in river flows and more water in the pre-monsoon months are expected, resulting in more frequent floods and droughts, and the risks of water-related disasters.

- Changes in temperature and precipitation, outlined in the key findings above, 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.

KEY CLIMATE AND WATER FINDINGS

#1 Temperature

- **Since the 1960s, winters are getting warmer, summers are getting cooler, and extreme hot days are getting hotter threatening crop productivity.**
- **Temperatures are projected to rise by 2–4 °C across the Indus basin up to 2050, and even more in the northern / upper parts of the basin, where an increase of up to 5 °C is projected by 2100.**

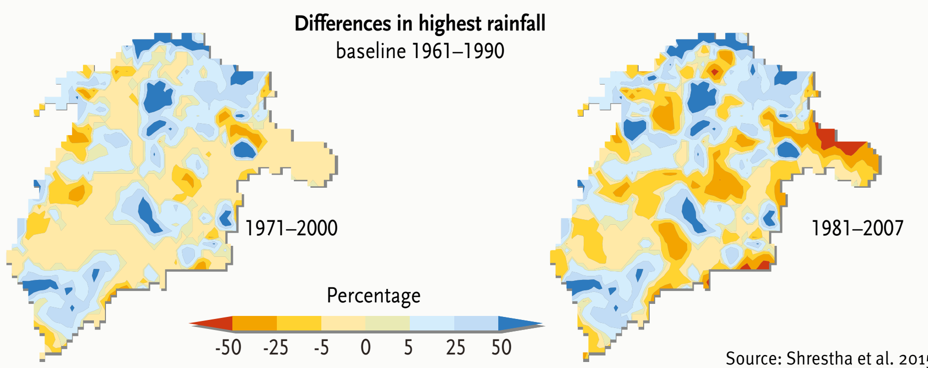
Across the Indus basin, the average maximum temperature is about 30°C in summer and 13°C in winter. Average minimum temperatures range from 18°C in summer to –0.3°C in winter. Since the 1960's, the average temperature show an increasing trend, driven mainly by increases in winter temperatures, especially since the 1980s.

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.

The Indus basin overall is projected to warm significantly and steadily over the rest of the century, with a slightly greater increase in minimum temperatures than in maximum temperatures. Warming is projected to be greater in winter than in the other seasons and greater in the upper Indus basin than the lower Indus basin, with a large area to the west of the basin projected to warm significantly. In summer, a major part of the basin is projected to warm by 2–3°C and up to 5°C or more (depending on the climate scenario)[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, about 1–2°C. Winters are projected to warm by 2–4°C across the basin in both scenarios, with a few areas either exceeding 4°C or warming by lower than 2°C.

Warming temperatures do not necessarily imply longer growing seasons. For example, a mild winter in 2014 brought increased cloud cover to the upper Indus valley. Snow melt was delayed by two weeks that year leading to a corresponding delay in sowing of wheat. Many farmers opted to harvest green wheat for use as fodder while others faced damage to their maize crop in autumn.

Extreme rainfall events – Indus



Source: Shrestha et al. 2015

#2 Precipitation (rainfall)

- **Since the 1960s, precipitation patterns have changed across the Indus basin although there is no consistent pattern. Up to 2050, projected changes in rainfall vary across the basin, increasing in some areas while decreasing in others. However, significant uncertainty still exists in projecting rainfall patterns into the future.**
- **The changing and more unpredictable precipitation patterns may have serious consequences for the region, including flash floods in the north and increased droughts in the southern plains.**

The average annual precipitation in the Indus basin is 365 mm, although the variation across the basin is considerable. 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, reaching up to 3,000 mm in some areas. Fifty-five per cent of precipitation falls during the monsoon (June-September) season. Winter contributes 17% of the total annual precipitation for the whole basin and as much as 30% in the upper basin.

The upper Indus basin receives more precipitation than the lower basin and plays an important role in water availability throughout the year. During the dry season, the flow from the meltwater of glaciers is particularly important, accounting for a large share of the total flow in the uppermost parts of the catchments .

Since the 1960s, precipitation patterns have changed across the Indus basin, although not consistently. 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 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.

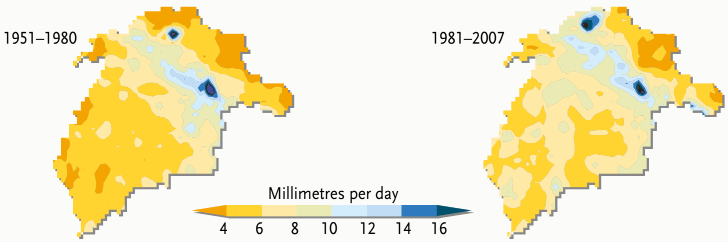
Extreme rainfall events have increased in intensity over the main mountain range in the upper basin (where annual precipitation is already the highest), especially in the eastern section, while the number of rainy days has decreased. This area now receives more rainfall over fewer days. Within the rest of the basin, the intensity has decreased while the number of rainy days has remained the same.

Projected changes in rainfall up to the year 2050 are varied across the basin, increasing in some areas while decreasing in others. Precipitation is projected to increase in summer over the northern, central-eastern and southern parts of the Indus basin, while decreases are projected over the central-western part of the basin. An increase of 10–25% is projected in the regions currently receiving the highest rainfall along the mountain range. Both winter and summer precipitation are projected to decrease in the central-western part of the basin while in the northern and southern parts of the basin it is projected to increase between 5–10%.

