ICIMOD

WORKING PAPER 2019/8

Potential impacts of climate change on water resources and adaptation policies in the Brahmaputra River basin

Published by
International Centre for Integrated Mountain Development
GPO Box 3226, Kathmandu, Nepal

ISBN 978 92 9115 683 2 (print)
978 92 9115 675 7 (electronic)

Production team
Nagraj Adve (Consultant editor)
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Photos:
Jitendra Bajracharya

Printed and bound in Nepal by
Quality Printers Pvt. Ltd., Kathmandu, Nepal

Citation
Gupta, N., Mishra, A., Agrawal, N.K., Shrestha, A. (2019). *Potential impacts of climate change on water resources and adaptation policies in the Brahmaputra River basin,* Working Paper 2019/8, ICIMOD, Kathmandu

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Potential impacts of climate change on water resources and adaptation policies in the Brahmaputra River basin

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Abbreviations and acronyms

CBFEWS	Community Based Flood Early Warning System
GLOF	Glacial Lake Outburst Flood
HICAP	Himalayan Climate Change Adaptation Programme
HKH	Hindu Kush Himalaya
ICIMOD	International Centre for Integrated Mountain Development
PDGL	Potentially Dangerous Glacial Lake
RMV	Resilient Mountain Villages

Executive summary

The Brahmaputra River basin is extremely important for over 600 million people, who depend on it for irrigation, domestic use, fisheries, tourism, transportation, and hydropower. The basin is dependent mainly on precipitation, while the upper part of the basin depends on meltwater from glacier and snow melt. Hence, understanding the changes taking place in relation to temperature, precipitation, and the flow regime is important for ecosystems, food security, and livelihoods. This working paper provides an introduction to the water challenges facing the Brahmaputra river basin in a climate change context. It offers a series of suggested actions for potentially complementing existing climate change adaptation initiatives and programmes around key climatic impacts, including rises in temperature, changes in rainfall patterns including extreme rainfall events, impacts on forests, and glacial lake outburst floods. The institutional level at which these adaptation measures can be optimally operationalized are indicated.

Keywords: adaptation, GLOFs, Hindu Kush Himalaya, Brahmaputra, PDGLs

Acknowledgements

This working paper was developed based on the results of the Himalayan Climate Change Adaptation Programme (HICAP), implemented from September 2011 to December 2017 by the International Centre for Integrated Mountain Development (ICIMOD), GRID-Arendal, and the Center for International Climate Research, Oslo (CICERO), in collaboration with local partners. Further work on the project and the publication of this paper has been supported by the Resilient Mountain Solutions (RMS) Initiative. Both the HICAP and RMS initiatives have been funded by the governments of Norway and Sweden.

The work was partially supported by ICIMOD core funds, contributed by the governments of Afghanistan, Australia, Austria, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Norway, Pakistan, Sweden, and Switzerland.

KEY MESSAGES

Temperature rises and changes in precipitation could impact riverine ecosystems adversely. The shrinking of Himalayan glaciers could lead to a decrease in the water flows of perennial rivers, thereby impacting tens of millions of people dependent on them.

SECTION 1

Introduction

Himalayan rivers, including the Brahmaputra, are facing critical pressures, and urgently require the application of management strategies for their immediate protection and long-term conservation.

Rivers have a multitude of key ecological and societal functions (Sarkar et al. 2008). They are vital for the maintenance of soil fertility, transportation, the development of forest resources, and wildlife conservation (Suthar et al. 2010) They cater to the industrial, agricultural, and domestic sectors (Solaraj et al. 2010), and contain numerous aquatic species (Allen et al. 2010). However, major rivers such as the Nile, the Ganges, the Amu Dar'ya, the Syr Dar'ya, the Yellow River, and the Colorado River are all facing various levels of anthropogenic stressors (Saunders et al. 2002).

The pressures from a growing population and subsequent urbanization has led to a surge in the demand for water (Pinder and Raghavan 2013). Key stressors include the overexploitation of riverine resources, water pollution (from point and non-point sources), modifications in river flows caused by obstructions and dams, the destruction and degradation of riparian habitats due to a growing demand for land for agriculture and urbanization, and the invasion of exotic fish species (Jena and Gopalakrishnan 2012). Additionally, environmental changes such as global warming and changes in precipitation patterns are also imperilling rivers and their biodiversity (Nel et al. 2009).

Freshwater species are vital components of riverine ecosystems. They control the trophic structures affecting the distribution of nutrients. Some freshwater species occur at the peak of food webs as apex predators, and others are used as indicators of riverine health (Schindler 2007). Importantly, aquatic species have now become a focus of attention; one of the reasons for this is that they are a crucial, and

sometimes the only source of protein for some poorer sections of society, especially in developing countries (Lakra et al. 2007). In view of the above, there is an urgent need to protect rivers and their aquatic species (Barua et al. 2012).

The Himalayan region provides a continuous supply of water through its numerous glaciers (Alfthan et al. 2018). It is the source of some of the major river systems in India, which are a lifeline for millions of people who depend on these rivers. The main rivers here are of the Indus and the Ganges–Brahmaputra–Meghna (GBM) systems. The major tributaries of the Indus are the Sutlej, Beas, Ravi, Chenab, and the Jhelum. The tributaries of the Ganges–Brahmaputra–Meghna include the Bhagirathi and Alaknanda, which form the Ganges. The major tributaries of the Brahmaputra are the Subansiri, Jia Bharali, Dhansiri, Puthimari, Pagladiya, and the Manas. The Barak River, the headwaters of the Meghna, rises in the hills of Manipur. The major tributaries of the Meghna are the Makku, Trang, Tuivai, Jiri, Sonai, Rukni, Katakhal, Dhaleswari, Langachini, Maduva, and the Jatinga.