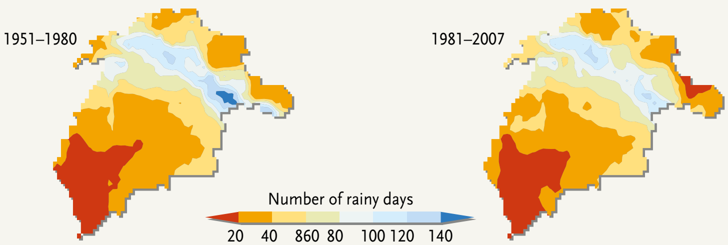
In terms of extreme rainfall events, an overall increase in the number of rainy days is suggested over the northern part of the basin and a decrease over the southern part. There is, however, also a projected decrease in the number of rainy days accompanied by an increase in rainfall intensity in the border area between the upper and lower basins where the rainfall amount is highest. These changing precipitation patterns may have serious consequences for the region, including flash floods in the north and increased droughts in the southern plains.

Indus basin climate indicators – Rainfall

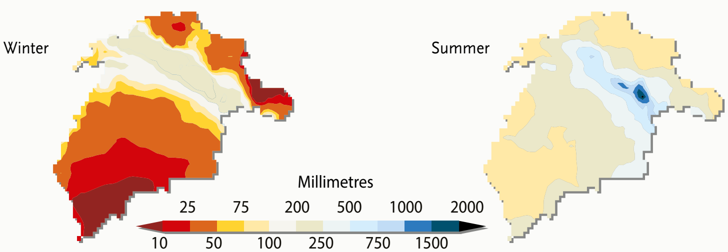
How much does it rain?
Rainfall intensity on a rainy day



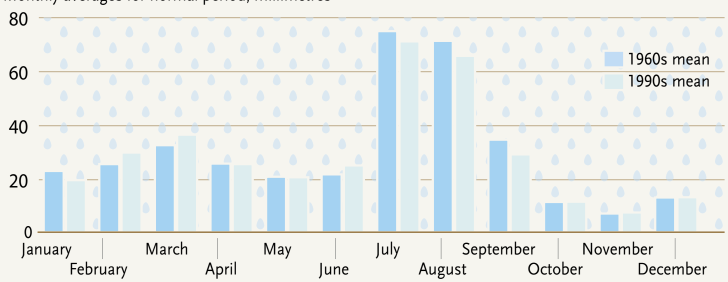
For how long does it rain?
Rainy days in a year



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

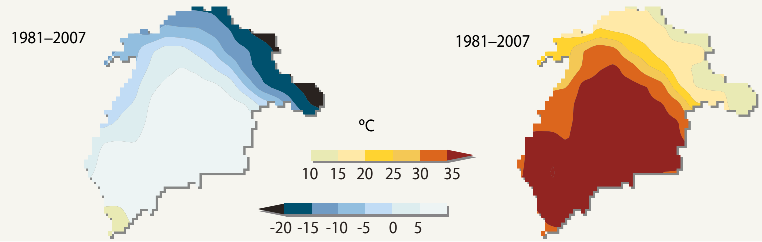


When does it rain?
Monthly averages for normal period, millimetres

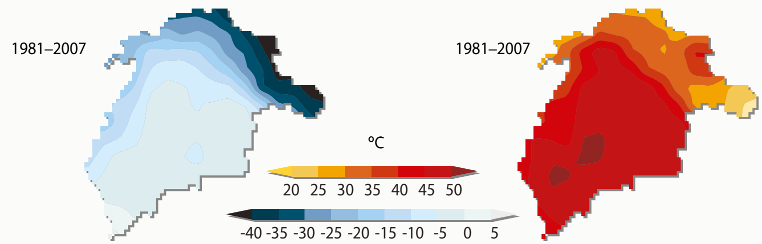


Temperature

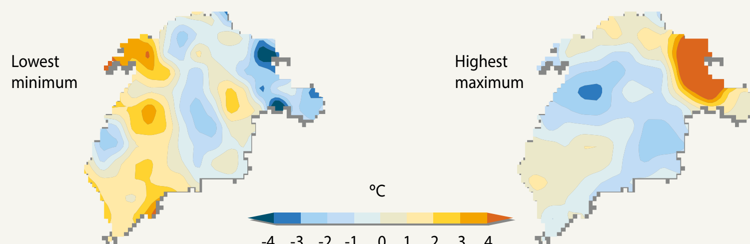
Where is it hot and where is it cold?
Average winter minimum temperature
Average summer maximum temperature



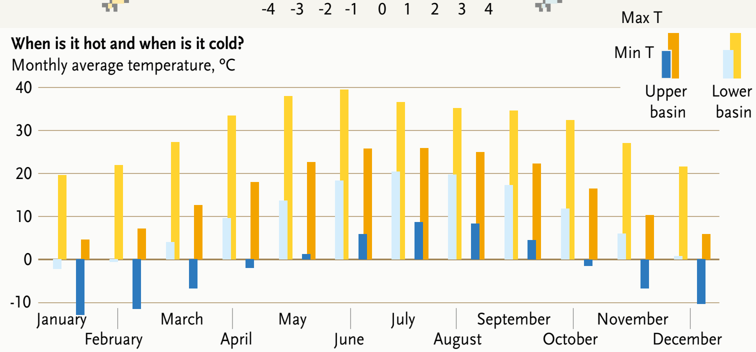
How hot and how cold?
Lowest minimum temperature
Highest maximum temperature



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



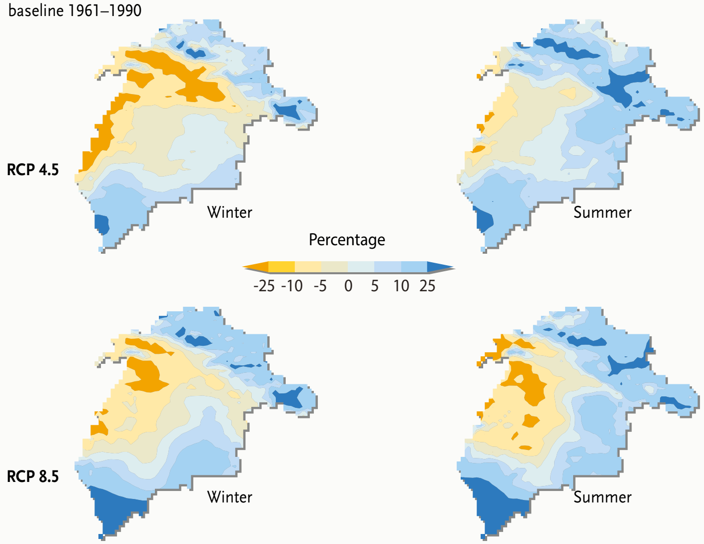
When is it hot and when is it cold?
Monthly average temperature, °C



Source: Shrestha et al. 2015

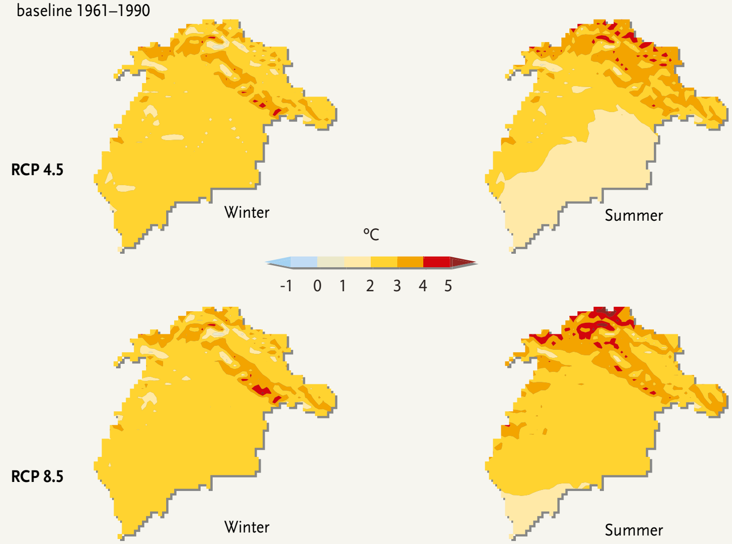
Indus basin future climate – Rainfall

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

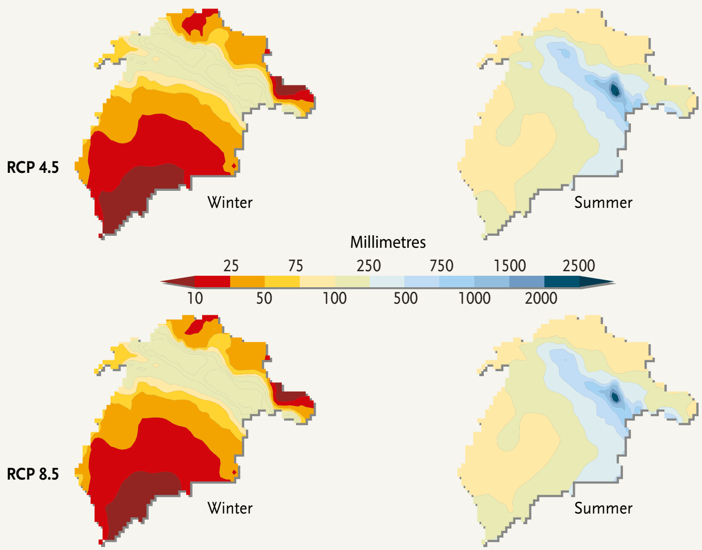


Temperature

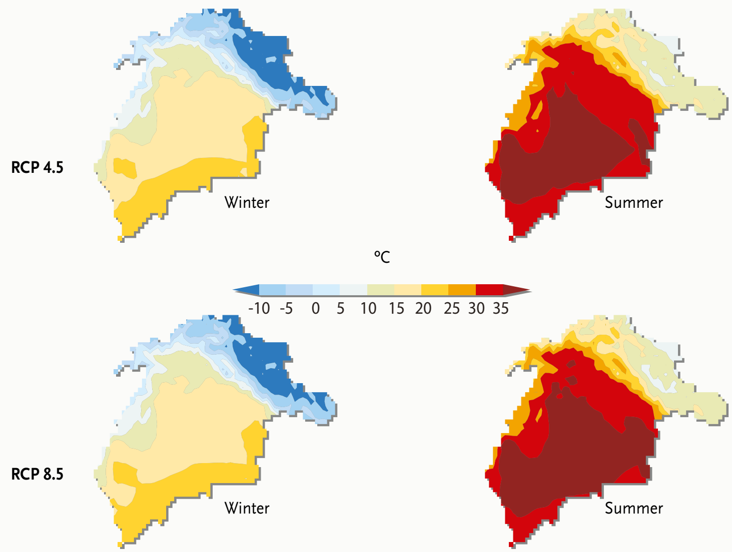
Change in average temperature, 2021–2050
baseline 1961–1990



Spatial distribution of projected future rainfall , 2021–2050



Spatial distribution of projected future temperature, 2021–2050



Source: Shrestha et al. 2015

#3 Response of glaciers to climate change

- **While most glaciers across the Himalayas are strongly retreating, some in the Karakoram region remain unchanged or have increased slightly in recent decades.**
- **The glacial area within the Indus basin is projected to decrease by 20–28% by 2050.**
- **As the glaciers retreat, more glacial lakes will form, increasing the risk of Glacial Lake Outburst Floods (GLOFS), which are already becoming increasingly common and hazardous in Northern Pakistan.**

Understanding why some glaciers in the Karakoram are advancing (a.k.a. the Karakoram Anomaly) is crucial for projecting the future water availability for millions of people in the Indus Basin. The glaciers in the Karakoram are unique for a number of reasons, including:

- A large concentration of very high and steep mountains leading to a greater contribution of avalanches to glacier mass;
- Being situated at a higher average altitude than other glaciers in the region and nourished primarily through heavy winter snowfalls.
- 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 advance quickly downhill. The debris cover insulates the ice below from melting.