An increase in the region's population, a rapid expansion of agriculture, the steady rate of deforestation due to the demand for fodder and fuelwood, and recurrent forest fires, have all resulted in the degradation of the Himalayan region. Additionally, developmental activities such as road-building, combined with heavy rainfall, have resulted in greater soil erosion, leading to the large-scale siltation of rivers and devastating floods.

Rivers in this region face further anthropogenic pressures due to land use changes. Riverine habitats are also undergoing serious damage through illegal sand and boulder mining, and point and non-point sources of pollution, for example, untreated sewage, industrial effluents, and mining wastes reaching the rivers. The local deployment of destructive fishing methods such as the use of dynamite and poisons, and the introduction of exotic fish species – for instance, the rainbow trout (*Oncorhynchus mykiss*), Atlantic salmon (*Salmo salar*), brown trout (*S. trutta*), and brook trout (*Salvelinus fontinalis*) – have proved deeply harmful for rivers and their fish species. Existing barrages and dams, those under construction, and the ones further planned, are all threatening the survival of rivers in the region.

Climate change too is now adding to these deleterious effects on Himalayan rivers (Alfthan et al. 2018). Temperature rises and changes in precipitation could impact riverine ecosystems adversely. The shrinking of Himalayan glaciers could lead to a decrease in the water flows of perennial rivers, thereby impacting tens of millions of people dependent on them. Summing up, Himalayan rivers are facing critical pressures, and urgently require the application of management strategies for their immediate protection and long-term conservation.

KEY MESSAGES

The Brahmaputra supports over 68 million people in Bangladesh, Bhutan, China, and India with water for irrigation, domestic use, fisheries, tourism, transportation, and hydropower generation. It also transports soil and nutrients to floodplains in India and Bangladesh, contributing to agricultural and fisheries production.

SECTION 2

The Brahmaputra and a changing climate

The Brahmaputra continues to be negatively impacted by several anthropogenic stressors, and climate change is placing further pressure on this river.

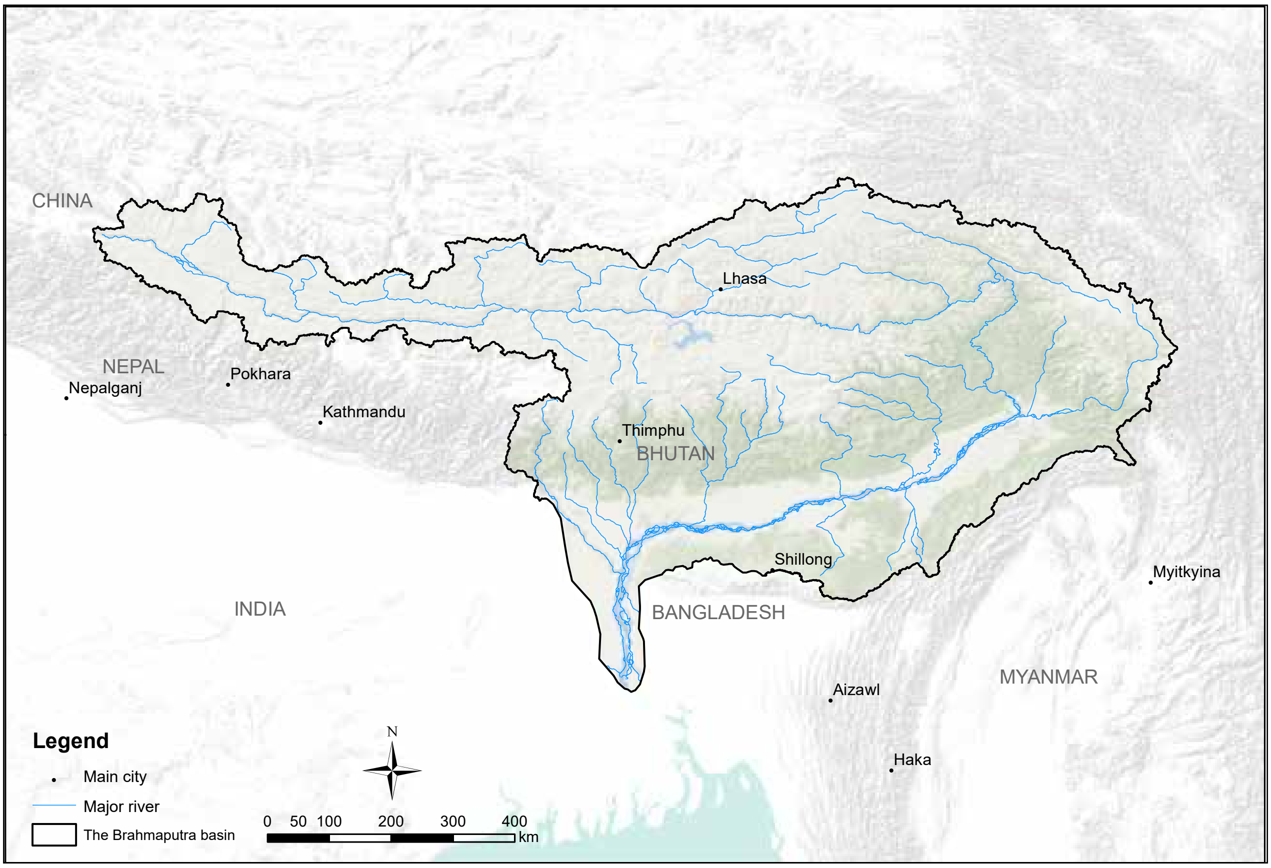
The Brahmaputra (Yarlung Tsangpo) originates from the Angsi Glacier in southern Tibet, China, at an elevation of 5,300 metres above sea level (masl). It travels 2,900 kilometres (km) with a drainage area of over 712,000 km^2, before emptying into the Bay of Bengal in Bangladesh. Its flow is dominated by rainfall run-off,[1] along with a modest contribution from meltwater (glacier melt and snowmelt) in the overall context of the basin.