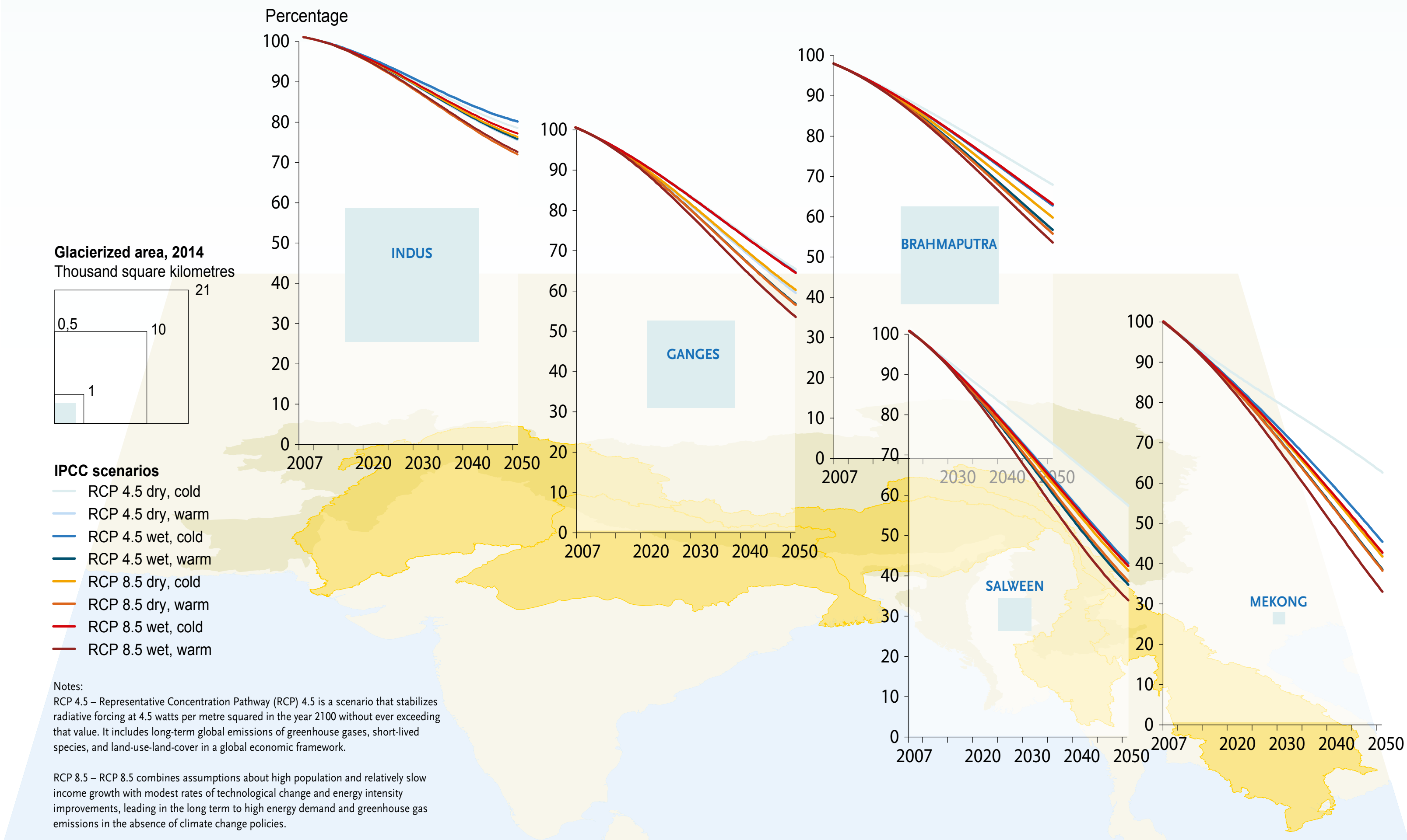
Although there is currently no definitive answer as to why glaciers in the Karakoram are behaving differently than the near-global signal of glacier retreat, increasing winter precipitation combined with decreasing summer temperatures could be one possible explanation. New science estimates that precipitation in the Karakoram high altitudes may be at least two and up to 10 times higher than previously thought.[6] New research also suggests an increase in the frequency of westerly disturbances, which could be responsible for the anomaly.[7]

Photo © iStock/Ravindra Joisa

The glacial area within the Indus basin is projected to decrease by 20–28% by 2050. Most models project substantial losses in glacial mass and area in the coming decades for most parts of the Hindu Kush Himalaya. Lower-lying river basins including the Salween and Mekong are expected to lose a much larger proportion of their glaciers (by up to 68%). Although the Indus basin shows the smallest decrease in percentage because it has the largest glaciated area within the Hindu Kush Himalaya, the absolute loss is likely to be the greatest in this basin.

Generally speaking, in the more extreme climate scenarios, the average glacial loss is projected to be much higher. Temperature increases will be the most important determining factor driving loss of glacial mass in this region. As temperatures rise, more glaciated area will be exposed to above-freezing temperatures. This means two things: first, that the glaciers will melt faster, and second, that more precipitation will fall as rain rather than snow so that the melting ice is not 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