The Brahmaputra supports over 68 million people in Bangladesh, Bhutan, China, and India with water for irrigation, domestic use, fisheries, tourism, transportation, and hydropower generation (Ravindranath and Bala 2017) (Figure 1). It also transports soil and nutrients to floodplains in India and Bangladesh, contributing to agricultural and fisheries production. The cultivated area of the basin is around 12.15 million hectares (Mha). About 30% of the river basin is covered by forests: tropical, semi-evergreen forests cover 22.5% of the total area of the basin; medium dense forests are spread over its northeastern parts; and other parts are covered by open, very dense, and non-forested areas (Chaitra et al. 2018).

The Brahmaputra continues to be negatively impacted by several anthropogenic stressors, and climate change is placing further pressure on this river. The Brahmaputra River, in its higher stretches, depends significantly on water from glacier and snow melt, and climate change has the potential to adversely affect cryospheric water reserves stored in the Hindu Kush, Karakoram, and Himalayan mountain ranges (Lutz et al. 2019).

[1] Run-off is that part of the total discharge from precipitation, glacier melt, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains, or sewers.

FIGURE 1 THE BRAHMAPUTRA RIVER BASIN



KEY MESSAGES

The projected temperature increase is likely to place a substantially higher demand on water resources, and likely impact the availability of water, food, and energy. Water bodies are likely to undergo greater rates of evaporation, adversely affecting the ecosystem services they provide. There is likely to be greater water requirements for agricultural crops.

SECTION 3

Key climatic trends

In the Upper Brahmaputra basin, the average annual temperature increased at a rate of 0.03°C y-1 between 1961 and 2005. An increase of 1–3°C is projected across the basin by 2050 in summers.

3.1 Changes in temperature

There has been a rise of 0.5°C in average minimum winter temperature across the Brahmaputra River basin since the 1960s. Average summer maxima are showing a slight increase as well. In the Upper Brahmaputra basin, the average annual temperature increased at a rate of 0.03°C y-1 between 1961 and 2005 (Wijngaard et al. 2017). An increase of 1–3°C is projected across the basin by 2050 in summers (Alfthan et al. 2018; Shrestha et al. 2015).

This projected temperature increase does not necessarily imply longer crop seasons or greater productivity, as agriculture and other ecosystem services are very sensitive to fluctuations in temperature. Furthermore, this temperature increase is likely to place a substantially higher demand on water resources, and likely impact the availability of water, food, and energy. Water bodies are likely to undergo greater rates of evaporation, adversely affecting the ecosystem services they provide. There is likely to be greater water requirements for agricultural crops. Although the opportunities of introducing new crops, intensifying agriculture, and increasing yields at higher altitudes are likely to be available, the warmer temperatures are likely to give rise to some invasive alien plant and animal species, insect attacks, and new crop pests, leading to crop damage and reduced crop yields (INCCA 2010). The projected warmer climate is also likely to cause a shift in the latitude of forest boundaries, the movement of tree lines towards higher altitudes, and changes in the composition of forests species and types of vegetation (Chaitra et al. 2018) (see Box 1).

BOX 1:

CHANGING CLIMATE AND SHIFTING FORESTS OF THE BRAHMAPUTRA RIVER BASIN

An assessment of the vulnerability of forests to future climate change in the mid-term (2021–2050) and long term (2071–2100) periods was conducted for the Brahmaputra River basin. The spatial distribution of the types of forest vegetation and net primary productivity were assessed using the Lund Potsdam Jena model. Changes were assessed using temperature and precipitation as key climate variables.

The study revealed significant shifts in forest vegetation and increases in net primary productivity in the future. The projected increase in temperature could be responsible for the shifts in vegetation, and potentially affect ecosystems and species. The increases in net primary productivity could be due to the projected increases in temperature and precipitation. In the mid-term, shifts in vegetation are projected in the central and north-eastern regions. In the long-term, a shift is projected in the central region. For net primary productivity, there is a projected increase by up to 15% in the mid-term, and by up to 45% in the long-term.

Source: Modified from Ravindranath and Bala (2017).

The populations of aquatic species important for fisheries are likely to be adversely affected as temperature is critical for fish physiology. Additionally, there is likely to be an increase in thermal stress, impacting humans and the health and productivity of livestock (Ebi et al. 2007). The window for the transmission of malaria is likely to remain open for a longer part of the year, further impacting the health of communities (INCCA 2010).

A poverty and vulnerability assessment (PVA) in the Brahmaputra basin during 2011–2012 and found that out of 2,647 households surveyed, 21% had experienced insect attacks, and 51% invasive plant and animal species in the prior 10 years due to climate change (ICIMOD 2012). As a result, 10% of the households had given up planting certain crops, and 12% had either changed their farming practices or introduced new crops. The increase in insect attacks and crop pests experienced by households here continue to hinder the storage and sale of cash and food crops, resulting in a loss of household income and livelihood options.

The projected increases in temperature are also likely to increase the risk of the occurrence of livestock and human diseases in the basin (Ebi et al. 2007). The PVA data revealed that over 80% of the households had experienced human disease and diseases in their livestock in the prior 10 years, whereas 82% had done so in the 12 months preceding the survey. Changes in the distribution and seasonality of vector-borne diseases are linked to climate change, and it is likely that vector-borne diseases will spread to higher altitudes as these areas become warmer (Ebi et al. 2007; Gautam et al. 2013).

3.2 Changes in rainfall

Extreme rainfall appears to have been decreasing in the northern parts of the Brahmaputra basin since the 1960s, but increasing over its eastern parts. Future scenarios project a 5%–25% increase in summer rainfall over most of the basin up to 2050 against the 1960 baseline (Alfthan et al. 2018; Shrestha et al. 2015). Additionally, 100-year floods (i.e., floods with a 100-year return period in the twentieth century) are projected to occur once every 26.1 years at the end of the twenty-first century (see Wijngaard et al. 2017).

An increase in rainfall in the summer monsoon season does not necessarily increase water availability, as most of the rainfall cannot percolate into saturated ground. It adds to run-off, which is likely to contribute to an increase in the severity of floods, and in landslides, especially if combined with increased meltwater flows (Alfthan et al. 2018). Nonetheless, there is a possibility that the extraction of groundwater during summer can create space in an aquifer, which would be recharged to a greater degree by the increase in rainfall. This would also reduce the intensity of floods, especially those that happen towards the end of the monsoon (Acciavatti 2015).

The projected change in the onset of the monsoon (early or late arrival), the frequency (i.e., the number of rainfall events), and the variability are all likely to lead to a possible increase in drought events (National Water Mission 2011). The risk to life and property is likely to increase in the coming years, both because floods are likely to become more frequent, and because increases in population are likely to result in more people settling in areas vulnerable to flooding (Mukherji et al. 2015). An increase in flooding is likely to influence the prevalence of water-related diseases and contaminate water sources. Conversely, the insufficient water during dry periods for purposes of hygiene is likely to increase the risk of water-washed diseases (Ebi et al. 2007; Moors et al. 2013) (see Box 2).

These changing and unpredictable precipitation patterns may have serious costs for the region. That is to say, floods, droughts, and landslides can have substantial consequences for the food and nutritional security of people in the basin. There has been a marked increase in the number of flood-related disasters and the number of areas affected, which has impacted the lives and homes of millions of people (Tse-ring et al. 2010).

The increase in extreme precipitation events during the monsoon will increase the risk of floods and landslides and also affect the operational, financial, environmental, and social performance of important infrastructure in the region, such as roads, bridges, and communication systems (Eriksson et al. 2009). Frequent floods and landslides can also give rise to increased sedimentation in rivers, and can severely damage and shorten the life of hydropower plants (Tse-ring et al. 2010). Additionally, heavy rainfall, flooding, and landslides can have a detrimental effect on nature-based tourism (such as on trekking and safaris) and take away the livelihoods of a large number of people (Alfthan et al. 2018).

BOX 2:

CLIMATE CHANGE AND THE INCIDENCE OF DIARRHOEA

- India is a leading country when it comes to child mortality caused by diarrhoea, with over 200,000 deaths reported in 2010.
- Most outbreaks of diarrhoea in India occur during the hot summer (March–May) and the wet and humid monsoon months (June–September).
- Above a minimum threshold, there is a linear relationship between (and a constant increase in) the incidence of all-cause diarrhoea and every unit increase in temperature, and also the duration of extreme rainfall events. For example:
    - For every 1°C rise in temperature, there is an increase of up to 6% in the incidence of all-cause diarrhoea.
    - For each day with extreme rainfall (above 64.5 mm/day), there is an increase of up to 2%.
- Further (above a minimum threshold), there is a linear relationship between (and a constant increase in) the incidence of all-cause diarrhoea and every unit decrease in precipitation, and also in relative humidity. For example:
    - For every 1 mm/month decrease in rainfall, there is an increase of 0.4% in the incidence of all-cause diarrhoea.
    - For each 1% decrease in relative humidity, there is over 2% increase in the incidence of gastroenteritis.

Source: Modified from Moors et al (2013).

Agriculture is reliant on water availability, and as most agriculture in the basin is rain-fed, the sector is vulnerable to changes in the timing of rainfall as well as its frequency. Farmers in the Brahmaputra basin had noticed an earlier or delayed onset of the monsoon season, with more erratic rainfall and dry spells (ICIMOD 2012). This had resulted in declining agricultural productivity, crop failures, increased crop destruction, loss of harvests, and an increase in pest attacks and diseases.

The unpredictable precipitation patterns will negatively affect freshwater species. With dry areas becoming drier, there will be a hardening of agricultural soils during droughts, resulting in increased physical labour of households. This could result in the movement of people away from such areas towards downstream areas (Alfthan et al. 2018).

3.3 Responses of glaciers to climate change

The Brahmaputra basin has over 11,000 glaciers. The glacial area within the basin is projected to decrease by 35%–45% by 2050 against the 1960 baseline (Bajracharya et al. 2015). Temperature increases are likely to be the most important factor driving the loss of glacial mass, along with black carbon soot emitted elsewhere settling on their surface, and the presence of surface debris such as pebbles and rocks (Alfthan et al. 2018; Shrestha et al. 2015).

Warmer temperatures are contributing to an increase in the number of glacial lakes in the Himalaya. Between 1990 and 2010, the number of glacial lakes in the Hindu Kush Himalaya increased from 4,600 to 5,700, almost 40% of them in the Brahmaputra basin (Alfthan et al. 2018: 35). As the glaciers retreat due to additional melting, more moraine-dammed glacial lakes are likely to form with the potential of generating dangerous Glacial Lake Outburst Floods (GLOFs). GLOFs can cause severe damage to lives, infrastructure, agricultural land, and livestock, and pose risks to the lives and livelihoods of people (Zhang et al. 2015). Being situated on rivers, existing and future hydropower plants are likely to be exposed to GLOFs.

Possible water shortages at high altitudes due to the retreating glaciers, and the ever-increasing demand for water from a rapidly expanding human population is likely to increase the vulnerability of communities, and adversely impact their socioeconomic well-being (Johnson and Hutton 2014).

3.4 Contributions of snow, ice, and rain to river flows

Glacier and snow meltwater contribute modestly to the Brahmaputra basin's flows. This means that fluctuations in the monsoonal patterns, and the retreat and advance of glaciers within the basin could have wide-reaching effects on water supply and flow patterns, thus influencing agriculture, water for domestic use, fisheries, hydroelectricity generation, and natural ecosystems. Increased flows in the basin (due to the likely increase in precipitation) could cause greater inundation and river bank erosion, and disturb economically sensitive agricultural calendars with consequential losses of resources, economic confidence, and agricultural outputs (Johnson and Hutton 2014).