#4 Contribution of snow, ice and rain to river flow

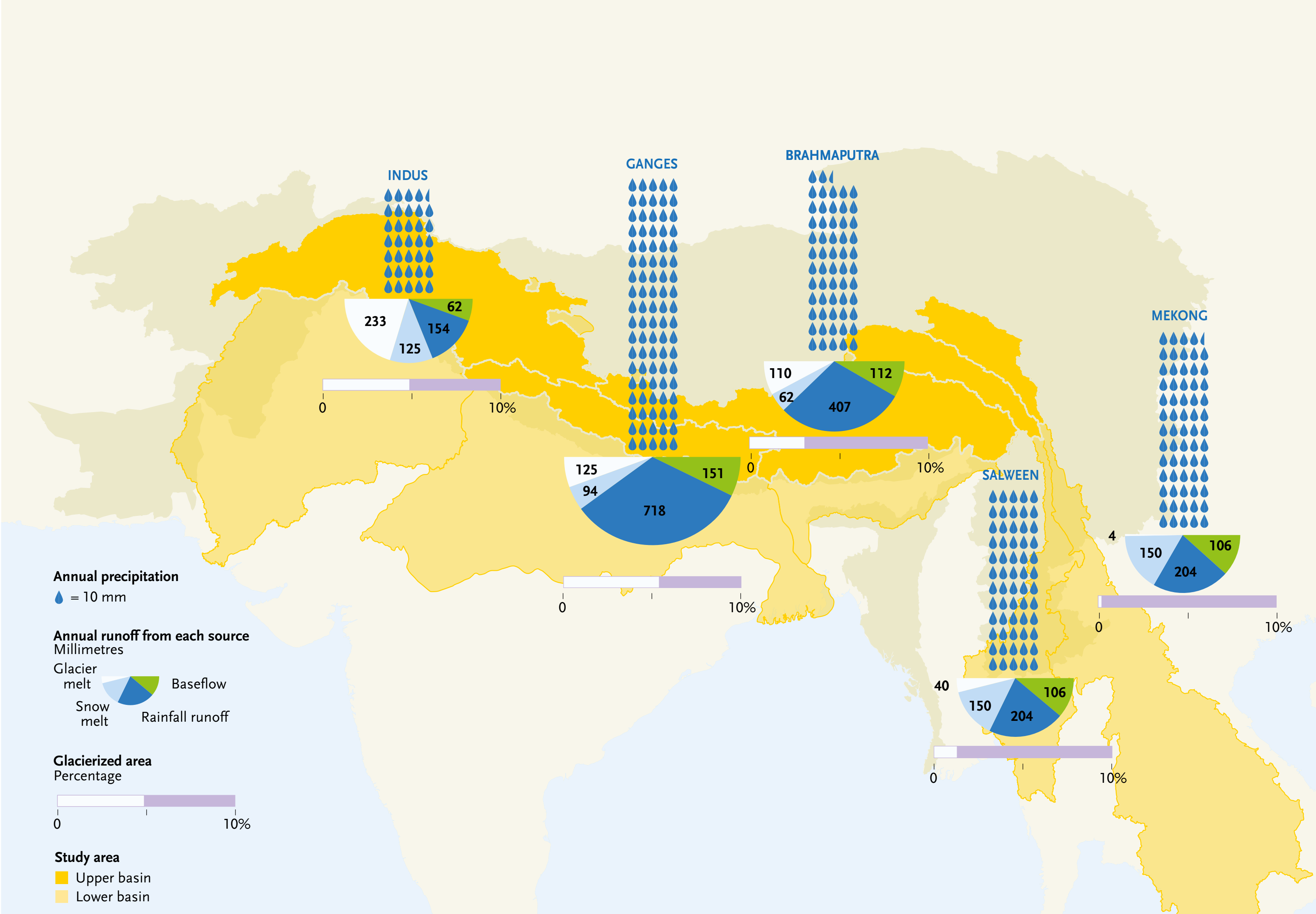
- **The (upper) Indus River is highly dependent upon meltwater with 41% of river flow coming from glacial meltwater and 22% from snowmelt. Only 27% of the river's flow comes from rainfall. Any change in snow and glacial melting will have serious consequences for the water availability in the river basin.**

The contribution of glacial meltwater to the flow in the Indus River is much greater than in Himalayan river basins dominated by monsoons, such as the Ganges, Brahmaputra or Salween-Mekong. This means that the retreat and advance of glaciers within the Indus basin have wide-reaching effects on water supply and flow patterns, thus influencing hydroelectric generation, agriculture, and natural ecosystems.

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, for example, into the reservoir behind Tarbela Dam is considered crucial. This reservoir 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.