The glaciers serve as natural storage reservoirs, providing year-round supplies to the Brahmaputra and some of its tributaries (Khandu et al. 2016). However, there will be greater unpredictability in river flows and more water in the pre-monsoon months, giving rise to a higher incidence of unexpected droughts and floods, and increasing the existing vulnerabilities of people in the basin (Mohammed et al. 2017).

3.5 Projected changes in river flows

An increase in run-off up to 13% by 2050 is projected for the basin. Increasing precipitation is likely to be the main driver of this change. There is likely to be more water in the monsoon months, with the possibility of more floods and landslides. This could be a concern for ecologically and socioeconomically significant high-altitude wetlands and lakes (Alfthan et al. 2018).

KEY MESSAGES

Solutions and adaptation measures will have to take into account the overall expected changes as well as the spatial variations and uncertainties in these changes.

SECTION 4

Ways forward

A range of adaptation measures undertaken at different institutional levels and community contexts can cushion the adverse impacts of climate change.

Given the projected changes in temperature and precipitation, and to glaciers, it is likely that there are going to be serious impacts and costs for communities and sectors that rely on the basin. For example, forest-dependent communities are likely to be adversely impacted due to fluctuations in previously easily-available ecosystem services. The projected changes in the availability of water (either as excess or as shortages) and increases in temperature are likely to negatively affect farmers' livelihoods and the health and well-being of human beings and livestock. The projected warmer climate and the resultant increase in glacier melt is likely to increase the risks of GLOFs, and impact the well-being of mountain and downstream communities (Nie et al. 2017). Solutions and adaptation measures will have to take into account the overall expected changes as well as the spatial variations and uncertainties in these changes. In this section of the paper, we present a range of adaptation measures that can be undertaken at different institutional levels and community contexts, to cushion these adverse impacts of climate change.

4.1 Mapping vulnerability and building climate resilience

At the national level, it would be important to strengthen climate vulnerability studies of forest ecologies, and of fish and other species, supported by field data. Investing in the capacity-building of identified research agencies and institutions at the state and district level can help with this data collection. The flow of this projected information to local government bodies and non-governmental organizations (NGOs) is critical for timely action at the community level, and can be achieved by investing in setting up periodic-warning services (for example, short message/broadcast services).

BOX 3:

RESILIENT MOUNTAIN VILLAGES: AN INTEGRATED APPROACH TO DEVELOPMENT

The Resilient Mountain Village (RMV) is an integrated approach to development in mountainous areas that combines economic, social, and environmental dimensions of sustainable development with climate change adaptation, resilience, and preparedness for future risks. It evolved at ICIMOD from elements of the concepts of climate smart agriculture and climate smart villages, of the Food and Agriculture Organization (FAO) and the Consultative Group on International Agriculture Research (CGIAR).

The RMV approach focuses on three goals: climate resilience, socioeconomic resilience, and future resilience. It is currently being implemented in 41 rural municipalities of Nepal.

Source: Modified from *Resilient Mountain Village (RMV): Laying foundations for resilient development through simple solutions.* Kathmandu: ICIMOD. www.icimod.org/?q=25213

BOX 4:

A REGIONAL FLOOD INFORMATION SYSTEM IN THE HKH

The overall objective of the HKH–HYCOS project – which extended from 2009 to 2012 – was to minimize the loss of lives and livelihoods by reducing flood vulnerability in the HKH region, with specific reference to the Brahmaputra river basin. The project focused on the timely exchange of flood data and information within and among participating countries, through the establishment of an agreed-upon platform that was accessible and user-friendly. It succeeded in strengthening a framework for cooperation over sharing regional flood data and information among participating member countries; establishing a flood observation network in the participant countries; establishing regional and national flood information systems to share real-time data and information, and increase lead time; enhancing the technical capacity of partners on flood forecasting and communication to the end users; and planning and agreeing upon a full-scale regional project among participant countries.

Source: Modified from *Establishment of a Regional Flood Information System in the Hindu Kush Himalayan Region.* http://www.icimod.org/?q=264

At the community level, investing in climate change awareness and adaptation training (based on the available information) will be key. Supportive adaptation measures include the closure of forest areas with crucial faunal species, regeneration of indigenous species, and the promotion of sustainable fishing methods. Further, additional investments by local governments at the NGO/community level are vital to building climate resilience by strengthening agroforestry, the development of nurseries with seedlings of commercial plants such as bamboo, indigenous fruits, and medicinal plants, and the controlled breeding of temperature-tolerant, commercially-important fish species (Government of Assam 2015) (see Table 1) (also see Box 3 for a related adaptation action).

4.2 Too much water, too little water: Identifying opportunities within challenges

At the national level, water resources management policies and legislations need to be harmonized in the context of climate change adaptation (Government of Assam 2015). There is a need to invest in strengthening probabilistic forecasting projections under India's National Mission on Sustainable Habitat (2010) regarding floods, landslides, droughts, human diseases, and available opportunities, and in the timely transfer of this information to the state, district, and local governments (Government of Arunachal Pradesh 2011; Government of Assam 2015) (see Box 4 for a potential knowledge-sharing approach to emulate).

With the available information, local governments need to invest in strengthening the technical capabilities of the line departments, the offices of the District Disaster Management Authority (DDMA), and the authorized councils for the development of flood- and drought-tolerant crop varieties (Government of Arunachal Pradesh 2011). They need to scale up flood preparedness and early-warning systems (Government of Assam 2015) (see boxes 5 and 6 for potential adaptation actions).

They also need to invest at the community level to increase awareness about the likely surge in malaria

TABLE 1	ADAPTATION ACTIONS FOR FOREST AND AQUATIC IMPACTS					
Projected impacts	**Possible adaptation actions**	**National**	**State / district**	**Local government**	**NGO**	**Individuals**
The projected warmer climate is likely to cause a shift in the latitude of forest boundaries, the movement of tree lines towards higher altitudes, and changes in species composition and vegetation types	Strengthen climate vulnerability studies of forest ecologies, and of fish and other species, supported by field data	√				
	Invest in capacity-building of research agencies and institutions at the state and district level to assist with this data collection	√	√			
Commercially important fish species are likely to be negatively affected as water temperatures are critical for their physiology	Invest in setting up periodic-warning services	√	√	√	√	√
	Invest in awareness and training that would promote the closure of forest areas with crucial faunal species, the regeneration of indigenous species, and sustainable fishing methods			√	√	√
There is likely to be greater instability in food availability (due to crop losses), and adverse impacts on local livelihoods (such as the loss of fisheries)	Build climate resilience through the promotion of agroforestry, the development of nurseries of commercial plants, and the controlled breeding of temperature-tolerant, commercially important fish species			√	√	√

and water-borne diseases. Further, local governments need to financially support NGOs who could promote among local communities the benefits of maintaining embankments, and constructing flood-resistant houses and toilets (see boxes 7 and 8).

Mixed cropping in a normal flood or drought year needs to be promoted in order to support local livelihoods. One needs to explore emerging agricultural opportunities, such as planting cash crops in such flood and drought affected areas (Government of Assam 2015). Local governments need to invest to promote or strengthen the reuse of wastewater for irrigation through on-farm sedimentation ponds and drip irrigation. Further, support should be provided for springshed development in hilly areas to restore perennial streams. Additionally, the concerned local authority should explore the possibilities of wetland management through community participation (Government of Arunachal Pradesh 2011; Government of Assam 2015) (see Table 2) (see Box 9 for a potential adaptation action).

BOX 5:

FLOOD PREPAREDNESS TRAINING IN ASSAM

ICIMOD, in partnership with the Institute of Integrated Resource Management (IIRM), Tezpur, and Swayam Sikshyan Prayog (SSP), conducted flood-preparedness training for 240 women in eight villages of Lakhimpur district in Assam, India, from 12–20 March 2015. The women came from remittance recipient households. The training was part of the action research initiated under ICIMOD's Himalayan Climate Change Adaptation Programme (HICAP). This research examines the role of training in enhancing the financial literacy and flood preparedness of remittance recipient households in flood-affected areas of Lakhimpur district. During the training, participants learnt how to develop skills and utilize their household income and savings to generate flood preparedness plans, use improved cooking stoves, access safe drinking water, create an emergency food storage, and create a flood preparedness calendar.

Source: Modified from *Women learn to invest in flood preparedness*. http://www.icimod.org/?q=17745

BOX 6:

AWARD-WINNING COMMUNITY BASED FLOOD EARLY WARNING SYSTEMS

A Community Based Flood Early Warning System (CBFEWS) is an integrated system of tools and plans prepared and managed by communities, in order to detect and respond in advance to flood emergencies. The objectives of such early warning systems are to minimize the risks of floods and flash floods by providing early warnings to downstream communities, and to enhance cooperation between upstream and downstream communities in the sharing of information about impending floods.

In 2013, ICIMOD and the NGO Aaranyak installed a CBFEWS in the Jiadhal and Singora rivers in Assam, India under the Himalayan Climate Change Adaptation Programme (HICAP). Subsequently, the CBFEWS in the Jiadhal River warned community members in Dihiri of the approaching floods, helping them save assets, including livestock, valued at USD 3,300. At the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) 20/CMP10 in Lima, Peru the following year, the UNFCCC awarded ICIMOD and Aaranyak the Momentum for Change 2014 Lighthouse Activity Award under the ICT Solutions category. ICIMOD, together with the local governments and partners, has also established CBFEWS along the Koshi River in Nepal and the Dushi River in Afghanistan.

Source: Modified from https://unfccc.int/climate-action/momentum-for-change/activity-database/community-based-flood-early-warning-system-india

BOX 7:

CLIMATE- AND FLOOD-RESILIENT HOUSING IN RANGPUR

Seasonal and increasingly erratic floods have begun to inundate villages on 'char' lands, and wash away the communities' crops (for example, in Char Dhushmara and Char Haiboth Khan in Kaunia Upazila, Rangpur district, Bangladesh).

As an adaptation measure, four cluster Climate- and Flood-resilient (CFR) houses (12 houses in all) were retrofitted on raised platforms with a provision for basic amenities, including sanitation and drinking water, homestead gardening, and improved cooking stoves. Scaling up this pilot project can bring relief from livelihood insecurity, and provide habitat security to residents during floods and inundation.

Source: Modified from http://lib.icimod.org/record/32711

BOX 8:

FLOOD-RESILIENT SANITATION – ECO-SAN TOILETS

Floods lead to the loss of access to basic amenities, adversely affecting health and sanitation, especially of communities living within embankments (for example, Naya Tola Bishambharpur in Nautan Block, West Champaran, Bihar, India).

Ecological sanitation (Eco-San) toilets (*phaydemand shauchalay*) are flood-resilient, odourless, and do not require flushing. They assist in decomposing human waste into 'humanure' that can be used as fertilizer on fields; prevent groundwater contamination; and provide a secure and clean enclosure for women, girls, and the elderly during floods. The scaling up of Eco-San toilets in Bihar has vastly improved health and hygiene outcomes in the state. Similar measures in other flood-prone areas of the HKH region could be taken up.