Hydrological charateristics of the HKH region

Selected upper river basins of the HICAP study

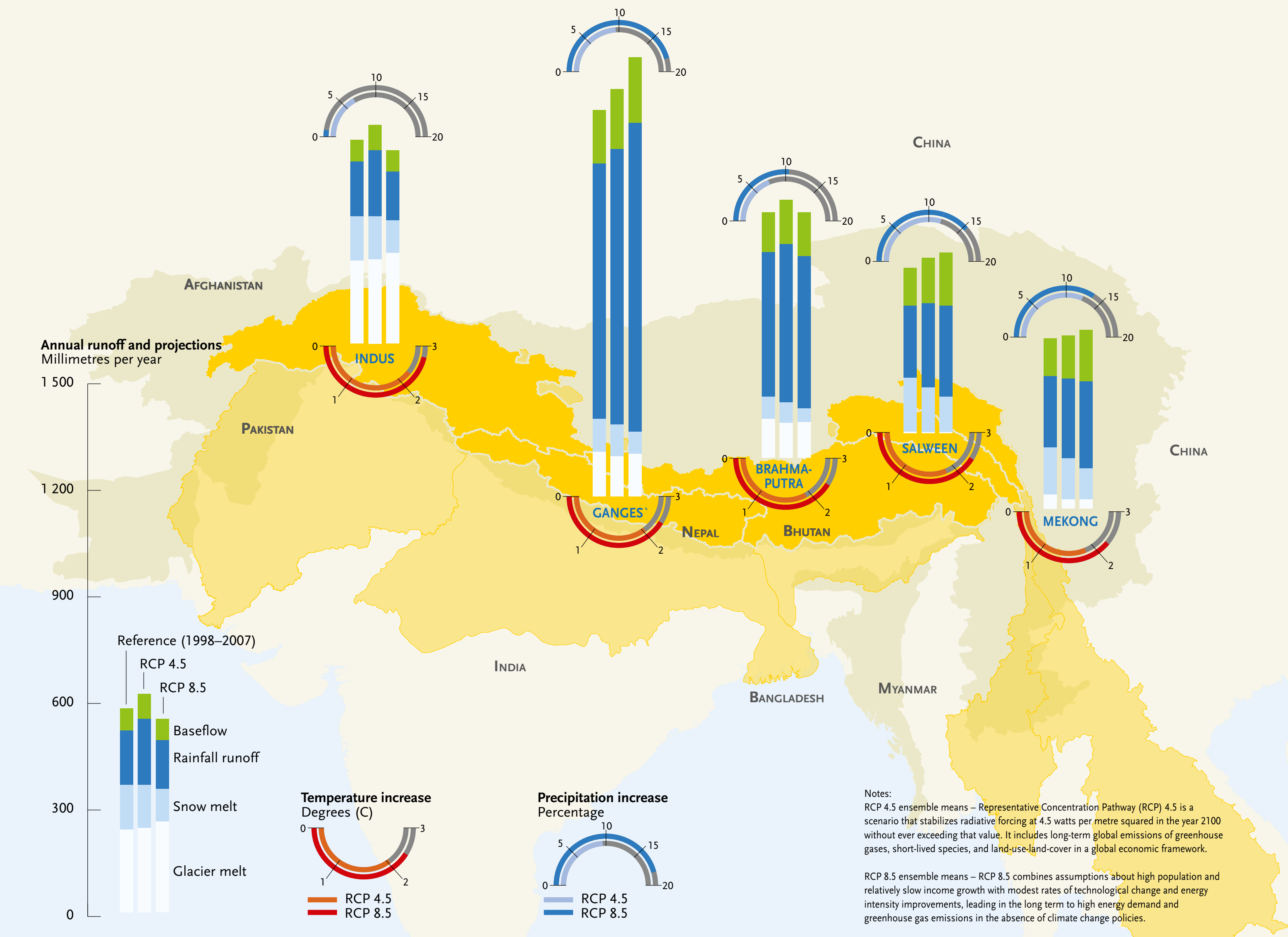


The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by ICIMOD, CICERO or GRID-Arendal.

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

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

#5 Projected changes in river flow to 2050

- **No significant decrease in runoff[8] is projected by 2050 in the Indus basin, and the contribution of glacial melt to total river flow in the Indus basin will continue to increase up until 2050.**
- **While the overall flow might not change significantly at larger scale, catchments close to the glacier may face water shortages.**

Depending on the climate projection used, however, there could be either a slight increase in runoff (under the more moderate scenario) or a slight decrease (under the more extreme scenario – RCP 8.5).[9] Under the moderate climate scenario (RCP 4.5 ensemble mean),[10] the total upper Indus river flow increases (12%), while under the more extreme scenario (RCP 8.5 ensemble mean) it decreases (–5%) compared to the reference period. The difference is due to the considerable difference in precipitation projected under each of the scenarios. Both scenarios, however, make it clear that the contribution of glacial melt to river flow will increase up until 2050.

It is important to note, however, that while the overall flow might not change significantly at larger scale, catchments close to the glacier may face water shortages. Furthermore, the downwasting of glaciers (i.e. thinning) can lead to non-functioning of the community managed irrigation canals. There are several such examples in upper Indus basin.