Source: Modified from http://www.hi-aware.org/index.php?id=91

BOX 9:

ECOSYSTEM SERVICE CHANGES AND LIVELIHOOD IMPACTS IN THE MAGURI–MOTAPUNG WETLANDS OF ASSAM, INDIA

The area consists of eight villages, and the wetlands provide diverse ecosystem services that support livelihoods. For instance, the sale of fish alone amounts to INR 7.8 million annually (equivalent to USD 110,000). The region is part of the Indo Burma Global Biodiversity Hotspot.

The wetland is a common property, not under any management prescription. Here, a management plan led by the district authorities, and developed with the engagement of communities, scientists, other experts, and line departments led to participatory wetland management.

Source: Modified from https://www.cifor.org/library/6125/

TABLE 2 ADAPTATION ACTIONS FOR PROJECTED CHANGES IN RAINFALL

Projected impacts	Possible adaptation actions	National	State / district	Local government	NGO	Individuals
The projected increase in rainfall will likely contribute to an increase in flooding and landslides, and risk to the lives of human beings and livestock and to infrastructure in the north and far-west of the basin	Harmonize water resources management policies and legislations in the context of climate change adaptation	√				
	Invest in strengthening probabilistic forecasting and projections under India's National Mission on Sustainable Habitat regarding floods, landslides, droughts, human diseases, and available opportunities; and the timely transfer of this information to the state, district, and local governments	√	√	√		
There will likely be an increase in morbidity/mortality from malaria because of more persistent standing water, and from water-borne diseases due to the contamination of freshwater supplies	Local governments need to invest in strengthening the technical capabilities of line departments and offices of the DDMA for the development of flood- and drought-tolerant crop species, and to scale up flood preparedness and early-warning systems			√		
With the projected reduction in rainfall in the southwestern and central-northern parts of the basin, rain-fed agriculture is likely to suffer. For example, there could be a decline in the production and areal coverage of horticultural crops	Invest at the community level to increase awareness regarding the likely surge in malaria and water-borne diseases			√		
	Financially support NGOs to promote among local communities the benefits of maintaining embankments and constructing flood-resistant houses and toilets; promote mixed cropping in a normal flood or drought year to support local livelihoods; explore emerging agricultural opportunities such as planting cash crops			√	√	√
Beneficial opportunities are likely due to the projected increase in rainfall in currently rain-deficit areas, and could provide improved crop yields and food availability	Invest to promote the reuse of wastewater for irrigation through on-farm sedimentation ponds and drip irrigation; support springshed development in hilly areas to restore perennial streams; promote wetland management through community participation			√	√	√

4.3 Increasing temperatures: Enhancing adaptation, reducing vulnerability

At the national level, there is a need to invest and strengthen existing institutional capacities to regularly assess and forecast water demand, examine the attitudinally upward shifts in agriculture, and identify 'hot zones' for forest fires and the location-specific occurrence of heat waves and outbreaks of disease (Government of Assam 2015). This information needs to be shared periodically with state governments and district authorities, allowing them to develop the technical guidance and support tools for early warning systems, emergency response plans, and appropriate individual behaviour.

At the state and district levels, there is a need to financially support local governments to promote the sustainable use of available water; encourage research on, and promote the development of water- and temperature-tolerant crop varieties through identified institutions/councils; improve infrastructure design to reduce the heat island effect (for instance, by planting trees and increasing green spaces); and formulate training programmes for appropriate responses during heat waves and outbreaks of disease (Government of Assam 2015) (see Box 10 for a potential adaptation action).

Local governments need to invest in capacity-building of forest managers, and awareness-building of communities, to enhance the control of forest fires (Government of Arunachal Pradesh 2011). It is important to invest in pastoral development and the institutionalization of rangeland resource management to address fodder shortages. It is also essential to strengthen the technical capacities of NGOs so they can assist communities in the construction of livestock and crop shelters with suitable ambient microclimates (Government of Assam 2015), and promote intercropping farming practices that match seasonal water availability (INCCA 2010) (see Table 3).

BOX 10

ACTION PLANS TO FIGHT RISING HEAT WAVES IN INDIA

There has been an increasing trend in the duration and intensity of heat waves in India over the past several years; several cities in India have been severely affected. For example, severe heat waves caused over 2,000 deaths in Odisha in 1998, and more than 1,200 deaths in southern India in 2002. More than 2,400 people died in Andhra Pradesh and Telangana in a severe heat wave in 2015. Heat waves also caused the deaths of cattle and wildlife, besides affecting animals in various zoos in India.

There is a need to facilitate the preparation of a heat wave action plan by stakeholders, by providing insights into heat-related illnesses and the necessary response actions to be undertaken. It will also help in the mobilization and coordination of various departments, individuals, and communities to prevent health problems during spells of very hot weather.

Source: Modified from NDMA, *Guidelines for Preparation of Action Plan*. http://ndma.gov.in/images/guidelines/guidelines-heat-wave.pdf

4.4 Warming climate, melting glaciers: Adapting to GLOFs

At the national level, there is a need to formulate an Adaptation Programme for GLOFs, and invest to strengthen identified institutions to obtain timely information on 'disaster zones'. It is essential that this information be disseminated to the state, district, and local governments to strengthen disaster risk reduction capabilities, and work towards draining potentially dangerous glacial lakes (PDGLs) (see Box 11). However, examples from Bhutan show that these lakes can be used for electricity generation and for providing water supply – another instance of potentially turning a threat into an opportunity.

Local governments need to integrate local communities in GLOF-related adaptation approaches through awareness-building, preparedness, and scaling up of disaster insurance (National Water Mission 2011) (see Table 4) (also see Box 12 for a potential adaptation action).

TABLE 3 ADAPTATION ACTIONS FOR PROJECTED RISES IN TEMPERATURES

Projected impacts	Possible adaptation actions	National	State / district	Local government	NGO	Individuals
Water bodies are likely to undergo greater rates of evaporation. There is likely to be greater water requirements for, and adverse effects on agricultural crops Likely to be an increase in the number and frequency of forest fires The projected increase in night-time temperatures is likely to unfavourably influence hill agriculture (including rice, horticultural crops, and plantations). There will likely be a decrease in the yields of winter crops There will likely be upward shifts in agriculture, leading to the loss of permanent pastures and grasslands and reduced fodder availability for livestock There are likely to be substantial impacts on the health of humans and livestock due to heat stress and the transmission window for vector-borne diseases remaining open for longer periods in the year	Invest and build institutional capacities to regularly assess and forecast the demand for water, the upward shift in agriculture, and identify 'hot zones' of forest fires, and location-specific occurrence of heat waves and outbreaks of disease	√				
	This information needs to be shared periodically with state governments and district officials, allowing them to develop the technical guidance and support tools for early warning systems, emergency response plans, and appropriate individual behaviour	√	√			
	Financially support local governments to support the equitable distribution of water through India's National Water Mission (2011), and promote the sustainable use of available water; encourage research on the development of water- and temperature-tolerant crop varieties; improve infrastructure design to reduce the heat island effect; and formulate training programmes for appropriate responses during heat waves and outbreaks of disease		√	√		
	Invest in capacity-building of forest managers, and awareness-building of communities to enhance the control of forest fires			√		
	Invest in pastoral development and the institutionalization of rangeland resource management to address fodder shortages			√		
	Strengthen the technical capacities of NGOs so that they can assist communities in the construction of livestock and crop shelters, and promote intercropping farming practices that match seasonal water availability			√	√	√

BOX 11

DRAINING THE DANGEROUS IMJA GLACIAL LAKE

Nepal drained the dangerous Imja glacial lake near Mount Everest to a safe level in late 2016. An earthquake in 2015 had destabilized Lake Imja. The lake, situated at nearly 5,000 masl (16,400 feet), was in danger of flooding downstream settlements, trekking trails, and bridges. The lake, which was originally 149 m deep in places, had its water levels lowered by 3.4 metres after months of work. Army personnel and locals worked for six months to create an outlet to gradually release the lake's water. After the outlet was constructed, nearly 4 million m3 of water was released over two months. Early warning systems were also installed for communities downstream. The process could be replicated in other potentially hazardous lakes to reduce risks of GLOFs.

Source: Modified from Navin Kheda, Nepal drains dangerous Everest lake. http://www.bbc.com/news/world-asia-37797559

BOX 12

ICE STUPAS: A FORM OF ARTIFICIAL GLACIER

The idea behind artificial glaciers is to freeze and hold the water that keeps flowing down streams and into rivers throughout the winter. This is achieved by freezing the stream water vertically in the form of huge ice towers or cones several metres high that look very similar to the local, sacred mud structures called stupas. The idea is to conserve this tower of ice as long into the summer as possible so that as it melts, it feeds the fields until the real glacier melt waters start flowing in June. Since these ice cones extend vertically upwards towards the sun, they receive little of the sun's rays per unit volume of water stored; hence, they take much longer to melt.

Source: Modified from *Ice Stupas: A Form of Artificial Glacier*. http://icestupa.org/about

TABLE 4 **GLACIAL CHANGES, GLOFS, AND DISASTER RISK REDUCTION**

Projected impacts	Possible adaptation actions	National	State / district	Local government	NGO	Individuals
Glaciers are projected to retreat due to warming temperatures, and their melting will likely create more moraine-dammed glacial lakes or expand existing lakes with the potential of generating dangerous GLOFs. Such GLOFs may lead to large-scale loss of lives and damage agricultural areas and infrastructure, affecting the well-being of mountain and downstream communities	Formulate an Adaptation Programme for GLOFs. Invest to strengthen identified institutions to obtain timely information on 'disaster zones'	√				
	This information should reach state, district, and local governments to strengthen their disaster risk reduction capabilities, and enable draining PDGLs	√	√	√		
	Integrate communities in GLOF-related adaptation approaches through awareness-building, preparedness, and scaling up of disaster micro-insurance			√		
Glacial melt is projected to increase, which is likely to lead to increased summer flows in some rivers, followed by a reduction in flows as glaciers disappear, adversely affecting mountain agriculture	Investment is required to conduct educational camps through local NGOs to inform communities of water storage techniques in view of the projected decrease in water availability at high altitudes			√	√	√

SECTION 5

Conclusion

We must focus on generating and sharing knowledge to close the science–policy–practice gap, promote evidence-based decision making, strengthen institutions, and integrate investments in the Brahmaputra River basin.

KEY MESSAGES

There is a critical need to balance water output with environmental protection, social equity, and sustainable economic development in the context of the projected climate future. With expected population increases and changing consumption patterns, the demand for water from the Brahmaputra is likely to rise and test the region's political, social, and economic stability. This changing situation warrants the implementation of sustainable climate actions.

The Brahmaputra is key to the region's growth as its water is crucial in the food–energy nexus (Yang et al. 2016). It is noteworthy that the *Assam State Action Plan on Climate Change (2015–2020)* draft report does take into account vulnerabilities due to climate change. It also recommends strategies such as flood modelling studies of the Brahmaputra River in association with international universities.

Nonetheless, there is a critical need to balance water output with environmental protection, social equity, and sustainable economic development in the context of the projected climate future. With expected population increases and changing consumption patterns, the demand for water from the Brahmaputra is likely to rise and test the region's political, social, and economic stability. This changing situation warrants the implementation of sustainable climate actions, some of which are discussed in this paper. In addition, focusing on generating and sharing knowledge to close the science–policy–practice gap, promoting evidence-based decision making in the basin, strengthening institutions, and integrating investments could be the way forward.

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

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ICIMOD gratefully acknowledges the support of its core donors: the Governments of Afghanistan, Australia, Austria, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Norway, Pakistan, Sweden, and Switzerland.

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ISBN 978 92 9115 683 2