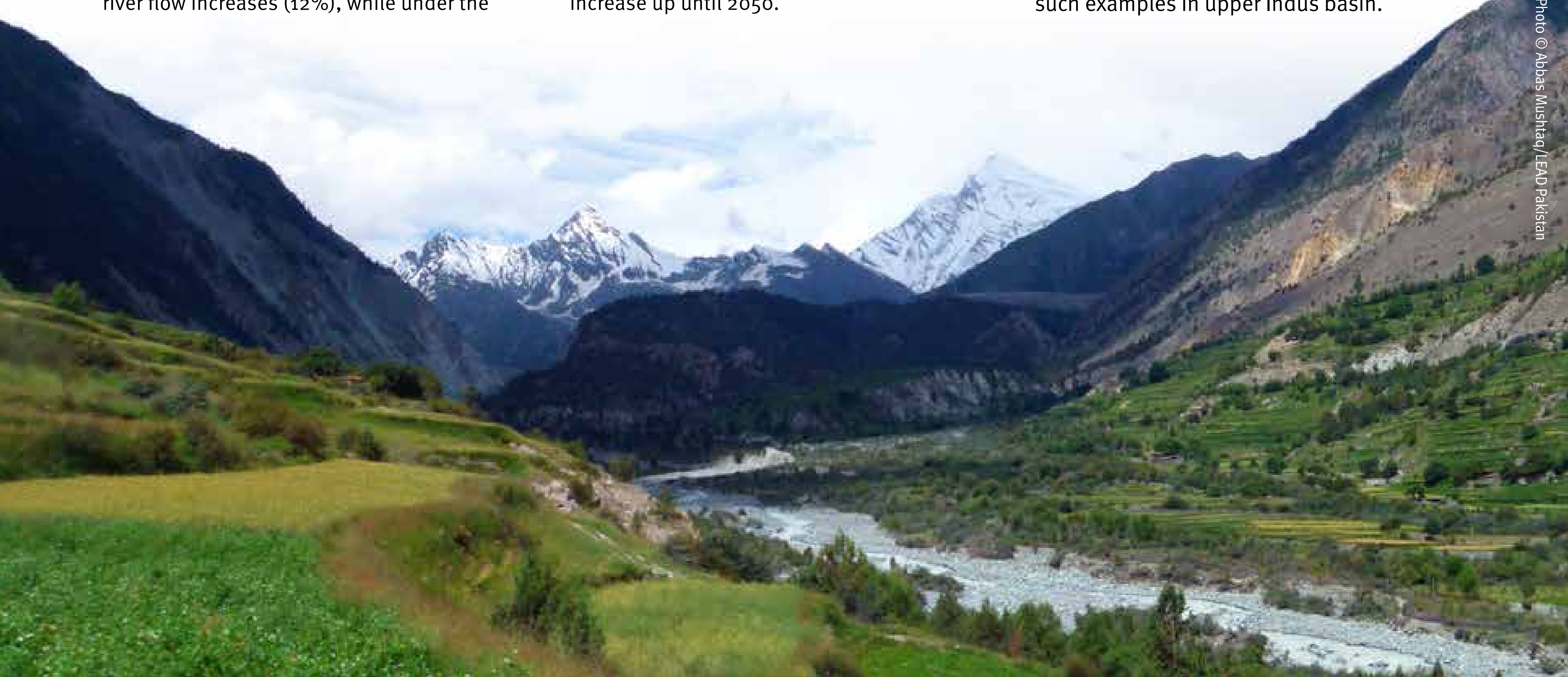


Photo © Abbas Mushtaq/LEAD Pakistan

OPTIONS FOR ADAPTATION

While climate change will pose additional risks to the already serious challenges facing the Indus basin, there are a number of options which can be considered to help communities – both upstream and downstream – and various water-dependent sectors adapt:

Policy

Adopt policies that promote water conservation and climate-smart agricultural production: Policies for the irrigation sector which reward farmers on efficient practices are needed. Current policies, such as subsidies on groundwater pumping, leads to inefficient irrigation methods. Policies that discourage flood irrigation should also be recommended.

Improve water management through policy reform to bring about sustainable water management, whilst also targeting policies in the agricultural sector to ensure farmers gain access to the right technology. Policy reform is needed on water conservation, crop yield improvement, climate resilience, integrated water resources management, and protect groundwater resources by regulating its use for irrigation to avoid soil salinization and depletion of natural aquifers.

Promote mechanisms for policy integration at all levels in order to avoid repetition and duplication. This includes between existing and pipeline national and provincial policies such as the National Water Policy of Pakistan, the National Climate Change Policy, the National Food Security Policy and various provincial policies such as the rangeland policies of Khyber Pakhtunkhwa and Gilgit-Baltistan.

Enhance capacity of the Government through participation in international climate change negotiations and linkages with major international institutes. Cooperation at all levels and between sectors will help devise effective adaptation and coping strategies.


Photo © iStock/pulpitis

Practice

Improve demand management and efficiency in all water-use sectors, particularly in the supply, distribution and use of irrigation water.

Improve water conservation and efficiency through smart crop selection and farming practises, and livestock management: measures include shifting toward less water thirsty crop varieties, and adjusting cropping pattern and planting time to match water availability and suitability of habitats.

Adopt more efficient irrigation methods, instead of flood irrigation as this is the least efficient irrigation method. Some innovative irrigation and water management methods – such as solar pumps – can address the problems of water scarcity in upstream areas of the basin. Improving irrigation efficiency by 20% could reduce the unmet water demand for most command canal areas by 2050.

Improve the management and maintenance of existing water supply systems: measures

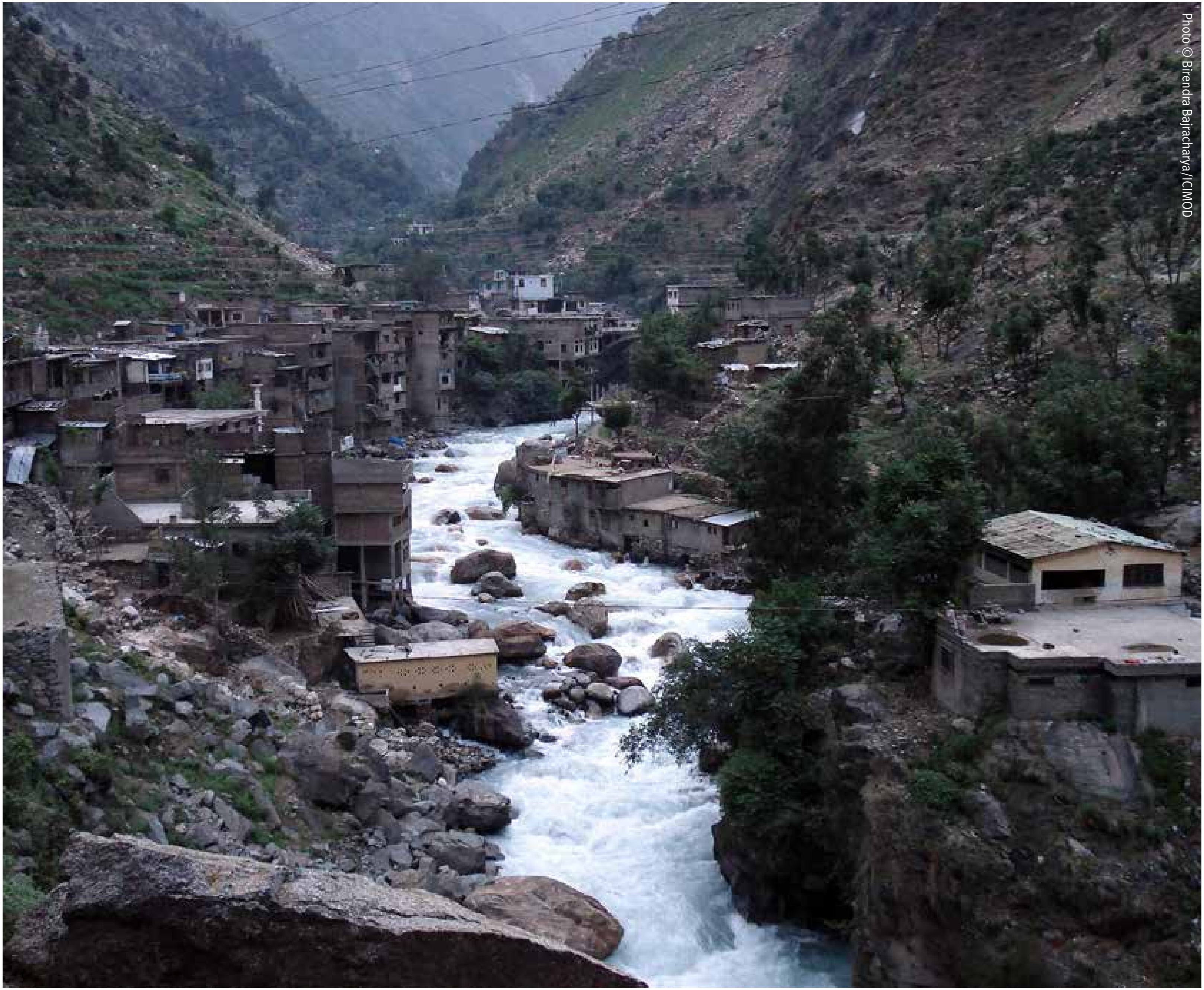


Photo © Birendra Bajracharya/ICIMOD

include lining of water channels to avoid seepage losses and development of water-logging/salinity, and protection of water catchment areas.

Improve the conservation of soil and water through resource-conservation technologies, such as bed and furrow sowing, laser land-leveling, furrow irrigation, zero tillage, and mulching which lowers evaporation and soil temperature. Encourage deep planting in rain-fed areas during the pre-rainy season to improve soil drainage, and rice cultivation by direct dry sowing and alternate wetting and drying method. Encourage groundwater and rainwater harvesting and desalination, and use of recycled water and marginal quality effluent for irrigation.

Conserve groundwater aquifers: Sustainable management of groundwater aquifers to provide buffer against climate shocks is needed, for example by introducing supply side solutions such as rainwater harvesting to balance aquifer discharge and recharge.

Restore lost wetlands, riparian zones and riverine aquifers to help improve the natural storage capacity of the system which has been severely degraded due to mega storages and diversions. Improved storage capacity of the system may offset the need for more dams, as well as improve natural ecosystems, resilience against floods and droughts, and the sustainability of the system as whole.

Develop new sustainable water resources to increase storage capacity (reservoirs), and establish floodwater earthen farm ponds (mini-dams) with community participation.

Photo © iStock/danishkhan

Applied Research

Enhance agricultural research to develop new or identify existing crop varieties that are better suited to changing climatic conditions (e.g., drought tolerant and pest resistant) and better varieties of livestock with higher productivity and more tolerant of heat.

Develop efficient irrigation systems which are more farmer friendly, consume less power, require less maintenance, and are eco-friendly, indigenously developed and gender sensitive. Although drip and sprinkler irrigation schemes could be introduced in drought-prone/water stressed areas, these systems are complicated, power dependent and maintenance heavy.

Improve knowledge about current climate trends, future scenarios, and climate hazards:

- Research short/long-term trends in glacier activity to evaluate water supplies and causes of glacial hazards.
- Monitor flood and drought risks, along with continued monitoring and analysis of climatic variability and trends. This includes monitoring of the risk of Glacial Lake Outbreak Floods (GLOFs), which are becoming increasing common and hazardous in Northern Pakistan.
- Improve weather forecasting systems in the region and establish a regional early warning system. Continued monitoring and analysis of climatic variability and trends is required. Regional information/data sharing should be encouraged.
- Scale up future water and climate change scenarios from watersheds to river basins to assist in determining water allocation for households, agriculture and ecosystems.

Undertake comprehensive vulnerability assessments regularly to devise appropriate mechanisms for communities. Capacity Building of local communities to cope with climate change impacts should be enhanced. This can be done by raising awareness through dialogue between different vulnerable sectors.

Notes

1. Shrestha, AB; Agrawal, NK; Alfthan, B; Bajracharya, SR; Maréchal, J; van Oort, B (eds) (2015) The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins. ICIMOD, GRID-Arendal and CICERO.
2. Yu, Winston, Yi-Chen Yang, Andre Savitsky, Donald Alford, Casey Brown, James Wescoat, Dario Debowicz, and Sherman Robinson. 2013. The Indus Basin of Pakistan: The Impacts of Climate Risks on Water and Agriculture. Washington, DC: World Bank. doi: 10.1596/978-0-8213-9874-6. License: Creative Commons Attribution CC BY 3.0
3. World Resources Institute / Aqueduct. 2013. Aqueduct Country and Rive Basin Rankings. http://www.wri.org/applications/maps/aqueduct-country-river-basin-rankings/#x=-27.42&y=-1.51&l=2&v=home&d=bws&f=1&o=-9999&init=y
4. Yu, Winston, Yi-Chen Yang, Andre Savitsky, Donald Alford, Casey Brown, James Wescoat, Dario Debowicz, and Sherman Robinson. 2013. The Indus Basin of Pakistan: The Impacts of Climate Risks on Water and Agriculture. Washington, DC: World Bank. doi: 10.1596/978-0-8213-9874-6. License: Creative Commons Attribution CC BY 3.0
5. 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 towards 2100. See Shrestha et al. 2015 for further details (page 89).
6. Immerzeel, W.W., Wanders, N., Lutz, A.F., Shea, J.M. & Bierkens, M.F.P. 2015. Reconciling high-altitude precipitation in the upper Indus basin with glacier mass balances and runoff. Hydrol. Earth Syst. Sci., 19, 4673–4687. http://www.hydrol-earth-syst-sci.net/19/4673/2015/hess-19-4673-2015.pdf
7. Ridley, J., Wiltshire, A. & Mathison, C. 2013. More frequent occurrence of westerly disturbances in Karakoram up to 2100. Sci Total Environ Dec 1: 468-469, Suppl:S31-5
8. 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.
9. Representative Concentration Pathway (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.
10. Representative Concentration Pathway (RCP) 4.5 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.

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Further details and information about the methodological approach can be found in the Himalayan Climate and Water Atlas, which is freely available to download at www.grida.no/publications and www.icimod.org/?q=20533